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TECHNOLOGY TRANSFER

FIELD GUIDE FOR THE BIOLOGICAL CONTROL OF WEEDS

IN EASTERN NORTH AMERICA

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Philip W. Tipping, Ellen C. Lake, and Judy Hough-Goldstein

Forest Health Technology Enterprise Team

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BIOLOGICAL CONTROL OF WEEDS IN EASTERN NORTH AMERICA

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Field Guide Components

Weed species are arranged first by flower color, then grouped by related species and listed alphabetically. All biocontrol agents introduced or established on each weed are included in that weed's section, listed according to efficacy on the target weed. **To look up a particular biocontrol agent or weed, refer to the index at the back of this guide.**

Efficacy Quick Reference Guide

In this quick reference, weed species are arranged in the order they appear in this guide: first by flower color, grouped by related species, and then listed alphabetically. Weeds that do not flower are colored gray. The biocontrol agents presently available (as of 2016) for each weed are then arranged according to their individual efficacy. Please note that efficacy designations are very broad. Some biocontrol agents thrive in certain settings and are ineffective in others.

The following broad categories are used:

US	CAN	Individual Biocontrol Agent Status
🟩	🟢	High priority; recommended for release/redistribution
🟨	🟡	Medium priority, recommended to complement other agents or control methods
🟧	🟠	Low priority; typically low impact and/or survival
🟥	🔴	Caution when redistributing; not recommended for use in all areas
☒	⊗	Illegal to redistribute
?	?	Ongoing releases, but establishment not yet confirmed
□	○	Released, but failed to establish

Status		Organism	Page
		Diffuse knapweed *Centaurea diffusa*	**30**
🟩	🟢	*Larinus minutus*	36
🟩	🟢	*Sphenoptera jugoslavica*	40
🟨	🟡	*Cyphocleonus achates*	34
🟨	🟡	*Larinus obtusus*	38
🟨	🟡	*Agapeta zoegana*	42
🟨	🟡	*Urophora affinis*	44
🟨	🟡	*Urophora quadrifasciata*	46
🟧		*Bangasternus fausti*	48
🟧	🟠	*Metzneria paucipunctella*	52
🟧	○	*Pelochrista medullana*	54
🟧	🟠	*Pterolonche inspersa*	56

Status		Organism	Page
		Spotted knapweed *Centaurea stoebe*	**32**
🟩	🟢	*Cyphocleonus achates*	34
🟩	🟢	*Larinus obtusus*	38
🟨	🟡	*Agapeta zoegana*	42
🟨	🟡	*Larinus minutus*	36
🟨	🟡	*Urophora affinis*	44
🟨	🟡	*Urophora quadrifasciata*	46
🟧	🟠	*Sphenoptera jugoslavica*	40
🟧		*Bangasternus fausti*	48
🟧	🟠	*Chaetorellia acrolophi*	50
🟧	🟠	*Metzneria paucipunctella*	52
🟧	○	*Pelochrista medullana*	54
🟧	🟠	*Terellia virens*	58

Efficacy Quick Reference Guide

Status	Organism	Page
	Purple loosestrife *Lythrum salicaria*	**62**
	Galerucella calmariensis	64
	Galerucella pusilla	64
	Hylobius transversovittatus	66
	Nanophyes marmoratus	68
	Eurasian watermilfoil *Myriophyllum spicatum*	**70**
	Euhrychiopsis lecontei	72
	Pale swallow-wort *Vincetoxicum rossicum*	**76**
?	*Hypena opulenta*	78
	Bull thistle *Cirsium vulgare*	**82**
	Urophora stylata	88
	Cheilosia grossa	96
	Trichosirocalus horridus	100
	Rhinocyllus conicus	98
	Larinus carlinae (=*L. planus*)	106
	Canada thistle *Cirsium arvensis*	**84**
	Hadroplontus litura	90
	Urophora cardui	92
	Larinus carlinae (=*L. planus*)	106
	Rhinocyllus conicus	98

Status	Organism	Page
	Musk thistle *Carduus nutans*	**86**
	Urophora solstitialis	94
	Cheilosia grossa	96
	Trichosirocalus horridus	100
	Rhinocyllus conicus	98
	Larinus carlinae (=*L. planus*)	106
	Waterhyacinth *Eichhornia crassipes*	**108**
	Megamelus scutellaris	110
	Neochetina bruchi/ *N.eichhorniae*	112
	Niphograpta albiguttalis	114
	Tansy ragwort *Jacobaea vulgaris*	**118**
	Longitarsus jacobaeae	120
	Cochylis atricapitana	122
	Botanophila seneciella	124
	Tyria jacobaeae	126
	Common St. Johnswort *Hypericum perforatum*	**130**
	Chrysolina hyperici	132
	Chrysolina quadrigemina	132
	Agrilus hyperici	134
	Aphis chloris	136
	Aplocera plagiata	138
	Zeuxidiplosis giardi	140

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	Dalmatian toadflax *Linaria dalmatica*	**142**
	Mecinus janthiniformis	146
	Brachypterolus pulicarius	150
	Rhinusa antirrhini	152
	Calophasia lunula	156

Status	Organism	Page
	Yellow toadflax *Linaria vulgaris*	**144**
	Mecinus janthinus	146
	Rhinusa pilosa	148
	Brachypterolus pulicarius	150
	Rhinusa antirrhini	152
	Rhinusa linariae	154
	Calophasia lunula	156

Status	Organism	Page
	Mile-a-minute weed *Persicaria perfoliata*	**160**
	Rhinoncomimus latipes	162

Status	Organism	Page
	Cypress spurge *Euphorbia crassipes*	**164**
	Aphthona nigriscutis	170
	Aphthona flava	172
	Aphthona lacertosa	168
	Aphthona cyparissiae	176
	Aphthona czwalinai	178
	Hyles euphorbiae	180
	Spurgia capitigena/S. esulae	186

Status	Organism	Page
	Leafy spurge *Euphorbia esula*	**166**
	Aphthona lacertosa	168
	Aphthona nigriscutis	170
	Aphthona flava	172
	Lobesia euphorbiana	174
	Aphthona cyparissiae	176
	Aphthona czwalinai	178
	Hyles euphorbiae	180
	Oberea erythrocephala	182
	Pegomya curticornis/P. euphorbiae	184
	Spurgia capitigena/S. esulae	186

Status	Organism	Page
	Tree-of-heaven *Ailanthus altissima*	**190**
	Verticillium nonalfalfae	192

Status	Organism	Page
	Alligatorweed *Alternanthera philoxeroides*	**194**
	Agasicles hygrophila	196
	Arcola malloi	198
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Status	Organism	Page
	Scentless chamomile *Tripleurospermum inodorum*	**202**
	Omphalapion hookerorum	204
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	Microplontus edentulus	208

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Status	Organism	Page
	Poison hemlock *Conium maculatum*	**210**
	Agonopterix alstroemeriana	212
	Hydrilla *Hydrilla verticillata*	**214**
	Hydrellia pakistanae	216
	Hydrellia balciunasi	216
	Bagous hydrillae	218
	Japanese knotweed *Fallopia japonica*	**226**
?	*Aphalara itadori*	228
	Melaleuca *Melaleuca quinquenervia*	**230**
	Boreioglycaspis melaleucae	232
	Lophodiplosis trifida	234
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	Phyllocoptes fructiphilus	242
	Tropical Soda Apple *Solanum viarum*	**248**
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Status	Organism	Page
	Waterlettuce *Pistia stratiotes*	**254**
	Neohydronomus affinis	256
	Air potato *Dioscorea bulbifera*	**260**
	Lilioceris cheni	262
	Old World climbing fern *Lygodium microphyllum*	**264**
	Floracarus perrepae	266
	Neomusotima conspurcatalis	268
	Common salvinia *Salvinia minima*	**272**
	Cyrtobagous salviniae	276
	Giant salvinia *Salvinia molesta*	**274**
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About This Field Guide

Invasive plants are a major concern worldwide. They displace native species, decrease forage/agricultural production, alter soil nutrient and water cycling, and lower the aesthetic value of natural areas. With the increase of world trade and travel, exotic plant introductions are on the rise. Biological control of weeds ("biocontrol") is the deliberate use of living organisms to limit the abundance of a target weed. In this field guide, biological control typically 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 weed biocontrol ("biocontrol agents" or "agents") include different organisms, such as insects, mites, nematodes, and fungi.

This guide focuses on the most problematic weeds in eastern North America for which there are at least some biocontrol agents established and/or available. Multiple photos and descriptions of each weed included in this guide emphasize key identification traits and plant ecology. For each weed included in this guide, all biocontrol agents released or currently found in North America are described individually. Photos highlighting key identification features and damage are included. The release history, current status, and recommended use of each biocontrol agent are described in detail. Because current impact and recommendations often vary between the US and Canada, information is presented separately. Symbols have been added for each biocontrol agent described in this manual to allow for quick recommendations:

US	Can	Individual Biocontrol Agent Status
■	●	High priority; recommended for release/redistribution
■	●	Medium priority, recommended to complement other agents or control methods
■	●	Low priority; typically low impact and/or survival
■	●	Caution when redistributing; not recommended for use in all areas
☒	⊗	Illegal to redistribute
?	?	Ongoing releases, but establishment not yet confirmed
□	○	Released, but failed to establish

Many biocontrol agents are already widespread. All target weed infestations should be surveyed prior to release to ensure the desired agents are not already present. Keep in mind some species are approved for use in only the US or Canada, but not both. In addition, some biocontrol agents cause damage to nontarget species. **Red text indicates the biocontrol agent is not recommended for release in all areas.**

Distribution maps are included for each weed included in this guide; maps can be found in the bottom right corner of each weed's description pages. Plant distribution data was collected from the USDA-PLANTS database and EDDMapS. Though significant effort is put into keeping both databases current, weed spread can be rapid, making distribution information quickly out of date. Please visit plants.usda.gov/du/DistributionUpdate.html for information on how to help update weed distribution information on the PLANTS site. For more information on how to utilize or contribute to the EDDMapS tools, visit www.eddmaps.org/about/ and apps.bugwood.org/.

Maps depicting each biocontrol agent's current establishment are presented in the bottom right corner on each species' respective description page. When a biocontrol agent attacks more than one weed species, multiple maps are presented and labeled by weed species. Maps were created using EDDMapS, available literature, and numerous personal communications with regional land managers. Like weeds, biocontrol agents can spread rapidly, making accurate distribution information elusive. Some biocontrol agents are not yet established, or are established on their target weeds only in western states and provinces not covered in this guide; the maps for these species appear blank for eastern states and provinces. The figure at right illustrates *Rhinocyllus conicus* is established on bull and musk thistle in eastern North America, but its establishment on Canada thistle is restricted to western states and provinces not covered in this guide.

Reported establishment of *Rhinocyllus conicus* in eastern North America on bull (left), Canada (middle), and musk thistle (right).

Biocontrol agents that were released but did not establish, natural enemies that are native to North America, and some natural enemies that are not currently approved for redistribution in the US and/or Canada (but are already present) are addressed separately from approved and established biocontrol agents. The description, ecology, and history/status for each of these additional species are described, accompanied by a photo. Should you encounter species previously believed to have failed establishment, contact your local weed superintendent, land grant university, or extension service personnel to confirm and document their establishment, and/or report the sighting to the EDDMapS database. Caution must be taken during field redistribution to ensure that species **not** approved for use are not inadvertently collected and redistributed along with approved biocontrol agents.

Biological Control of Weeds

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

To be approved for release in North America, weed biocontrol agents must be host-specific, meaning they must develop only on the target weed. Rigorous tests are required to confirm biocontrol agents are host specific and effective. Candidates often undergo five or more years of testing to ensure that rigid host specificity requirements are met, and results are vetted at a number of stages in the approval process.

The Technical Advisory Group (TAG) for Biological Control Agents of Weeds is an expert committee with representatives from US 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 US, and make recommendations to USDA-APHIS-PPQ regarding the safety and potential impact of candidate biocontrol agents. Weed biocontrol researchers work closely with USDA-APHIS-PPQ and TAG to accurately assess the environmental safety of candidate weed biocontrol agents and programs. In addition, some states and some National Parks in the US 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 Regional Standards for Phytosanitary Measures 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 candidate agent in the US. When release of an agent is proposed for both the US and Canada, APHIS and the CFIA attempt to coordinate decisions based on the assessed safety of each country's plant resources.

Biocontrol 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 both improve the efficacy of, and reduce the potential for negative impacts from, weed biological control. In following the Code, practitioners reduce the potential for causing environmental damage through the use of weed biological control by voluntarily restricting biocontrol activities to those most likely to result in success and least likely to cause harm.

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

As per rule 4 of the Code of Best Practices above, **species that have not been approved are illegal to introduce to the US and Canada. When non-indigenous natural enemies of a target weed arrive accidentally, it is generally illegal to redistribute them intentionally within the US**. A few cases where this is legal are described in this manual. Some species introduced accidentally to Canada are safe to utilize, however **redistribution of non-indigenous natural enemies should only be done under the guidance of Canadian biocontrol experts**.

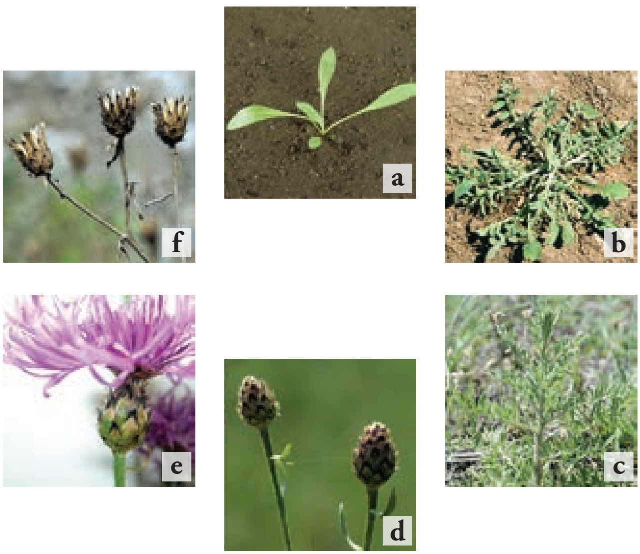
Although weed biological control is an effective and important weed management tool, it does not work in all cases and should not be expected to eradicate the target weed. Even in the most successful cases, biocontrol often requires multiple years before impacts become noticeable. Ideally, biological control should be integrated with chemical, mechanical, and/or cultural methods of weed management to improve overall weed control success.

Selected Plant Features

Weed descriptions utilized in this manual refer to a variety of life stages and characteristic features to help readers determine the key traits that set the weed apart from other plants. Traits referred to most commonly include:

Life cycle

The first recognizable stage of a plant life cycle is a seedling, when a plant has one to a few small leaves. Many perennial plants then grow into rosettes, which are clusters of leaves typically of the same height. Annual plants and vining species frequently do not have an obvious rosette stage. Plants then grow a flowering stem in a stage called bolting. In bud, immature flowers appear on flowering stems and branches. These open during flowering and then set seed upon maturation. At senescence, a plant has typically released its seeds and dies back for the winter or permanently.



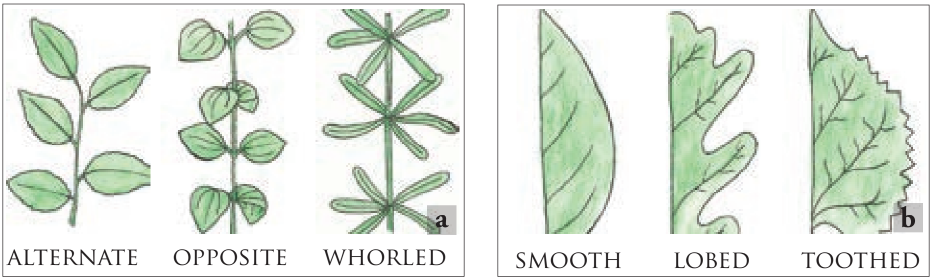
Generalized stages of spotted knapweed a. seedling; b. rosette; c. bolting,; d. bud; e. flowering; f. senescence (Credits: a, f Ohio State University Weed Lab Archive; b Steve Dewey, Utah State University; c K. George Beck & James Sebastian, Colorado State University; d John Cardina, Ohio State University; e Michael Shephard, Forest Service (a-f bugwood.org)

Duration

Annual species complete their life cycle (from germination to production of seed) within one year and then die. Summer annuals germinate during spring/early summer and mature by fall of the same year. Winter annuals germinate during fall and mature during the spring or summer of the following calendar year. **Biennial**

species take two years to complete their life cycle. In the first year, the plant is a rosette. During the next spring or summer, the plant bolts, sets seeds, and dies. **Perennial** species live for more than two years.

Typical leaf arrangement and margination



Leaf a. arrangement (how leaves are arranged along a stem); b. margination (shape of a leaf's edges) (a,b Jacqi Sullivan, MIA Consulting)

Flower heads

Many of the weeds included in this manual are members of the sunflower family (Asteraceae). Members of this family produce flower heads, or capitula, that are an aggregation of many individual flowers. These flowers, called florets, are clustered together and attached to a receptacle. There are two types of florets: disc and ray. Some species produce only one type, while others produce both. The receptacle and florets are enclosed by modified leaves called bracts. The type, color, and shape of florets and bracts can help in weed species identification. Each floret produces one seed (achene) from mid- to late summer. Some species produce seeds with a tuft of whitish hairs (pappus) on one end, similar to those on seeds of dandelions.

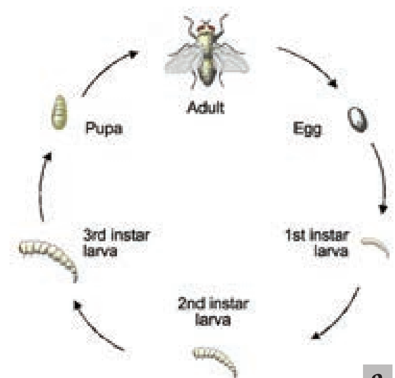
Flower heads in the sunflower family a. Canada thistle, all disc florets (Richard Old, XID Services, Inc, www.xidservices.com); b. rush skeletonweed, all ray florets (Rachel Winston, MIA Consulting); c. tansy ragwort, both disc (center) and ray (outer) florets (Strobilomyces)

Biological Control Agent Life Cycles

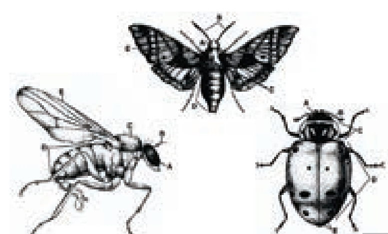
Classical biocontrol agents may be found in a number of taxonomic groups. The majority of approved biocontrol agents are animals in the phylum Arthropoda. More specifically, most biocontrol agents are insects (class Insecta) in the orders Coleoptera (beetles), Lepidoptera (butterflies and moths), and Diptera (true flies). In addition to insects, there are also mite, nematode, fungi, bacteria and virus biocontrol agents.

Insects

Insects are the largest, most diverse class of animals in the phylum Arthropoda. An understanding of basic insect biology and anatomy will help users recognize and identify the insects used as biocontrol agents of weeds. Most insects included in this field guide have complete metamorphosis, which means they exhibit a life cycle with four distinct stages: egg, larva, pupa, and adult. All adult insects have an exoskeleton (a hard external skeleton), a segmented body divided into three regions (head, thorax, and abdomen), three pairs of segmented legs, and may have one or two pairs of wings. The head of an adult insect has one pair each of compound eyes and antennae.



a



b

a. Complete metamorphosis of an insect (L. Wilson); b. body parts of adult insects A. head, B. antenna, C. thorax, D. abdomen, E. wing (adapted from Biological Control of Weeds in the West)

Immature insects have an exoskeleton that must be shed in order for them to grow to the next stage. This process is called molting, and larval stages between molts are called instars. The larvae of insects with complete metamorphosis (e.g. Lepidoptera, Coleoptera, Diptera) generally complete 3-5 instars before molting into pupae. During the pupal stage, insects change from larvae to adults. Insects do not feed or molt during the pupal stage. Adult insects emerge from the pupal stage and do not grow or molt.

Insects in the Hemiptera and Thysanoptera have incomplete metamorphosis, which does not include a pupal stage. Instead, their young are called nymphs and resemble the adults to a large degree. The transformation from nymph to adult primarily involves the development of wings (only in some species) and functioning reproductive organs.

Butterflies and Moths (Order Lepidoptera)

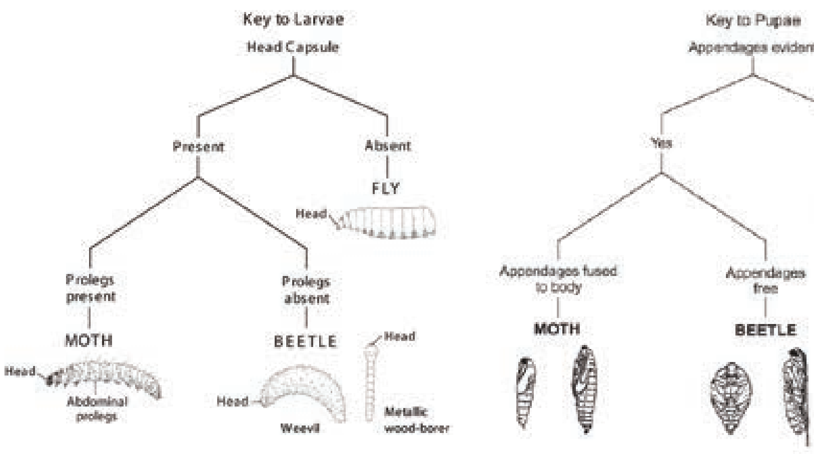
Adult Lepidoptera have two pairs of membranous wings covered with powder-like scales, prominent antennae, and coiled mouthparts adapted to siphoning nectar from plant flowers. Adult Lepidoptera described in this manual usually feed very little, if at all. Lepidoptera larvae (known as caterpillars) have a toughened head capsule, chewing mouthparts, and a soft body; they are active feeders. The pupal stage of Lepidoptera can be naked or enclosed in a cocoon, depending on the species.

Beetles (Order Coleoptera)

Adult beetles are hard-bodied with tough exoskeletons and possess two pairs of wings. The two front wings (elytra) are thickened and meet in a straight line down the abdomen, forming a hard, shell-like, protective covering. The two hind wings are membranous, larger, and used for flight; these are folded under the elytra when not in use. Beetle larvae are grub- or worm-like, often with three small pairs of legs, allowing some to be quite mobile. Many are pale white with a brown or black head capsule. All beetles have chewing mouthparts.

Flies (Order Diptera)

Adult true flies are easily distinguished from other orders of insects by their single pair of membranous wings and typically soft bodies. Larvae of most true flies, called maggots, are legless and wormlike. Many insects have the word "fly" in their name, though they may not be true flies. In the common names of true flies, "fly" is written as a separate word (e.g., house fly) to distinguish them from other orders of insects that use "fly" in their name (e.g., butterfly in the order Lepidoptera).



Key to differentiate biocontrol insects with complete metamporphosis as a. larvae; b. pupae (L. Wilson)

Biological Control Agent Life Cycles

Thrips (Order Thysanoptera)

Adult Thysanoptera can be wing-less or have two pairs of stalk-like wings with long hair fringing the margins. There are two actively feeding nymphal stages for all thrips and 2-3 inactive (non-feeding) stages. Adult and actively-feeding nymphal stages feed by piercing plants and sucking out the contents.

True Bugs (Order Hemiptera)

Many adult Hemiptera possess two pairs of wings, though some are wing-less. In winged individuals, the hind pair is membranous; the two front wings may be entirely membranous or only membranous at their tips and hardened at their base. Nymphs and adults feed by piercing plants and and sucking out the cell contents.

Mites

Like insects, mites are in the phylum Arthropoda and have an exoskeleton; however they belong to the class Arachnida, whose adult members are usually characterized by having 8 legs (compared to the 6 legs of insects). In some mite species, the first immature stage is called larva; mites in this stage have only 6 legs. The second immature stage is called a nymph and has 8 legs. Nymphs typically resemble adults. Some mite species do not have a larval stage, and some mite families have only 4 legs.

Nematodes

Nematodes, or roundworms, are animals in the phylum Nematoda. They are cylindrical, unsegmented worms that are typically 0.1-2.5 mm long and 5-100 µm thick. They have tubular digestive systems with openings at both ends. Eggs hatch into larvae that resemble adults but have underdeveloped reproductive systems.

Fungi

Fungi belong to their own kingdom (Fungi). Most fungi described in this manual are rusts, which are in the phylum Basidiomycota. Rust fungi are obligate parasites, meaning they require a living host to complete their life cycle. They obtain nutrients from living plant cells and can produce up to five spore types during their lifetime. Rusts are most commonly seen as colored powder (typically yellow, orange, or brown) composed of tiny aeciospores that land on vegetation and produce pustules, or uredia, on the lower surfaces. Urediniospores are red/orange and are a characteristic sign of rust fungus infection. These spores can re-infect the same host plant. During late spring or early summer, hair-like structures called telia grow on the leaves and produce teliospores which will germinate into aerial basidiospores to spread the infection to new hosts.

Scientific Name Changes

The weeds included in this guide are listed according to their common name, beneath which is included their scientific (Latin) name. The biocontrol agents are listed by their scientific name. Some species have recently undergone changes in their taxonomy. The following tables list weeds and biocontrol agents whose names have changed most recently (listed in the order in which they appear in this guide).

Weed Common	Scientific Name	Previous names
Spotted knapweed	*Centaurea stoebe*	*Centaurea biebersteinii, C. stoebe subsp. micranthos, C. maculosa*
Black swallow-wort	*Vincetoxicum nigrum*	*Cyanchum louiseae*
Pale swallow-wort	*Vincetoxicum rossicum*	*Cynanchum rossicum*
Musk thistle	*Carduus nutans*	*Carduus thoermeri*
Tansy ragwort	*Jacobaea vulgaris*	*Senecio jacobaea*
Dalmatian toadflax	*Linaria dalmatica*	*Linaria genistifolia, L. genistifolia* ssp. *dalmatica*
Mile-a-minute weed	*Persicaria perfoliata*	*Polygonum perfoliatum*
Alligatorweed	*Alternanthera philoxeroides*	*Achyranthes philoxeroides*
Bohemian knotweed	*Fallopia xbohemica*	*Polygonum ×bohemicum, Reynoutria ×bohemica*
Giant knotweed	*Fallopia sachalinensis*	*Polygonum sachalinense, Reynoutria sachalinensis*
Japanese knotweed	*Fallopia japonica*	*Polygonum cuspidatum, Reynoutria japonica*
Scentless chamomile	*Tripleurospermum inodorum*	*Matricaria perforata, Tripleurospermum maritimum* ssp. *inodorum, T. perforatum*

Agent Current Name	Target(s)	Previous names
Hadroplontus litura	Thistles	*Ceutorhynchus litura*
Cheilosia grossa	Thistles	*Cheilosia corydon*
Trichosirocalus horridus	Thistles	*Ceuthorhynchidius horridus*
Larinus carlinae	Thistles	*Larinus planus*
Niphograpta albiguttalis	Waterhyacinth	*Epipagis albiguttalis, Sameodes albiguttalis*
Bellura densa	Waterhyacinth	*Arzama densa*
Cercospora piaropi	Waterhyacinth	*Cercospora rodmanii*
Botanophila seneciella	Tansy ragwort	*Hylemyia seneciella, Pegohylemyia seneciella*
Rhinusa antirrhini; R. linariae; R. neta	Toadflaxes	*Gymnetron antirrhini; G. linariae; G. netum*
Austromusotima camptozonale	Lygodium	*Cataclysta camptozonale*
Pegomya curticornis, P. euphorbiae	Leafy spurge	*Pegomya argyrocephala*
Spurgia capitigena, S. esulae	Leafy spurge	*Bayeria capitigena*
Arcola malloi	Alligatorweed	*Vogtia malloi*
Omphalapion hookerorum	Scentless chamomile	*Apion hookeri*
Microplontus edentulus	Scentless chamomile	*Ceutorhynchus edentulus*
Spodoptera pectinicornis	Waterlettuce	*Namangana pectinicornis, Epipsammea pectinicornis*

Collection Methods

Some of the most commonly used methods for collecting biocontrol agents are sweep netting with or without aspirating, hand-picking/tapping, vacuuming, and light traps. The effectiveness of each method depends on the type and abundance of biocontrol agents being collected and the habitat. Regardless of the method used, **extraneous debris (e.g., other insects, weed seeds, etc.) must be sorted and removed**. Cooling the collected sample for 10 to 15 minutes reduces insect activity and makes sorting easier. **Any cooling should be done in a refrigerator, not a freezer.**

Sweep netting

Sweep nets are made of cotton or muslin on a hoop 10-15 in (25-38 cm) diameter attached to a handle 3 ft (0.9 m) long. 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" biocontrol agents off weeds.

Laura Parsons, University of Idaho

A sweep is made by swinging the net through the plant canopy. It is best to use no more than 25 sweeps before removing hard-bodied insects from the net, or as few as five times for fragile adult moths and flies. Removing the contents at regular intervals reduces the potential harm that could result from knocking biocontrol agents around with debris, and reduces the opportunity for predator insects and spiders from finding and devouring the biocontrol agents.

Aspirating

Use an aspirator to suck the biocontrol agents (usually small species) directly from the weed or the sweep net. This provides selective sorting; no unwanted or unknown material is inadvertently collected. 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.

Laura Parsons, University of Idaho

Berlese funnels

Berlese funnels are used to extract biocontrol agents from soil or plant litter by using light or a heat source. Place plant or soil material on a wire mesh suspended over a collection container (e.g. a jar), and secure the heat/light source (e.g. a heat lamp) above it all. As the light/heat penetrates the material, insects migrate down and fall into the collection container. Rubbing petroleum jelly around the rim of the collection container helps prevent insects from climbing back out. When using a heat source, place a moist napkin in the collection container and check often to ensure water is available to organisms collected.

Hand-picking/tapping

Stationary or slow-moving insects can be picked from foliage by hand using forceps. Other species can be tapped onto a tray or into a bottle topped with a large funnel using a tool such as a racquet. Plant segments infested with galls or fungal spores can be hand-picked and moved to new infestations. Take care when moving plant material to ensure seeds or other propagules are not included as this may introduce new genotypes.

Ray Willard, Washington Dept. Transportation

Vacuuming

Either a leaf blower with reverse capability or an industrial strength wet-dry vacuum cleaner can be equipped with a nylon mesh net on the inside mouth of the blowing tube (held in place with a rubber band or bungee cord) to suck up organisms. This is particularly useful for collecting small biocontrol agents such as flea beetles from weed rosettes. Rocks or debris vacuumed up may harm collected organisms, so this method should be applied to foliage collections only. Adding rosette leaves to the net gives biocontrol agents substrates to crawl and hide on and reduces the suction strength. Net contents should be aspirated to separate biocontrol agents from unwanted material.

Eric Coombs, Oregon Dept. Agriculture

Light trap

Light traps are used to collect nocturnal biocontrol agents (typically moths) that are otherwise difficult to collect during the day. Construct a wire or wooden framework to support a battery-operated lantern and beneath it a large funnel (with a wide enough opening for large insects) that rests inside a wide-mouth jar with target weed material in the bottom. Place it in a sheltered place near a target weed infestation. Start the light at dusk, and empty it in the morning. Alternatively, prop up a white sheet to serve as a reflecting surface, and place a lantern in front of it on a stool. Hand-collect the biocontrol agents attracted to the sheet as they land on the surface.

Jerry Payne, USDA ARS

Transport Considerations

Containers

Collected biocontrol agents must be transferred to containers to protect and prevent them from escaping. Containers should be rigid to resist crushing and ventilated to provide adequate air flow and prevent condensation. Unwaxed paperboard cartons are ideal for most species. Alternatively, use light-colored, lined containers (e.g. ice cream cartons) or plastic containers, providing they are ventilated. Cut or poke holes in the container or its lid, and cover the holes with a fine mesh screen. Gall- or fungus-infected foliage should be stored in large, breathable bags made of paper or gauze. Do not use glass or metal containers for insects or foliage; they are breakable and make it difficult to regulate temperature, air flow, and humidity.

For insects, fill containers two-thirds full with crumpled tissue paper to provide a substrate for insects to rest on/hide in, and to help regulate humidity. Include a few fresh sprigs of the target weed foliage. Sprigs should be free of roots, seeds, flowers, dirt, spiders, and other insects. Do not place sprigs in water-filled containers; they may crush the biocontrol agents or drown them upon leaking. Seal the container lids either with masking tape or rubber bands. Be sure to label each container with (at least) the name and number of biocontrol agent(s), the collection date and site, and the name of the person(s) who did the collecting.

Transporting biological control agents

When transporting short distances, place the containers in large coolers with sealed ice packs wrapped in crumpled newspaper or bubble wrap to prevent direct contact with containers. Place extra packing material in the coolers to prevent the ice packs from shifting and damaging the insect containers. Always keep coolers out of direct sunlight. If you sort and package your biocontrol agents indoors, keep them in a refrigerator (no lower than 40°F or 4.4°C) until you transport or ship them.

Shipping long distances

If you will be shipping your biocontrol agents to their final destination, use a bonded carrier service with guaranteed overnight delivery (e.g. USPS, FedEx, UPS, or DHL). In such cases, the release containers should be placed in insulated shipping boxes or coolers with one or more ice packs. The sealed 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 box to prevent them from having direct contact with the release containers and also to prevent crushing should they move about during shipping. Empty spaces in the shipping box should be loosely filled with crumpled paper, packing peanuts, etc. Enclose all paperwork accompanying the biocontrol agents (including permits and release forms) before sealing the shipping box.

Other factors to consider

- Make shipping arrangements well before agents are collected and ensure the carrier can guarantee overnight delivery and the proper treatment of package contents.
- Plan collection/packaging schedules so that delivery occurs Monday-Thursday.
- Clearly label packages and specify that they contain perishable material.
- Provide the receiver with a tracking number and verify someone will be there to accept the shipment.
- Releases should be made immediately upon receipt. If that is not possible, biocontrol agents should be checked for food depletion, excess moisture, and overcrowding and then be refrigerated.
- Have the receiver provide feedback to the shipper on the overall condition of the shipment. This can provide important guidance on packing/shipping methods.

REGULATIONS FOR THE TRANSFER OF BIOLOGICAL CONTROL AGENTS

US, 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 of your specific biological control agent. The state of California regulates release permits at the county level.

US, interstate: The interstate transportation of biocontrol 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 biocontrol agent or shipment of previously-released biocontrol agents entering the country. Permit requests are reviewed and issued by the Plant Health Division of the Canadian Food Inspection Agency. Redistribution within a province (or within Canada) of weed biocontrol agents that have been officially approved for release in Canada is not prohibited; however, you should consult with federal and provincial authorities and specialists prior to moving any weed biocontrol agent, especially across ecozones (e.g., from the prairies to the interior or coast of British Columbia). Similarly, you should consult with appropriate experts when considering the movement of adventive biocontrol agents that have become established in a region, or native organisms that may feed on a weed targeted for control.

Releasing Biocontrol Agents

Select release site

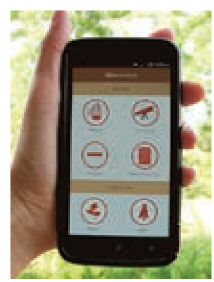
Survey prospective release sites early to ensure the targeted biocontrol agent is not already present. We recommend release sites be large patches with plenty of host plants. Different biocontrol agents will have different habitat preferences, so select sites on an individual basis. Avoid transferring agents to areas with high disturbance, other control methods (e.g. mowing, insecticide/herbicide use), or with a large number of ant mounds or ground dwelling animals which may predate biocontrol agents. Good sites should be readily accessible year after year. To reduce mortality or injury, it is best to redistribute biocontrol agents the same day they are collected. Releases of most biocontrol agents should be made under moderate weather conditions (mornings or evenings of hot summer days, mid-day for cold season releases). If you encounter an extended period of poor weather, however, it is better to release biocontrol agents than wait three or more days for conditions to improve, as the agents' vitality may decline with extended storage.

Establish permanent location marker

Place a steel or fiberglass pole as a marker at the release point. Avoid wooden or plastic posts; they are vulnerable to weather, decay, and fire. Markers should be colorful and conspicuous (e.g. red, orange, white). Where obvious posts may encourage vandalism, mark your sites with tent/surveyor's stakes or steel plates that can be tagged with release information and located later with a metal detector and GPS. Where a sign is appropriate, include contact information. The landowner and local weed management authority should be notified and given a map of the release location.

Record site geographical coordinates

Map coordinates of the release site marker should be determined using a GPS device or a GPS-capable tablet/smartphone and 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.



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 biocontrol 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 coordinates and elevation; a summary of its biological and physical characteristics and land use; the name(s) of the target weed and 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. The best time to record this information is while you are at the field site. Consider using a smartphone and reporting app, such as the iBiocontrol map from EDDMapS. Once back in the office, submit the information to your local weed control authority/agency. Always keep a copy for your own records.

Set up photo point

A photo point is used to visually document changes in weed 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.

Photo point with photos spanning three years (Rachel Winston, MIA Consulting)

Release as many biocontrol agents as possible

As a general rule of thumb, it is better to release many individuals of a biocontrol agent species at one infestation than it is to spread those individuals too thinly over multiple infestations. Releasing all biocontrol 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; 2/3 mile (1 km) or more is ideal.

Monitoring Biocontrol Agents

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 agent in an area where it is already abundant, and/or helping them avoid land management activities that would harm local biocontrol agent populations or worsen the weed problem.

Monitoring activities utilize standardized procedures to help determine:

- If the biocontrol agents have become established at the release site
- If biocontrol agent populations are increasing or decreasing and how far they have spread from the initial release point
- If the biocontrol agents are having an impact on the target weed
- 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, changes in the target weed population and plant community, and changes in other factors such as climate or soil.

Monitoring: a. checking biocontrol agent abundance; b. measuring vegetation along a transect; c. measuring vegetation in a more systematic grid (a-c Rachel Winston, MIA Consulting)

Assessing biocontrol agent populations

If you wish to determine whether or not 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. Recommendations for the best stages to monitor are given for each biocontrol agent in the following section of this guide. 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 that the agents 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 weed biological control expert for assistance.

To determine the changing densities of biocontrol agent populations, a systematic monitoring approach is required. A generalalized biological control agent monitoring form can be found in Appendix I.

Assessing the target weed & co-occurring plants

The ultimate goal of a weed biocontrol program is to permanently reduce the negative impacts of the target weed on ecosystem function; success is frequently measured as a reduction in target weed abundance. To determine if biocontrol efforts are effective, 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 occurs 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 target weed and the rest of the plant community at the management site. Examples include listing plant species occurring at the site, rough estimates of density (e.g. low, moderate, high), age (e.g. young, old) and distribution classes (e.g. isolated plants, small patches, dense infestations), visual infestation mapping (e.g. deliniating infestations by hand rather than via GPS), and maintaining a series of photos from designated photo points. Qualitative monitoring conducted consistently through time may provide insight into the status or change of target weed populations. However, its descriptive nature does not generally allow for quantitative statistical analyses. Qualitative monitoring may help you recognize what quantitative monitoring data/protocol might be most useful for the target weed system, which you can apply to new release sites in the future.

Monitoring Biocontrol Agents

Quantitative vegetation monitoring

Quantitative monitoring measures changes in the target weed population and associated vegetation community by precisely measuring specific plant and community characteristics. When conducted before and after a biocontrol agent release, quantitative data can be analyzed using a variety of statistical tests to identify where significant changes have occurred. Quantitative monitoring may be as simple as counting the number of target weed stems in a small sample area, or as complex as measuring plant height, flower and seed production, biomass, species diversity, and species cover. Pre- and post-release monitoring should follow the same protocol and be employed at the same time of year to ensure that the data is consistent and trends are easily identified. Post-release assessments should be planned annually for at least 3-5 years (and ideally longer than that) after the initial biocontrol agent release. A generalalized vegetation monitoring form can be found in Appendix II; it can be easily modified to meet your personal or agency needs.

Assessing impacts on nontarget plants

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

If you observe approved biocontrol agents feeding on and/or developing on nontarget species, the vegetation sampling procedures described above and in Appendix II 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 many "look-alike" native insects feed on related native plants.**

If you observe approved biocontrol agents feeding on and/or developing on native species, take samples to a biocontrol specialist in your area. Alternatively, send the specialist the site data so he/she can survey the site for nontarget impacts. Be sure not to ascribe any observed damage to any specific bioocntrol agent and thus bias the confirmation.

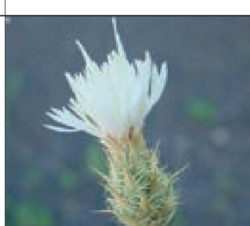
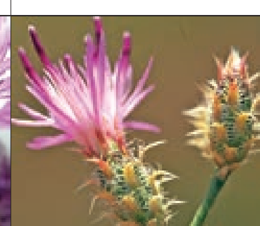
Additional Considerations

Avoiding parasitism

Some biocontrol agent populations are plagued by parasitoids that reduce their numbers and, consequently, their impact. When redistributing such species, it is important to ensure that parasitoids are not transferred along with the desired biocontrol agent. This can be accomplished by collecting plants infested with the desired biocontrol agents in the fall and storing them at 39-46°F (4-8°C) over the winter. Two to three weeks prior to their normal emergence time, bring them to room temperature in rearing cages or breathable, clear containers. Any parasitoids that emerge should be separated and destroyed. Emerging biocontrol agents can be safely transferred to new target weed patches during the appropriate plant stage.

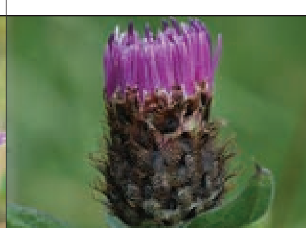
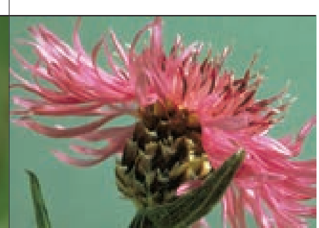
Knapweed species comparison (*Centaurea*)

Diffuse and spotted knapweed are the most common knapweed species in North America and the primary targets of knapweed biological control efforts. They are most problematic in western states and provinces, but are included in this eastern guide because some eastern infestations may benefit from biocontrol agent releases. Below is a comparison of these two knapweed species, as well as four others that are typically considered less problematic in North America but are occasional hosts to knapweed biocontrol agents. Russian knapweed is in a different genus,

Trait	**Diffuse** *Centaurea diffusa*	**Spotted** *Centaurea stoebe*	**Squarrose** *Centaurea virgata* ssp. *squarrosa*
Life History	Annual to short-lived perennial (usually biennial)	Short-lived perennial	Long-lived perennial
Preferred Habitat	Disturbed initially; Dry	Disturbed initially; Dry to mesic	Disturbed initially; Dry
Average Height	1.5’ (0.45 m)	2.5’ (0.75 m)	1.5’ (0.45 m)
Basal Leaf Description	4-8” long (10-20 cm); Deeply divided into linear lobes; Gray-green; Densely hairy	4-8” long (10-20 cm); Deeply divided into elliptic lobes; Gray-green; Densely hairy	4-8” long (10-20 cm); Deeply divided into fine lobes; Gray-green; Densely hairy
Capitulum Diameter	0.25-0.4” (7-10 mm)	0.25 - 0.6” (6-15 mm)	0.12-0.25“ (3-6 mm)
Bract Description	Narrow; Fringed by sharp spines; Terminal spine longer than laterals and not curved backward	Fringe short and rigid; Dark brown triangular tip	Narrow; Fringed by sharp spines; Terminal spine longer than laterals and strongly curved backward
Capitulum			

Rhaponticum, with a distinct biocontrol program not included in this guide because it currently pertains only to western North America.

Credits: Diffuse: Richard Old, XID Services, Inc, www.xidservices.com; Spotted: Michael Shephard, USDA Forest Service, bugwood.org; Squarrose: Steve Dewey, Utah State University, bugwood.org; Meadow: Eric Coombs, Oregon Department of Agriculture; Black: Mikrolit; Brown: Cindy Roche, bugwood.org

MEADOW *Centaurea jacea* nothosubsp. *pratensis*	**BLACK** *Centaurea jacea* ssp. *nigra*	**BROWN** *Centaurea jacea* ssp. *jacea*
Perennial	Perennial	Perennial
Moist sites	Mesic to moist	Disturbed initially; Mesic to Moist
2’ (0.6 m)	1.5’ (0.45 m)	2’ (0.6 m)
6” long (15 cm); Entire margins (sometimes tiny teeth or lobes); Tapered both ends, widest past middle; Green; Less hair	6” long (15 cm); Entire margins (sometimes tiny teeth or lobes); Wide at base then taper near stem; Green; Fine hair	6” long (15 cm); Entire margins (sometimes tiny teeth or lobes); Tapered both ends, widest past middle; Green; Less hair
0.5-0.75” (12-18 mm)	0.6-1” (15-25 mm)	0.5-0.85” (12-22 mm)
Bearing papery, deeply fringed margins	Tipped with comb-like, black teeth	Bearing papery, translucent margins
		

Diffuse knapweed

Centaurea diffusa Lam.

SYNONYMS: white knapweed, tumble knapweed

ORIGIN: First recorded in North America in 1907 in an alfalfa field.

DESCRIPTION: A winter-hardy forb that usually grows as a biennial but may at times grow as an annual or short-lived perennial. This plant has a deep and fibrous taproot. Stems are 1-3.5 ft tall (0.3-1 m) with numerous, spreading branches that give the plant a ball-shaped appearance and tumble-weed mobility when broken. Rosette leaves are deeply divided, gray-green, and covered in small hairs. Stem leaves are stalkless, getting smaller and less divided higher up the stem. Flower heads have white (sometimes pink or lavender) florets that occur at the ends of branches and produce numerous bristle-topped seeds. Receptacle bracts are edged with a fringe of spines; the terminal spine is distinctly longer.

Diffuse knapweed a. plant (K. George Beck & James Sebastian); b. infestations (Eric Coombs, Oregon Department of Agriculture)(a,b bugwood.org)

Diffuse knapweed c. leaf (K. George Beck & James Sebastian); d. capitulum with white florets (Richard Old, XID Services, Inc, www.xidservices.com); e. capitulum with pink florets (Steve Dewey, Utah State University)(c-e bugwood.org)

HABITAT: This plant rapidly colonizes dry and disturbed lands, thriving most in shrub-steppe zones and dry, open forests.

ECOLOGY: Diffuse knapweed spreads only by seeds. Unlike other knapweeds, the flower heads of diffuse do not open to shed seeds. Instead, seeds are shed as the mature plants tumble in the wind after the stiff central stalk breaks. Seeds are also spread by vehicles, animals, and people, and can remain viable for many years. Flowering occurs from June through October. Seeds germinate throughout the growing season.

BIOLOGICAL CONTROL: The majority of releases on diffuse knapweed have been made in western North America, where this weed is most problematic. As of 2016, only *Bangasternus fausti, Larinus minutus, Sphenoptera jugoslavica, Urophora affinis*, and *U. quadrifasciata,* have established on diffuse knapweed in the East, and typically only with small populations and limited impact. In the West, successful diffuse knapweed control has been achieved at some sites by using a combination of insects attacking seeds, foliage, and roots of knapweed plants; *Larinus* spp. and *Cyphocleonus achates* have been the most important.

NOTES: A diploid, fertile hybrid between diffuse knapweed and spotted knapweed has been identified as *C.* ×*psammogena*.

Spotted knapweed

Centaurea stoebe L. sensu latu

SYNONYMS: bushy knapweed; *Centaurea biebersteinii* DC, *Centaurea stoebe* L. ssp. *micranthos* (Gulger) Hayek, *Centaurea maculosa* Lam.

ORIGIN: Introduced in contaminated hay from Europe and Asia as early as 1890.

DESCRIPTION: A bushy, winter-hardy, biennial or perennial forb. This upright plant is often found in dense infestations. Plants grow from 1-3.5 ft (0.3-1 m) in height and are supported by a deep taproot. Rosette leaves are gray-green, woolly, and deeply divided. Stem leaves are pinnately divided, becoming smaller and less divided towards the tips of multiple woolly, hairy stems. Mid-plant branches are topped by a few to many pink or lavender flower heads producing numerous tiny, bristle-topped seeds. Receptacles are covered by shortly fringed bracts with dark brown tips which give the plant its common name of "spotted knapweed."

Spotted knapweed a. plant (Angelica Velazquez, Cowlitz County Noxious Weed Control Board); b. infestation (Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

Spotted knapweed c. rosettes (Rob Routledge, Sault College); d. leaf (John Cardina, The Ohio State University); e. flower head (Michael Shephard USDA Forest Service)(c-e bugwood.org)

HABITAT: This species rapidly colonizes disturbed and often dry sites (including rocky roadsides, talus slopes, pastures, sandplain grasslands, and coastal dunes), then invades adjacent undisturbed grasslands and open forests.

ECOLOGY: Spotted knapweed spreads only by seeds that are dispersed by wind, water, livestock, wildlife, and human activity and which can remain viable in the soil for many years. Flowering occurs from June to October. Seeds germinate throughout the growing season. Heads persist on the stiff stems through the winter, eventually breaking off when new rosette growth appears the following spring.

BIOLOGICAL CONTROL: The majority of releases on spotted knapweed have been made in western North America, where this weed is most problematic. As of 2016, *Agapeta zoegana, Bangasternus fausti, Cyphocleonus achates, Larinus minutus, L. obtusus, Urophora affinis*, and *U. quadrifasciata* have established on spotted knapweed in the East, but typically with small populations and limited impact. In the West, successful spotted knapweed control has been achieved at some sites by using a combination of insects attacking seeds, foliage, and roots of knapweed plants. *Larinus* spp. and *Cyphocleonus achates* have been the most important in the West; the role of *Agapeta zoegana* is under study.

NOTES: *Centaurea stoebe* L. is the appropriate name for the diploid form present throughout Europe; the nomenclature for the tetraploid form invasive in North America remains to be resolved.

Cyphocleonus achates (Fåhraeus)

Knapweed root weevil

DESCRIPTION: Eggs are <2 mm in diameter and white or pale yellow initially, but darken during incubation. Larvae are plump, creamy white or yellowish, with large, light brown head capsules. They can be up to 13 mm long. Similar to most weevils, they are C-shaped. Adults are large, 13–15 mm long, brown-gray mottled, and have short, thick snouts. Females have rounded abdomens, while the males' are flattened.

Cyphocleonus achates a. larva and root damage (Mark Schwarzländer, University of Idaho, bugwood.org); b. pupa in root; c. adult (b,c Jennifer Andreas, Washington State University Extension)

LIFE CYCLE: Adults emerge in late summer through early fall and spend most of their life on the root crown, just below the surface. On hot, sunny days they climb to the tops of plants in search of mates. Females lay their eggs in notches they excavate on the root crown, just below the soil surface. A typical female may lay over 100 eggs. Larvae hatch in 10-12 days and mine towards the center of the roots. They develop through four instars, with third- and fourth-instars often causing a gall-like enlargement of the root. Larvae overwinter in the roots, and pupation occurs in the root over a two-week period in early summer. New adult weevils chew through the root and crawl to the surface. They live for 8-15 weeks but do not overwinter. There is one generation per year.

DAMAGE: Small plants can be killed by larval feeding. Most damage is done when multiple larvae occupy a root, which leads to a reduction in plant biomass and density of knapweed populations. Tunneling in the root also exposes the plant to bacterial and fungal infection that can cause secondary injury.

PREFERRED HABITAT: This weevil prefers hot and dry sites, with loose, well-drained, coarse soils in temperate areas. It favors bare soil surfaces where grasses do not crowd the target plants. It disperses by walking so does best at infestations with continuous knapweed plants.

RELEASE HISTORY: This weevil was introduced from Austria, Hungary, and Romania and released on both spotted and diffuse knapweed in the western US in 1988 and in western Canada in 1987. Eastern North American releases were made only on spotted knapweed in the US, beginning in 1994 (IN, MI, MN, NE, NY, SD, WI) and only on spotted knapweed in ON, Canada in 1993. Successful redistributions were made to squarrose knapweed in the western US in 1995. Attempted redistributions to meadow knapweed in the western US failed to establish.

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America. In the eastern US, *C. achates* is confirmed established only on spotted knapweed and only with limited populations. In the western US, the principal host is spotted knapweed, on which its abundance and impact vary. Numerous studies claim this biocontrol agent can be effective, but largely in combination with *Larinus* spp., with high plant competition, under dry conditions, and in loose soil. Damage to diffuse knapweed in the western US is usually (but not always) less extensive compared to spotted knapweed. This weevil is established on squarrose knapweed in the western US, but only in limited numbers and with unknown impact. This weevil is not established in eastern Canada. In western Canada, spotted knapweed is also the preferred host, on which high weevil populations can decrease plant density and stature, though evidence supporting this is anecdotal. Its impact there is greatest in conjunction with other biocontrol agents. Populations are smaller on diffuse knapweed than spotted knapweed in western Canada, but the weevil is having increasing impact on diffuse knapweed, especially at hot, dry, and open sites with loose soil.

REDISTRIBUTION: Adults can be can be netted in late summer, but are large enough to be hand-picked. They are most apparent on sunny days and in the afternoon. Releases of 50-100 individuals should be made at large infestations with hot climates and loose, well-drained soil. Establishment can be monitored by observing adults the following late summer or dissecting roots for feeding larvae the following autumn through early summer. Note that root damage without larvae present can be difficult to distinguish from other root-feeding insects.

NOTES: Multiple larvae are often found attacking the same root, along with other species.

diffuse

spotted

Larinus minutus Gyllenhal
Lesser knapweed flower weevil

DESCRIPTION: This species is very similar to *Larinus obtusus*. Eggs are elongate, yellow, and often clustered in the flower head between pappus hairs. Larvae are white, C-shaped, and have brown head capsules. They are approximately 8 mm long. Pupae are 6 mm long and white, turning brown shortly before emergence. Adults are 4-5 mm long, a mottled-brown color, and have a large, bent snout.

Larinus minutus a. pupa (Gary Brown, USDA APHIS PPQ); b. adult (Laura Parsons & Mark Schwarzländer, University of Idaho); c. adult feeding damage to stem and leaves (Rachel Winston, MIA Consulting); d. emergence hole (Jennifer Andreas, Washington State University Extension)

LIFE CYCLE: Overwintering adults emerge from plant litter throughout the summer. Mating occurs continuously during this long period. Adults feed on knapweed leaves, outer stem tissue, and flowers prior to laying eggs. Up to five eggs are deposited in a flower head between pappus hairs; females lay 28-130 in a lifetime. Larvae hatch in three days and feed on pappus hairs before consuming seeds and receptacle tissue. Larvae feed through the entire knapweed flowering period of and develop through three instars in four weeks. The number of larvae per flower head depends on flower head size and knapweed species. Pupation occurs in chambers made of chewed seeds and pappus hairs within the flower head. New adults emerge by chewing their way out, leaving behind the now-open pupal chamber. They feed on foliage and florets before moving to overwintering sites at plant bases. There is one generation per year.

DAMAGE: Defoliation by adults can be severe, which can stunt and even kill affected plants. Larval feeding consumes large portions of developing seeds, reducing the rate of knapweed spread.

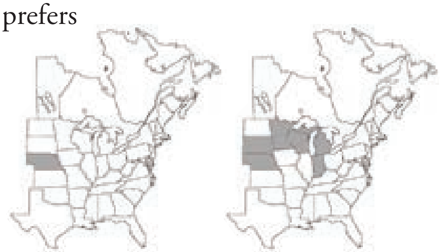
PREFERRED HABITAT: This weevil typically prefers sites more dry and hot than those tolerated by *L. obtusus*. It favors dense knapweed stands with little plant competition and requires well-drained, coarse soils. Sites with compacted soil (especially those grazed with livestock during the bolting stage) or places with prolonged rainfall are not suitable for this insect.

RELEASE HISTORY: This weevil was introduced from Greece and Romania and released on both diffuse and spotted knapweed in the western US in 1991. Eastern US releases began in 1992 on both diffuse knapweed (MN, NE, SD, TX) and spotted knapweed (IN, MI, MN, NE, NY). The weevil spread naturally and via intentional redistributions to meadow and squarrose in the western US in 1997. A redistribution attempted on purple starthistle in the western US failed to establish. Individuals from Greece were released on diffuse and spotted knapweed in western Canada in 1991. In eastern Canada, it was redistributed only to spotted knapweed (ON 2007, MB 2012).

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America, but populations and impact are greatest in western states and provinces. Larval feeding decreases knapweed seed output while adult feeding stunts plant growth. In the western US, this weevil causes widespread decreases in density of diffuse knapweed. Impact on spotted knapweed is variable; it can reportedly be high, but is typically less dramatic than on its preferred diffuse knapweed. The weevil's impact on meadow and squarrose knapweed in the western US is typically lower than its impact on diffuse knapweed. In Canada, this weevil is only established in western provinces, where it prefers diffuse knapweed; it causes extensive damage to diffuse and localized damage to spotted.

REDISTRIBUTION: Adults can be collected with a sweep net (with or without an aspirator) during summer when plants are in early flowering. Releases of at least 200 individuals should be made at new (uninfested) patches of knapweed. Establishment can be monitored the following summer by checking for adults and/or feeding larvae within capitula. Note that feeding larvae can be difficult to distinguish from other knapweed weevil species.

NOTES: *Larinus minutus* reportedly prefers diffuse knapweed while *L. obtusus* prefers spotted. Both are difficult to differentiate with the naked eye, with some evidence pointing to them being variants of the same species. Many releases of either biocontrol agent likely contained a mixture of both. Rodent predation can be high at some sites.



diffuse spotted

Larinus obtusus Gyllenhal
Blunt knapweed flower weevil

DESCRIPTION: This species is very similar to *Larinus minutus*. Eggs are elongate, yellow, and deposited in the flower head between pappus hairs. Larvae are white, C-shaped, and have brown head capsules. They are approximately 8 mm long. Pupae are 6 mm and white, turning brown shortly before emergence. Adults are 5-7 mm long, a mottled brownish-black, and have a large, bent snout.

Larinus obtusus a. adult (Laura Parsons & Mark Schwarzländer, University of Idaho); b. adult feeding damage (Rachel Winston, MIA Consulting); c. larval feeding damage (Montana State University Archive, bugwood.org)

LIFE CYCLE: Overwintering adults emerge from plant litter throughout the summer. Adults feed on knapweed foliage and flowers prior to laying eggs. Eggs are deposited in the flower head between pappus hairs. Larvae hatch in three days and feed on pappus hairs and developing seeds. Larvae feed through the entire knapweed flowering period, and develop through three instars in 3-4 weeks. The number of larvae per flower head depends on on flower head size and knapweed species. Pupation occurs in 9 days in pupal chambers made of chewed seeds and pappus hairs within the flower head. New adults emerge in late summer by chewing their way out, leaving behind the now-open pupal chamber. They feed on foliage and senescing florets before moving to overwintering sites at the base of plants. There is one generation per year.

DAMAGE: Defoliation by adults can be severe, which can stunt and even kill affected plants. Larval feeding consumes large portions of developing seeds, reducing the rate of knapweed spread.

PREFERRED HABITAT: This weevil favors more moist sites with cooler temperatures than those tolerated by *L. minutus.* It establishes on south and west slopes with well-drained coarse soils, often near water. Excess competing vegetation may discourage its establishment.

RELEASE HISTORY: This weevil was introduced from Romania and Serbia and released on both diffuse and spotted knapweed in the western US in 1992. Eastern US releases were made only on spotted knapweed and beginning in 1995 (MI, MN, NE, NY, SD). The weevil spread naturally and via intentional redistributions to meadow, black, and brown knapweed in the western US beginning in 1999. The weevil was introduced from Romania and released on both diffuse and spotted knapweed in western Canada in 1992; no releases or redistributions have been made to eastern Canada to date.

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America. In the eastern US, *L. obtusus* is confirmed established only on spotted knapweed and only with limited populations. Throughout the western US, the principal host is spotted knapweed, on which its abundance and impact vary. Larval feeding decreases knapweed seed output while adult feeding may stunt plant growth. This weevil successfully reduces spotted knapweed abundance at some locations in the Pacific Northwest but has little to no impact at some other knapweed infestations. Populations are more limited and have less impact on diffuse, meadow, black, and brown knapweed in the western US, largely via seed reduction. In Canada, the weevil is only established in the western province of BC where it prefers spotted knapweed. The weevil prefers more moist conditions, so it has a smaller distribution than *L. minutus,* and its overall impact on spotted knapweed is moderate. The weevil's impact on diffuse knapweed in western Canada is unknown.

REDISTRIBUTION: Adults can be collected with a sweep net (with or without an aspirator) during summer when plants are in early flowering. Releases of at least 200 individuals should be made at new (uninfested) patches of knapweed. Establishment can be monitored the following summer by checking for adults and/or feeding larvae within capitula. Note that feeding larvae can be difficult to distinguish from other knapweed weevil species.

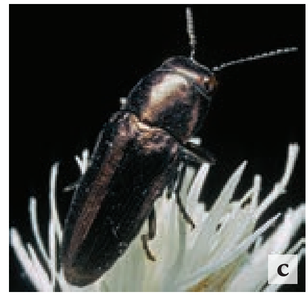
NOTES: *Larinus obtusus* reportedly prefers spotted knapweed while *L. minutus* prefers diffuse. Both are difficult to differentiate with the naked eye, with some evidence pointing to them being variants of the same species. Many releases of either biocontrol agent likely contained a mixture of both. Rodent predation can be high at some sites.


diffuse


spotted

Sphenoptera jugoslavica Obenberger
Bronze knapweed root borer

DESCRIPTION: Eggs are flat and white when first laid, but change to dark bluish-purple after five days. Larvae have an enlarged head and a long, thin, cylindrical body that tapers to the end. They are whitish with inflated segments and dark brown head capsules. Pupae are initially white, but later darken. Adults can be up to 10 mm long. They are a metallic bronze color and somewhat flattened, with their bodies tapering towards the narrowed abdomen tip.



Sphenoptera jugoslavica a. eggs; b. larva in root (a,b Eric Coombs, Oregon Department of Agriculture); c. adult (Laura Parsons & Mark Schwarzländer, University of Idaho)(a-c bugwood.org)

LIFE CYCLE: Adults emerge in summer as knapweed flowers. They feed on knapweed leaves for 2-3 days before mating. During late summer, females lay multiple eggs between the bases of rosette leaves. Leaf stems with diameters of 3-6 mm are preferred over smaller leaves. Females lay an average of 50 eggs during their lifetimes. Larvae hatch after two weeks and feed between leaf stalks. As knapweed sets seed, second instars mine into the upper root; their feeding creates swollen galls and tunnels often filled with frass. Larvae overwinter in roots. Pupation (nine days) occurs within the feeding chamber during early summer the following year. There is one generation per year.

DAMAGE: Adults feed on knapweed foliage, leaving characteristic circular and oval feeding holes over the entire leaf. Feeding larvae consume roots which, in turn, may kill plants outright, prevent rosettes from flowering, or decrease the reproductive output of already-flowering stalks.

PREFERRED HABITAT: This beetle prefers arid environments with a period of drought in summer. It thrives in well-drained, coarse soils with southern aspects. Exposed soil between plants increases the soil temperature, making sites even more suitable.

RELEASE HISTORY: Individuals from Greece were released in the western US on diffuse knapweed in 1980. The beetle spread naturally and via intentional redistributions in the western US to spotted knapweed by 1987 and squarrose knapweed by 1996. Redistributions to western meadow knapweed infestations failed to establish. Though not intentionally introduced in the eastern US, this beetle likely spread naturally from nearby states. Individuals from Greece were released in BC, Canada on diffuse knapweed from 1976. It was redistributed from diffuse to spotted knapweed in BC in 1987.

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America. In the eastern US, *S. jugoslavica* is confirmed established only on diffuse knapweed and only with limited populations. It is established on diffuse, spotted, and squarrose knapweed in the western US, though diffuse is the preferred host, on which it reduces plant density and seed output, especially among competing vegetation. The overall impact on diffuse is moderate, as the agent is largely restricted to hot, dry sites. While spotted knapweed can be attacked, agent distribution and impact are typically limited. It is slightly to moderately effective on squarrose knapweed in the western US. In Canada, *S. jugoslavica* is established on both diffuse and spotted knapweed, but only in the western province of BC where diffuse knapweed is again the preferred host. On diffuse, high agent populations can be found throughout the driest part of the weed's range; high beetle numbers in conjunction with other biocontrola gent can decrease weed stature, seed production, and rosette density, though most impact is only localized. On spotted knapweed, *S. jugoslavica* can decrease seed production and stature of plants growing in hot dry areas, but most spotted infestations are too moist to support beetle populations.

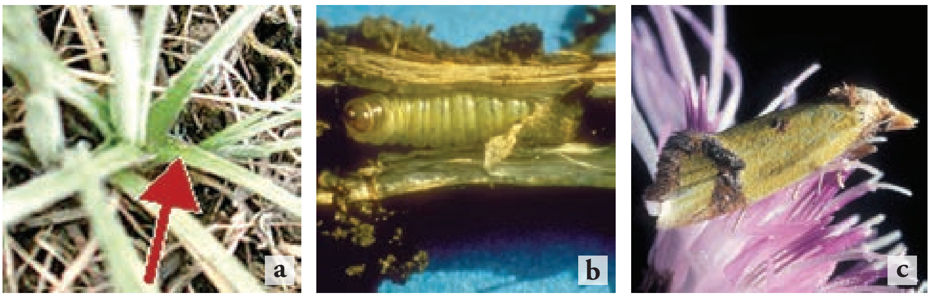
REDISTRIBUTION: Adults can be collected with a sweep net (with or without an aspirator) during summer when knapweed plants are in flower. Releases of 50-200 individuals should be made at large infestations with hot climates and loose, well-drained soil. Establishment can be monitored by observing adults the following summer or dissecting roots for feeding larvae the following autumn through early summer. Note that root damage without larvae present can be difficult to distinguish from other root-feeding insects.

NOTES: Plants rarely support more than one larva; if two develop on a single root, the larva feeding lowest in the root is usually smaller.

diffuse spotted

Agapeta zoegana (L.)
Sulfur knapweed moth

DESCRIPTION: Larvae are white with brown mouthparts and can be up to 7 mm long. Adults are usually 11 mm long with a wingspan measuring 15-23 mm. Forewings are bright yellow with brownish band markings; hind wings are dark gray. Females have a larger, more rounded abdomen than males and lay white, flattened eggs that turn yellow-red in a few days.



Agapeta zoegana a. egg (Nez Perce Biological control Center Archive); b. larva and root damage (USDA ARS); c. adult (Laura Parsons & Mark Schwarzländer, University of Idaho)(a-c bugwood.org)

LIFE CYCLE: Larvae overwinter in knapweed roots and feed within the roots the following spring. Pupation occurs in the roots; adults emerge from summer to early fall when knapweeds are in bud and flowering. Adults mate within 24 hours of emergence and are short-lived. They are most active in early mornings or evenings, and rest low on plants or on the soil surface during the day. Females deposit eggs on knapweed stem crevices and leaves as early as the following day. A single adult female lays 21-78 eggs in her lifetime. Larvae hatch in 7-10 days and migrate to the crown area and mine roots, developing through six instars. As they mine outer root layers, larvae produce a whitish web tunnel that encloses them. They create a spiral trail downward before they turn back towards the top of the root. There is usually only one generation per year.

DAMAGE: When larvae feed within roots, root tissue can be completely consumed. This reduces knapweed biomass and density and may kill small plants.

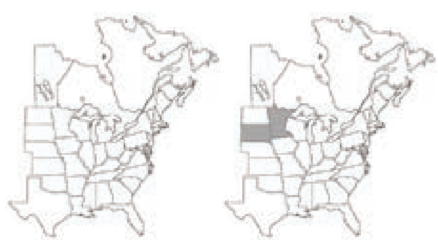
PREFERRED HABITAT: This moth is found mostly in dry, well-drained, open sites with loamy soil. It survives in areas characterized by a moderately humid climate or in areas with arid, subcontinental climates. It can tolerate cold winter temperatures, but requires a long growing season. Suitable host plants have root diameters of at least 0.1 in (2.5 mm).

RELEASE HISTORY: This moth was introduced from Austria and Hungary and released on spotted and diffuse knapweed in the western US in 1984 and subsequently redistributed to MN, SD and WI in the eastern US. It remains unclear if attempted redistributions to squarrose knapweed in the western US were successful. Austrian and Hungarian populations were also used for releases on spotted and diffuse knapweed in western Canada in 1982. Redistributions were made from spotted to squarrose knapweed in western Canada in 2006.

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America. In the eastern US, *A. zoegana* is confirmed established only on spotted knapweed. This moth can cause significant reduction of spotted knapweed above-ground biomass and number of capitula per plant, but it has not demonstrated any obvious effect on plant density. It is expected to primarily affect large plants. Its abundance is believed to be limited, and its overall impact is likewise believed to be low throughout the US, though this is currently under study. In Canada, this moth is established only in western provinces not covered in this guide, where high populations may have a significant impact on diffuse and spotted knapweed populations, especially in conjunction with other biocontrol agents. Though widely distributed in western Canada, moth abundance is variable.

REDISTRIBUTION: Because moths are delicate, distribution efforts should use larvae. Infested plants can be dug up (including the roots) and transferred to new sites in late fall or early spring. Alternatively, roots can be collected in fall and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time, bring them to room temperature in rearing cages or breathable, clear containers. Once they emerge, adults can be transferred to new knapweed infestations. Releases of 100-200 individuals should be made on continuous, nonlinear patches of knapweed in loamy soil. Establishment can be monitored the following spring by dissecting roots for feeding larvae or observing adults in low foliage during late summer. Note that root damage without larvae present can be difficult to distinguish from other root-feeding insects.

NOTES: Multiple larvae may attack the same root. In one observation, more than 50 *A. zoegana* larvae and 20 *Cyphocleonus achates* larvae were found attacking one very long segment of knapweed root.



diffuse spotted

Urophora affinis (Frauenfeld)
Banded knapweed gall fly

DESCRIPTION: Eggs are white and elongate. Larvae are creamy white, barrel-shaped, and with heads that retract slightly. Larvae of flies do not have head capsules but do develop dark brown anal plates by the end of the feeding period. The pupa is brown, barrel-shaped, and 3 mm long. Adults can be up to 4 mm long. They have dark bodies and clear wings marked with faint horizontal bars. Females have long, pointed, black ovipositors.

Urophora affinis a. larva in gall (Eric Coombs, Oregon Department of Agriculture); b. multiple galls (Jim Story, Montana State University); c. adult (Laura Parsons & Mark Schwarzländer, University of Idaho)(a-c bugwood.org)

LIFE CYCLE: There is usually one generation per year, though two may occur in warm climates. Overwintering as third instars, flies pupate for ~14 days in the spring. Adults emerge when knapweed is in bud. Females lay up to 120 eggs in groups of 1-5 among immature florets inside closed flower heads. After 3-4 days, larvae hatch and tunnel into the base of the capitulum to feed on receptacle tissue. Larval feeding triggers the formation of a hard, woody gall that surrounds the larva. 2-4 galls per capitulum is common, though the number depends on capitulum size and knapweed species. Most larvae require a cold period to induce pupation, and thus overwinter in flower heads; 10-25% of larvae may pupate early in suitable climates, with second generation adults emerging in early fall.

DAMAGE: Larval feeding directly destroys some seeds, reducing the rate of knapweed spread. In addition, galls drain nutrients from other parts of the plant, which causes stunting and reduces the number of flower heads produced.

PREFERRED HABITAT: This species is well adapted to a variety of conditions and can be found throughout much of North America. It shows a preference for mesic sites and appears to do better on dense knapweed populations.

RELEASE HISTORY: Individuals from Austria, France and Russia (some via

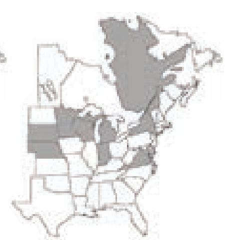
Canada) were released on diffuse and spotted knapweed in the western US in 1973. Eastern US releases were made on diffuse knapweed in 1983 (MD) and on spotted knapweed beginning in 1983 (IN, MD, MI, MN, NY, PA, VA, WI). This fly spread naturally and via intentional redistributions to squarrose knapweed in the western US from 1988. Individuals from France and Russia were first introduced to western Canada in 1970 and subsequently released in MB, QC, and ON on spotted knapweed beginning in 1970 and on diffuse knapweed in 1980. Many releases contained a mixture of *U. affinis* and *U. quadrifasciata*.

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America. Throughout the US, and along with *U. quadrifasciata,* this fly contributes to diffuse and spotted knapweed seed reduction >50% at some sites. This may slow the rate at which knapweed spreads, but it has not appreciably lowered stand density because sufficient seeds remain. At other sites, the direct effect of *Urophora* galls on seed production is negligible, and it is not considered as important or effective as other knapweed agents. It has limited abundance and impact on squarrose knapweed in the western US. In Canada, high fly populations stunt plant growth and significantly decrease seed production, but have not resulted in any apparent decline in knapweed density to date.

REDISTRIBUTION: Sweeping adult flies is possible, though flies are fragile and can be damaged during collection. The species is best transferred by placing plants with infested capitula into uninfested patches during late fall or early spring. Transferring infested capitula may also transfer unwanted parasitoids, insects, or knapweed seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, flies can be transferred to uninfested knapweed patches in groups of 50-100. Establishment can be monitored by observing adults on knapweed foliage the following summer or by dissecting capitula for larvae from summer to spring. Note that feeding larvae can be difficult to distinguish from other knapweed fly species. *Urophora* species have dark brown anal plates and can be found within galls.

NOTES: This species does not disperse as rapidly as *U. quadrifasciata*, but is often the dominant species where both flies coexist. Deer mice feed heavily on *Urophora* larvae, and mice populations are known to increase as a result.


diffuse


spotted

Urophora quadrifasciata (Meigen)
UV knapweed seedhead fly

DESCRIPTION: Eggs are white and elongate. Larvae are creamy white, barrel-shaped, and with heads that retract slightly. Larvae do not have head capsules but do develop dark brown anal plates by the end of the feeding period. The pupa is brown, barrel-shaped, and 3 mm long. Adults can be up to 4 mm long. They have dark bodies and clear wings marked with distinctive dark bands forming a "UV" pattern on each wing. Females have long, pointed, black ovipositors.

Urophora quadrifasciata a. larva (USDA ARS); b. adult (Laura Parsons & Mark Schwarzländer, University of Idaho)(a,b bugwood.org)

LIFE CYCLE: There are usually two generations per year. Overwintering as third instars, flies pupate for 14 days in spring, and adults emerge as knapweed is in bud. Females lay up to 120 eggs in groups of 1-5 among immature florets inside closed flower heads; females prefer well-developed capitula. After 3-4 days, larvae hatch and tunnel into the base of the capitulum and feed on receptacle tissue through three instars. Larval feeding induces the formation of a papery gall that surrounds the larva. 2-4 galls per capitulum is common, though the number depends on capitulum size and knapweed species. Pupation occurs in galls in late summer. Second generation adults emerge in early fall, attacking late-developing seed heads. Larvae overwinter in capitula.

DAMAGE: Larval feeding directly destroys some seeds, reducing the rate of knapweed spread. In addition, galls drain nutrients from other parts of the plant, which causes stunting and reduces the number of flower heads produced.

PREFERRED HABITAT: This species is well adapted to a variety of conditions and throughout much of North America. It is tolerant of severe winter conditions but requires considerably more protective snow cover than *U. affinis*.

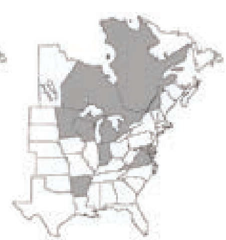
RELEASE HISTORY: Individuals from Russia were released in western Canada on diffuse knapweed in 1972 and subsequently spread naturally to spotted knapweed by 1975 and meadow knapweed by 2000. Eastern Canada releases began on spotted knapweed in 1979 (MB, ON, QC) and diffuse knapweed starting in 1993 (MB, ON). The fly spread naturally from Canada to the western US by 1979 (diffuse and spotted knapweed) and subsequently spread naturally and via intentional introductions throughout the western US to brown, meadow, and squarrose knapweed, yellow starthistle, and bachelor's button. Eastern US redistributions occurred only on spotted knapweed beginning in 1983 (AR, IN, MD, MI, MN, NY, VA, WI), often under the assumption it was the approved *U. affinis*. It was officially approved for redistribution in the US in 1989.

CURRENT STATUS: Attacks both diffuse and spotted knapweed in North America. Throughout the US, this fly is more widely distributed than *U. affinis* but less abundant. Together seed reduction can be >50% at some sites, but negligible at others. Seed reduction may slow the rate at which knapweed spreads, but has not appreciably lowered stand density as sufficient seeds remain. This species is not considered as important or effective as other biocontrol agents. It has limited abundance and impact on brown, meadow, and squarrose knapweed, yellow starthistle, and bachelor's button in the western US. In Canada, high fly populations decrease diffuse and spotted knapweed growth and seed production but result in no apparent decline in knapweed plant density. Impacts on meadow knapweed in western Canada are even lower.

REDISTRIBUTION: Sweeping adult flies is often damaging. Instead, transfer infested capitula into uninfested patches during fall or early spring. This may also transfer unwanted parasitoids, insects, or knapweed seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions. Once they emerge in spring, flies can be transferred to new knapweed infestations in groups of 50-100. Establishment can be monitored by observing adults on knapweed foliage the following summer or by dissecting capitula for larvae from summer to spring. Note that feeding larvae can be difficult to distinguish from other knapweed flies. *Urophora* species have dark brown anal plates and can be found within galls.

NOTES: This species disperses more rapidly than *U. affinis,* but *U. affinis* is often the dominant species where both flies coexist. Deer mice feed heavily on *Urophora* larvae, and mice populations are known to increase as a result.

diffuse



spotted

Bangasternus fausti (Reitter)
Broad-nosed knapweed seedhead weevil

DESCRIPTION: Eggs are yellow ovals covered with dark egg caps. Larvae are white with brown head capsules, C-shaped, and and up to 8 mm long. Pupae are white and up to 5 mm long. Adults are small and gray to brown/black. They can be 4 mm long, and they have shorter, more blunt snouts compared to the *Larinus* weevils.

Bangasternus fausti a. pupa (USDA ARS European Biological Control Laboratory); b. adult (Laura Parsons & Mark Schwarzländer, University of Idaho)(a,b bugwood.org)

LIFE CYCLE: Overwintering adults emerge from soil and plant litter in spring and feed on knapweed foliage prior to egg laying. Eggs are laid from late spring through summer, individually on the underside of leaflets or on stems below the developing flower head. Eggs are covered with masticated plant tissue (which forms a black egg cap) and hatch in 8-12 days. Depending on egg placement, hatching larvae either mine into the midrib of the leaflet or into the stem prior to tunneling into the flower head. Larvae develop through four instars and feed on developing seed tissue throughout summer. Pupation occurs in the flower head within a chamber made of frass and fused seeds. Adults emerge in late summer or early fall when knapweeds are senescing. Adults drop to the ground to overwinter. There is one generation per year.

DAMAGE: Larval feeding destroys seeds and receptacle tissue. Seed consumption does not kill existing plants, but does help reduce the rate of knapweed spread.

PREFERRED HABITAT: This weevil prefers hot, dry areas and does not do well in areas with prolonged rain or at high elevations.

RELEASE HISTORY: This weevil was introduced from Greece and originally released on diffuse knapweed in the western US in 1990. It was subsequently redistributed to spotted knapweed in numerous western states, in MN and NE in 1992, and in NY in 2009. It was also successfully redistributed to squarrose knapweed in the western US in 1993. Attempted redistributions to meadow knapweed and purple starthistle in the western US failed to establish.

CURRENT STATUS: *Bangasternus fausti a*ttacks both diffuse and spotted knapweed in North America. It currently has limited establishment in the eastern US. It is established on diffuse knapweed in NE and on spotted knapweed in NE and WI. Larvae can consume up to 100% of seed in attacked capitula, though a proportion of seeds often escape attack in large flower heads. Its abundance is low throughout the US, but not likely due to interspecific competition. The overall impact of this weevil is limited in the US. This weevil has not been released and is not established in Canada.

REDISTRIBUTION: Though populations are typically low in the US, some populations in OR and WA are reportedly large enough for redistribution. Adults can be collected with a sweep net (with or without an aspirator) during summer when plants are in early bud to early flowering. Releases of 200 individuals should be made on patches of at least 2,000 m^2 (0.5 acre). Establishment can be monitored the following summer by checking for adults and/or feeding larvae within capitula. Note that feeding larvae can be difficult to distinguish from other knapweed seed-feeding weevil species.

NOTES: **This species is not approved for release in Canada.**

diffuse

spotted

Chaetorellia acrolophi White & Marquardt

Knapweed peacock fly

DESCRIPTION: Eggs are shiny white, elongate, and have a long filament thickened at one end. First generation larvae and pupae are white and barrel-shaped. Second generation larvae and pupae are more yellowish-brown in color. Adults are 4-5 mm long and have bright green eyes, orange-yellow colored abdomens, and overall spotting on the thorax. Wings are clear with light brown bands.

Chaetorellia acrolophi a. larva (Rachel Winston, MIA Consulting); b. adult (USDA APHIS PPQ Archive, bugwood.org)

LIFE CYCLE: There are usually two generations per year; however, a rare third generation is possible under ideal conditions. Adult flies emerge in early summer as knapweed buds form. Mating occurs immediately, and oviposition starts within two days. Females lay eggs individually or in small groups of 2-4 underneath bracts of unopened buds. A single female may lay 70 eggs in her lifetime. Larvae hatch in 4-5 days and penetrate buds, feeding on immature florets until they reach the developing seeds where they feed through three instars. Pupation occurs in the flower head 10-15 days after larvae hatch. First generation adults typically emerge throughout July, mate, and lay eggs. New larvae of this generation continue to feed on developing seed tissue. Third instars overwinter. Pupation occurs within the flower head the following spring.

DAMAGE: Larval feeding destroys some developing seeds. This does not damage existing plants, but helps reduce the rate of knapweed spread.

PREFERRED HABITAT: This fly is most effective in areas with low density knapweed, which is less preferred by other knapweed seed feeders. It generally does better at higher elevations and in regions with high rainfall.

RELEASE HISTORY: This fly was introduced from Austria and Switzerland and released on spotted knapweed in the western US in 1992; it was subsequently redistributed to MN, NE and SD in the eastern US. Populations from Switzerland were released on spotted knapweed in western Canada in 1991. Redistributions were made from spotted to diffuse knapweed in western Canada in 2011.

CURRENT STATUS: *Chaetorellia acrolophi* attacks both diffuse and spotted knapweed in North America, but it is established only in western states and provinces not included in this guide. In the western US, it is established only on spotted knapweed, on which larval feeding reduces seed production; however, populations are limited throughout its established range so its overall impact is minimal. This fly is established on both diffuse and spotted knapweed in Canada, but only in a western province not covered by this guide (BC) where its abundance is limited and its impact is currently unknown.

REDISTRIBUTION: Sweeping adult flies is possible, though this is typically not the best stage for collection as flies are fragile and can be damaged during collection. This species is best transferred by placing plants with infested capitula into uninfested patches during late fall or early spring. Transferring infested seed heads may also transfer unwanted parasitoids, other seed head insects, or knapweed seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, flies can be transferred to new spotted knapweed infestations in groups of 50-100. Establishment can be monitored by observing adults on knapweed foliage the following summer during the heat of the day or by dissecting capitula for larvae from summer throughout the following spring. Note that feeding larvae can be difficult to distinguish from other knapweed fly species. *Urophora* species can be differentiated by their dark brown anal plates and from being enclosed by galls.

NOTES: At some western US infestations of spotted knapweed, populations of this fly are limited by interspecific competition.

diffuse

spotted

Metzneria paucipunctella Zeller
Spotted knapweed seedhead moth

DESCRIPTION: Eggs are elongate, oval, and reddish-brown when first deposited, but turn yellowish as they mature. Larvae are 4-5 mm long, white with dark brown head capsules, distinct body segments, and several pairs of prolegs. Pupae, enclosed in a cocoon, are brown with appendages fused to the body. Adult moths are small (8 mm long). Their front wings are slightly fringed and light gray with peppery spotting and dark tips. When at rest, the wings are folded over their backs, giving them a slender appearance.

Metzneria paucipunctella a. larva and pupa; b. adult (a,b Norman Rees, USDA ARS bugwood.org)

LIFE CYCLE: Adults begin emerging and mating in late spring and early summer when knapweeds are in the rosette and bolting stages. They fly at dusk and are rarely seen. Female moths may lay 60-100 eggs, beginning in early summer. Eggs are placed singly on bracts at the base of young flower heads, or on stems just below the capitula. Larvae hatch in 10-12 days as flower heads are opening. Larvae enter opened capitula and feed on florets, seeds, and receptacle tissue (which reduces the viability of uneaten seeds). There are five instars total. Several young larvae can occupy a flower head early in the season, but only one larva survives beyond the third instar. Larvae overwinter in flower heads. Pupation occurs in the capitulum in spring and lasts 3-4 weeks. There is one generation per year.

DAMAGE: Feeding larvae can destroy eight seeds per larva (on average) and reduce the viability of other seeds. Older larvae bind seeds together, preventing seeds from dispersing over long distances.

PREFERRED HABITAT: This moth does not tolerate severe winter temperatures. Favored sites are south slopes in dry climates with mild winters. Snow cover during winter enhances larval survival. It appears to do best in areas where knapweeds flower early.

RELEASE HISTORY: This moth was introduced from Switzerland and released on spotted knapweed in western Canada from 1973. It was redistributed to diffuse knapweed in western Canada from 1981 and redistributed to spotted knapweed in ON, Canada in 1993. The moth was redistributed from Canada to spotted knapweed in the western US from 1980; it was subsequently redistributed to MN and VA in the eastern US from 1986. It spread naturally and via intentional redistributions to diffuse and meadow knapweed in the western US from 1980.

CURRENT STATUS: *Metzneria paucipunctella* attacks both diffuse and spotted knapweed in North America, but it is established only in western states and provinces not included in this guide. In the western US, spotted knapweed is the preferred host, though even on this species moth abundance is rarely high and seed reduction is typically insufficient to impact knapweed populations. Attack to diffuse and meadow knapweed in the western US is far less common; impact is insignificant on these species. This moth is established on both diffuse and spotted knapweed in Canada, but only in western provinces. It is moderately abundant on spotted knapweed but has only limited impact on plant populations. Diffuse knapweed is rarely attacked- largely only when growing amongst spotted knapweed infestations.

REDISTRIBUTION: Sweeping adults is possible though it would be difficult to collect many, and this method is not recommended due to the likelihood of causing damage during collection. The species is best transferred by placing plants with infested capitula into uninfested patches during early spring. Transferring infested seed heads may also transfer unwanted parasitoids, other seed head insects, or knapweed seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, adults can be transferred to new knapweed infestations in groups of 50-100. Establishment can be monitored by dissecting capitula for larvae from late summer throughout the following spring.

NOTES: Populations in western states and provinces of the US and Canada are limited by overwintering mortality, parasitism, and predation (frequently deer mice).

diffuse

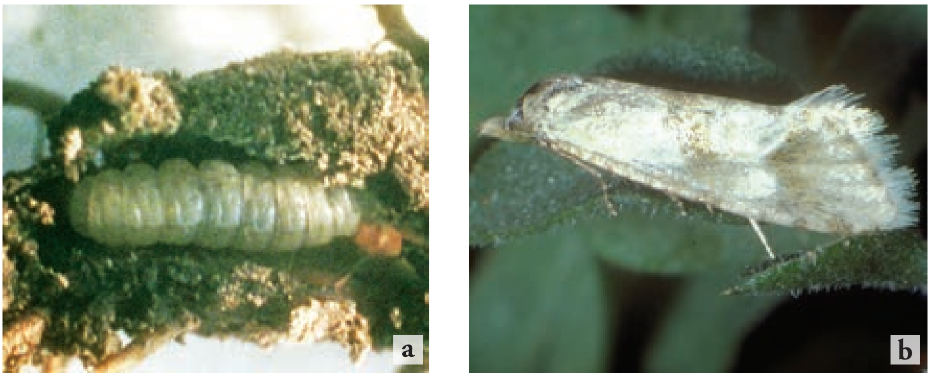
spotted

KNAPWEEDS

Pelochrista medullana (Staudinger)

Brown-winged knapweed root moth

DESCRIPTION: Eggs are oval, somewhat flattened, and have a strong outer shell with distinct ribs. Initially they are white, but gradually turn dark yellow during incubation. The segmented larvae are whitish-yellow with brown head capsules. They are usually less than 10 mm long. Adult moths are tan to gray with mottled wings fringed at their tips. They can be up to 10 mm long.



Pelochrista medullana a. larva in root (USDA APHIS PPQ Archive); b. adult (Bob Nowierski, Montana State University)(a,b bugwood.org)

LIFE CYCLE: Adults emerge throughout summer when knapweed is bolting and flowering. They mate within 24 hours of emergence and lay eggs primarily on the lower surface of rosette leaves. Females can lay up to 120 eggs in warm dry weather, but this can be greatly reduced by cold, rainy conditions. Larvae hatch 7-9 days after oviposition, move to the center of the rosette, and mine into the root crown. Larvae feed on outer layers of root tissue, similar to *Agapeta zoegana*. Webbed tubes are produced along feeding tracks, which can be irregular, downward or spiralling; tunnels are lined with a silken web. There are six larval instars. This species seems to prefer rosette plants; larvae that feed on roots of flowering plants develop poorly. Larvae overwinter in roots and complete development in spring or early summer. Pupation occurs within webbing inside the root. There is one generation per year.

DAMAGE: Larval damage to the roots is similar to that caused by *A. zoegana.* Larvae reduce root storage capacity and expose the plant to pathogens, but only the third to sixth instars cause measurable damage. Small plants with <0.4 in (10 mm) root diameter can be completely destroyed. Plants that survive insect attack usually grow smaller and produce fewer flower heads than uninfested plants.

PREFERRED HABITAT: This moth prefers hot, dry areas and dense knapweed patches. Knapweed populations growing in poor, coarse, or gravel soils are ideal.

RELEASE HISTORY: This species has only been released in western North America. Individuals from Austria and Hungary were released on diffuse and spotted knapweed in the western US in 1984. Individuals from Austria were released in western Canada on diffuse knapweed (beginning in 1982) and spotted knapweed (beginning in 1986 in rearing tents).

CURRENT STATUS: *Pelochrista medullana* attacks both diffuse and spotted knapweed in North America, but it is established only in the western US in a state not covered by this guide (MT). In MT, its preferred host is diffuse knapweed. Populations remain limited on both knapweed species for unknown reasons, causing only minimal damage at localized sites. This moth failed to establish on either diffuse or spotted knapweed in Canada.

REDISTRIBUTION: Populations are so small as to likely preclude redistribution. Where established, infested plants can be dug up (including the roots) and transferred to new sites in late fall or early spring. Alternatively, roots can be collected in fall and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time, bring them to room temperature in rearing cages or breathable, clear containers. Once they emerge, adults can be transferred to new knapweed infestations. Releases of 50-100 individuals should be made on continuous, nonlinear patches of knapweed. Establishment can be monitored the following spring by dissecting roots for feeding larvae. Note that root damage without larvae present can be difficult to distinguish from other root-feeding insects.

NOTES: Usually only one larva develops per root, likely due to intraspecific competition. Very large roots have been observed to contain up to four.

diffuse

spotted

Pterolonche inspersa Staudinger

Grey-winged knapweed root moth

DESCRIPTION: Eggs are black and oval-shaped with a slightly depressed center. Larvae are pearly white with inflated segments and have brown head capsules. Pupae are enclosed in silken "chimney tubes". Adult moths can be up to 8 mm long. Their wings are light brown, exhibiting a silvery sheen. Wingspans are up to 20 mm. When at rest, adults hold their wings close to their sides.

Pterolonche inspersa a. larva and root damage (Eric Coombs, Oregon Department of Agriculture); b). silken chimney tube (USDA ARS European Biological Control Laboratory); c. adult (USDA APHIS PPQ Archive)(a-c bugwood.org)

LIFE CYCLE: Adults emerge from late summer through early fall, mate, and lay eggs during their short, 15-20 day life span. Eggs are laid singly or in small groups on the lower surfaces of rosette leaves. A single female may lay 140+ eggs in her lifetime. Larvae hatch within 12 days and mine down the root, feeding on the root's woody central portion or soft tissue near the outer edges causes galls to form. There are five larval instars; third instars typically overwinter within roots and resume feeding the following spring. Larvae construct silken "chimney" tubes that extend from the galls upward to 20 mm above the soil surface, where they pupate. The chimneys provide easy exits for emerging adults. Pupation usually lasts 15 days and occurs in early summer. There is one generation per year.

DAMAGE: Larvae feed on roots, which interrupts the vascular flow of nutrients plants, thereby decreasing the plant's biomass and flowering ability. Damaged roots become spongy and fragile and easily break apart. Damage attracts other predators, which move into the roots and provide secondary attack.

PREFERRED HABITAT: This moth prefers hot, dry sites with low to moderate knapweed densities. It requires a period of drought during summer, so it is only suited to more arid environments. Preferred soils consist of loosely compacted sand or gravel.

RELEASE HISTORY: This species has only been released in western North America. Individuals from Austria, Hungary and Greece were released on diffuse knapweed in the western US in 1986. Individuals from Hungary were reintroduced and released on spotted knapweed in the western US in 1988. Eggs imported from Greece were distributed on squarrose knapweed in the western US in 1990. Individuals from Austria and Hungary were released on diffuse and spotted knapweed in western Canada in 1986.

CURRENT STATUS: *Pterolonche inspersa* attacks both diffuse and spotted knapweed in North America, but it is established only in western states and provinces not included in this guide. In the western US, this moth is established on diffuse knapweed in one region in OR where insect populations are now rare and provide no impact because of dramatic control of diffuse knapweed by *Larinus* spp. The moth was believed to have failed establishment on spotted knapweed, but it was recently recovered in very limited numbers at one site in MT where its impact is unknown but likely insignificant. Releases on squarrose knapweed failed. In western Canada, it is confirmed established only on diffuse knapweed, even in patches with spotted and diffuse knapweed interspersed. Moth populations on diffuse knapweed are moderately abundant and may stunt plants, though the impact due to this biocontrol agent alone remains unclear.

REDISTRIBUTION: Populations are so small as to likely preclude redistribution. Where established, infested plants can be dug up (including the roots and any attached larval chimneys) and transferred to new sites in late fall or early spring. Alternatively, roots can be collected in fall and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time, bring them to room temperature in rearing cages or breathable, clear containers. Once they emerge, adults can be transferred to new knapweed infestations. Releases of 50-100 individuals should be made on continuous, nonlinear patches of knapweed. Establishment can be monitored the following spring by dissecting roots for feeding larvae. Note that root damage without larvae present can be difficult to distinguish from other root-feeding insects.

NOTES: Usually only one larva of this species develops per root, due to aggressive intraspecific competition. However, very large roots may contain up to four larvae. The moth can co-occur with *Sphenoptera jugoslavica* by feeding below *S. jugoslavica* galls.

diffuse

spotted

Terellia virens (Loew)

Green clearwing knapweed fly

DESCRIPTION: Eggs are elongate, about 1 mm long, and shiny white. Larvae are plump, barrel-shaped, and white, but turn yellow-brown as they mature. Pupae are yellow-brown. Adults are approximately 5 mm long. They have clear wings and large, bright green, and iridescent eyes.

Terellia virens a. larva; b. adult (a,b Eric Coombs, Oregon Department of Agriculture)

LIFE CYCLE: Adults emerge in spring when knapweed is still in the rosette or bolting stage. Adults feed heavily on nectar when knapweed flower heads bloom. Mating begins with the onset of warm weather and continues throughout summer. In summer and fall, females lay one to several eggs between florets in young flower heads. The female lays an average of 80 eggs in her lifetime and often marks the bracts of the flower head with a substance to discourage egg laying by other females. Eggs hatch in 3-5 days, and larvae feed on ripening seeds and receptacle tissue through three instars. Larvae overwinter within capitula, then pupate in chambers made of pappus in spring. Weather conditions determine the number of generations (one or two) of *Terellia virens*; however, only one generation has been confirmed at most North American sites.

DAMAGE: Larvae can consume up to 90% of seed in flower heads. Seed consumption does not damage existing plants, but does reduce knapweed's rate of spread.

PREFERRED HABITAT: This fly prefers plants on south-facing slopes and at dry locations.

RELEASE HISTORY: Individuals from Austria and Switzerland were released on spotted knapweed in the western US in 1992 and in the eastern US (MN) in 1994. Redistributions were attempted on purple starthistle and squarrose knapweed in the western US but failed to establish. Individuals from Austria and Switzerland were released on spotted knapweed in western Canada from 1991.

CURRENT STATUS: *Terellia virens* attacks and is established only on spotted knapweed and only in western states and provinces of the US and Canada not covered by this guide. In western North America, populations are limited, likely due to competition with *Urophora* spp. and *Larinus* spp. This fly causes only minor reductions in seed production with minor impact overall. In western Canada, *T. virens* established initially. No recoveries have been made in recent years; however, sampling times may not accurately reflect the agent's life cycle. This fly is currently considered rare in BC, and impact is unknown.

REDISTRIBUTION: Sweeping adult flies is possible, though this is not always the best stage for collection as flies are fragile and can be damaged during collection. The species is best transferred by placing plants with infested capitula into uninfested patches during late fall or early spring. Transferring infested seed heads may also transfer unwanted parasitoids, other seed head insects, or knapweed seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, flies can be transferred to new knapweed infestations in groups of 50-100. Establishment can be monitored by observing adults on knapweed foliage the following summer during the heat of the day or by dissecting capitula for larvae from summer throughout the following spring. Note that feeding larvae can be difficult to distinguish from other knapweed fly species. *Urophora* species can be differentiated by their dark brown anal plates and by their presence within galls.

NOTES: This fly may attack diffuse knapweed, but to a much smaller extent than spotted knapweed.

diffuse

spotted

Unapproved Non-Indigenous Natural Enemy

Urophora jaceana L.
(Diptera: Tephritidae)

Urophora jaceana adult (AfroBrazilian)

DESCRIPTION AND LIFE CYCLE: Adults emerge in spring to early summer, are up to 4 mm long, and have dark bodies. Wings are clear with two distinctly separate black bands followed by a "V" pattern. Females have long, black ovipositors. Eggs are laid in flower buds just starting to open. Larvae feed on receptacle tissue, forming woody galls. They are creamy white, barrel-shaped with retracting heads, and have dark anal plates. Larvae overwinter in galls inside the capitula; pupation occurs in spring.

HISTORY AND CURRENT STATUS: This fly was accidentally introduced to Canada, likely as a contaminant of ship's ballast. It was discovered on brown and black knapweed in Newfoundland and Nova Scotia by 1937 where up to 75% of seed heads are attacked. High fly populations decrease knapweed growth and seed production but result in no apparent decline in knapweed plant density. It was subsequently redistributed to BC in western Canada, but failed to establish. **This species is not approved for redistribution in the US.**

Purple loosestrife
Lythrum salicaria L.

SYNONYMS: purple lythrum, spiked loosestrife

ORIGIN: Native to Europe, northern Africa, Asia; introduced to North America in the early 1800s in ship ballast, wool, and as an ornamental or medicinal herb.

DESCRIPTION: Herbaceous, upright perennial typically growing numerous stems 2-9 ft tall (0.5-2.75 m) from a spreading, robust, woody root. Stems are squarish in cross-section with 4-6 sides. Leaves are lance-shaped, smooth-margined, stalk-less, and are 2-5 in long (5-12 cm). Leaves are usually opposite but may be whorled near the base. Flowers are less than 1 in across (2.5 cm) with 5-7 pink to purple (sometimes crumpled-looking) petals. Flowers occur in spiked clusters; each flower can produce well over 100 small, light-colored seeds.

HABITAT: An invader of sunny or partially shaded wetlands, this plant can be found along lakes, ponds, moist roadsides, streams, rivers, and irrigation ditches/

Purple loosestrife a. plant (Jennifer Andreas, Washington State University Extension); b. infestation (Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Purple loosestrife c. leaves and stem (Jennifer Andreas, Washington State University Extension); d. flowers (Richard Old, XID Services, Inc, www.xidservices.com); e. fruit and seeds stem (Gary L. Piper, Washington State University)(d,e bugwood.org)

canals and in swamps and freshwater tidal flats. It can tolerate a wide range of water levels, pH, soil, climatic conditions, and vegetation types. Consequently it can be problematic in seasonally wet meadows and wet prairies, and infestations can expand from moist locations into neighboring areas with drier conditions.

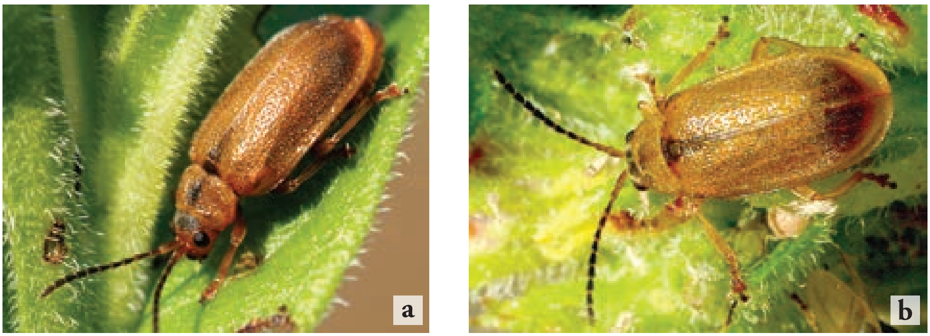
ECOLOGY: Purple loosestrife spreads primarily by seeds that are easily carried by water, people, and animals, but can also reproduce from buds on root fragments and cut stems. Seeds may remain viable for more than three years following dissemination, but potentially much longer. Seedlings germinate in late spring or early summer, and plants may flower the first year. Flowers occur in spiked clusters from summer to early fall. Plants die back in winter temperatures, and the standing dead vegetation is persistent for many years.

BIOLOGICAL CONTROL: Since 1992, four beetles have been introduced and established in the US and Canada. *Galerucella calmariensis* and *G. pusilla* are the most abundant and effective; they defoliate plants, reduce seed production, and stunt plant growth. Root-feeding by *Hylobius transversovittatus* can result in plant death. Populations of *H. transversovittatus* are believed to be limited, but its cryptic nature makes assessments difficult. The flower-feeding *Nanophyes marmoratus* reduces loosestrife seed output, which reduces spread. *Galerucella* spp. have the highest priority for redistribution.

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

Black-margined loosestrife beetle & Golden loosestrife beetle

DESCRIPTION: *Galerucella* species cannot be distinguished in the egg or larval stage. Larvae are up to 5 mm long. They are greenish-yellow with darkened head capsules and black spots down their backs. 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 heads. Adult *G. pusilla* are light gold to orange-brown with dark antenna from the middle to the tips. Coloration differences develop fully only in overwintered beetles.



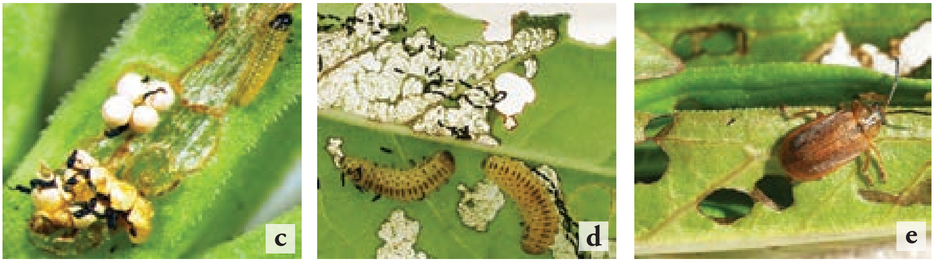
Adult a. *Galerucella calmariensis* (David Cappaert, Michigan State University, bugwood.org); b. *G. pusilla* (Eric Coombs, Oregon Department of Agriculture)

LIFE CYCLE: Overwintering adults feed on leaves and young shoot buds in early spring when purple loosestrife shoots emerge. Females lay up to 400 eggs in groups of 2-10 on stems and leaves from late spring through summer. Hatching larvae feed on shoot tips and then developing leaves and flowers. There are three larval instars. Pupation occurs in plant litter or in stem tissue if stems are in standing water. Adults emerge in summer, resume feeding, then overwinter in plant litter. There is usually one generation per year (two at some locations).

DAMAGE: Larval feeding strips photosynthetic tissue off leaves, creating a "window-pane" effect. Adult feeding causes a characteristic "shot-hole" defoliation pattern. Larval and adult feeding stunt plant growth, reduce seed production, and may kill plants outright over several years and at high insect densities.

PREFERRED HABITAT: Both species are established in a wide variety of climatic conditions. Both prefer sites without shade or dramatic water fluctuations (such as dam reservoirs or tidal flats).

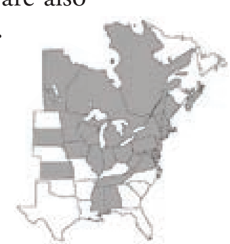
RELEASE HISTORY: Both species were introduced from Germany and released (often as a mix) throughout the US and Canada in 1992.



Galerucella spp. c. eggs and larva; d. larval window-pane feeding (c,d Bernd Blossey, Cornell University); e. adult shot-hole feeding (Eric Coombs, Oregon Department of Agriculture)(c-e bugwood.org)

CURRENT STATUS: Throughout the US, both species are well established in some states but infrequent in others. *Galerucella calmariensis* is generally more abundant than *G. pusilla,* but the reverse is true at some sites for unknown reasons. High densities have heavy impact on purple loosestrife by reducing seed production and stunting growth. At some sites, purple loosestrife density has decreased up to 90%; 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, followed by increases in biocontrol 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. Together they have provided excellent control throughout the majority of purple loosestrife's range. Both species were initially widespread, but more recent surveys indicate populations at many sites now consist primarily or wholly of *G. calmariensis*.

REDISTRIBUTION: Adults can be collected in spring using a funnel or sweep nets and aspirators; new generation adults can be collected in mid-summer. Adults should be transferred to uninfested sites in groups of 100-200 in spring or groups of 2,000 in mid-summer. Establishment can be monitored the following year by observing shot-hole or window-pane feeding characteristic of adults and larvae, respectively. Eggs, larvae, and adults are also readily observed on foliage throughout the growing season.



NOTES: Following mass outbreaks of *Galerucella* spp., limited spillover feeding has been observed on a few nontarget species. Predation and parasitism may limit some populations.

Hylobius transversovittatus (Goeze)

Loosestrife root weevil

DESCRIPTION: Eggs are white and oval-shaped. Larvae are C-shaped, off-white, and have brown head capsules. 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. They are thick insects and up to 12 mm long.

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

LIFE CYCLE: This species often requires two years to complete one generation. 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. Females lay eggs singly (though up to 100 annually) in the soil or loosestrife stems. Larvae emerge in late summer, mine into purple loosestrife roots as they feed, and overwinter in roots. Larvae may feed within roots for one to two years. Adults often overwinter, and can live up to three years. Overwintering adults emerge after purple loosestrife sprouts in spring. They are most active at night, and during warm, sunny days adults hide in plant litter at the base of purple loosestrife plants.

DAMAGE: Adult feeding is typically not significant. Roots attacked by larvae have reduced reserve capacity leading to reduced plant size, lower seed production, and even death, especially for small root systems. Large roots can withstand substantial feeding pressure, however, and several larval generations will be necessary before significant impacts are observed.

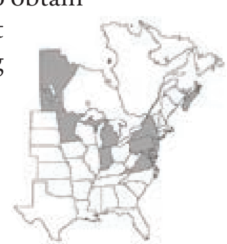
PREFERRED HABITAT: This weevil tolerates a wide range of environmental conditions. Though adults and larvae can survive extended submersion, permanently flooded sites will prevent adult access to plants and will eventually kill developing larvae.


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

RELEASE HISTORY: Individuals from Germany, Finland, Austria, France, Sweden, and Switzerland (though largely from Germany and Finland) were released beginning in 1992 in the eastern US (IL, IN, IA, KS, ME, MD, MA, MI, MN, NE, NH, NJ, NY, ND, OH, PA, RI, SD, TN, VA, VT, WI) and eastern Canada (MB, NS, ON).

CURRENT STATUS: In the eastern US this weevil is slower to disperse and reproduce than the other established biocontrol agents. It is believed to have well-established populations in NY and MN, but information is largely limited elsewhere. It may be well established throughout the range of purple loosestrife in North America. Extensive root feeding by this weevil can complement defoliation by *Galerucella* spp., often resulting in plant death. However, its establishment and impact are both difficult to fully assess as larvae are hidden feeders, and adults are active at night. In Canada, its limited populations and cryptic nature make this species difficult to study so its current status in Canada is largely unknown.

REDISTRIBUTION: Where populations are sufficiently large, adults can be tapped or hand-picked from purple loosestrife foliage or plant litter in mid- to late summer. Adults are nocturnal, so should be collected at night with the aid of flashlights. Because of the difficulty in this method, and because this species is not widely established at present, it will often be necessary to obtain weevils from laboratory rearing operations. Establishment can be confirmed the following growing season by observing adults on foliage at night, or (more easily) by dissecting roots to find larval damage over the course of the next few growing seasons.



NOTES: Up to 40 larvae have been found per root system.

Nanophyes marmoratus (Goeze)

Loosestrife flower-feeding weevil

DESCRIPTION: Eggs are tiny, spherical, and white. Larvae are C-shaped, creamy white, and have brown head capsules. They can be up to 2 mm long. Adults are dark brown with orange legs and large, whitish-yellow shoulder patches. Adults are very small (up to 2.5 mm long) and have a long snout and wide body.

Nanophyes marmoratus a. egg in purple loosestrife flower; b. larva in flower bud (a,b Gary Piper, Washington State University); c. adult (Laura Parsons & Mark Schwarzländer, University of Idaho) (a-c bugwood.org)

LIFE CYCLE: Overwintering adults emerge in late spring and feed on purple loosestrife shoot tips and young leaves. Adults then feed on developing flowering buds. Females lay 60-100 eggs singly inside immature flower buds throughout summer as purple loosestrife flowers. Hatching larvae feed on flower petals and ovaries through three instars. Pupation occurs in the base of attacked buds. New adults emerge in late summer and feed on remaining green leaves of purple loosestrife before overwintering in plant litter. There is one generation per year.

DAMAGE: Adult and larval feeding cause flower bud abortion 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%. This does not kill existing plants, but helps reduce the rate of spread.

PREFERRED HABITAT: This flower weevil is well adapted to a variety of environmental conditions throughout the range of purple loosestrife in North America. It does not do as well at sites with high populations of *Galerucella* spp. which often reduce the availability of *Nanophyes* feeding and oviposition sites.

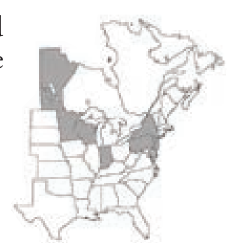
RELEASE HISTORY: Individuals from France and Germany were released in the eastern US beginning in 1994 (CT, IA, IN, MN, NE, NJ, NY, PA, SD, WI). Weevils from Germany were released in eastern Canada (MB) in 1997.

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

CURRENT STATUS: In the US, *N. 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 and oviposition sites). 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 other biocontrol agents. In Canada, though the flower weevil is established, it only occurs in MB, and its abundance and impact are not known.

REDISTRIBUTION: During the heat of the day in summer, bend and shake developing purple loosestrife inflorescences over a sweep net or tray, dislodging adult beetles into the net or tray. Adults can be transferred to uninfested sites in groups of 100-200. Establishment can be monitored the following spring and summer by observing adults on foliage and flowers or dissecting flower buds during the growing season for signs of larval feeding.

NOTES: This weevil has successfully overwintered on exposed islands in an estuary with high tidal exchange where multiple releases of *Galerucella* spp. have failed. It can also persist where purple loosestrife plants are scattered at low densities. A related species, *Nanophyes brevis*, was tested and approved for importation but was never released in North America because of problems with a parasitic nematode.



EURASIAN WATERMILFOIL

Myriophyllum spicatum L.

SYNONYMS: spiked watermilfoil

ORIGIN: Native to Europe, northern Africa, and Asia, Eurasian watermilfoil was introduced possibly unintentionally in ship ballast by the 1880s or possibly intentionally by US federal authorities in the 1940s.

DESCRIPTION: Submersed, aquatic perennial with roots typically buried in the hydrosoil. Roots are slender and white and stoloniferous in the hydrosoil or may grow from stem nodes. Stems are slender but thicken significantly further away from the inflorescence. Stems are reddish-brown to light green, typically 6-20 ft (2-6 m) long, and become more branched at the surface, forming dense intertwined mats. Submersed leaves occur in whorls of 4 all along the stem. Leaves are 0.6-1.6 in (1.5-4 cm) long and feather-like with 14-24 pairs of filamentous divisions. Tiny pink flowers occur on red emergent spikes 1.5-8 in (4-20 cm) long. Fruits are 4-chambered; each fruit produces a single seed.

Eurasian watermilfoil a. plant (Chris Evans, University of Illinois); b. infestation (Graves Lovell, Alabama DCNR)(a,b bugwood.org)

Eurasian watermilfoil c. leaves (Graves Lovell, Alabama DCNR); d. fragment (Rob Routledge, Sault College); e. flowers on center spike (Leslie J. Mehrhoff, University of Connecticut)(c-e bugwood.org)

HABITAT: This species grows in freshwater lakes, ditches, springs, marshes, and rivers with slow-moving water. It can grow in water depths from a few inches (7.5 cm) to 33 ft (10 m). It can tolerate a wide variety of temperatures and brackish water and capitalizes on disturbance and nutrient runoff.

ECOLOGY: Eurasian watermilfoil produces seeds, though seedlings are rare in the field. It primarily reproduces vegetatively. New stems grow from stolons and roots in spring. Throughout the growing season and especially after flowering, the plant auto-fragments. Stem fragments containing a single node (whorl of leaves) can sprout new plants; segments grow roots prior to separating from the parent plant. Flowering typically occurs in summer. At some locations, plants flower both in late spring and early fall. In warm climates, the plant continues to grow over the winter. At extremly cold sites, stems die back to the stolons, lower stem segments, and roots, and new stems re-sprout the following spring.

BIOLOGICAL CONTROL: Despite extensive foreign exploration, as of 2016, there are no classical biocontrol agents approved for use in North America. The native weevil *Euhrychiopsis lecontei* has been redistributed extensively, suppressing Eurasian watermilfoil in some lakes but not others. **It feeds on native *Myriophyllum* spp. when densities are high; caution should be used in redistribution.** The accidentally introduced *Acentria ephemerella* is widely distributed in NE North America, but with variable impacts. **It feeds on many native species and is not approved for redistribution.**

Native Natural Enemy

Euhrychiopsis lecontei (Dietz)
(Coleoptera: Curculionidae)

Euhrychiopsis lecontei adult (Robert L. Johnson, Cornell University, bugwood.org)

DESCRIPTION AND LIFE CYCLE: Adults are 3 mm long and dark with black and yellowish mottled stripes. Adults feed on leaves and stems. Females lay hundreds of eggs singly on milfoil stems. Larvae are whitish tan turning purplish gray. They feed on stem tips and mine plant stems before pupating in chambers within stems. There are up to 5 generations per year, though 3 is more common in the field. In late summer, adults move to shore to overwinter in leaf litter.

HISTORY AND CURRENT STATUS: The original host of this weevil is the native northern milfoil *Myriophyllum sibiricum*. After it was found feeding on and suppressing Eurasian watermilfoil, the weevil was redistributed to Eurasian watermilfoil in multiple states in the US (previously commercially available). While *E. lecontei* occurs naturally in Canada on northern watermilfoil, it has not been redistributed there for Eurasian watermilfoil control. The weevil is widely distributed throughout North America and is associated with weed declines in some lakes in the Northeast but not in others. High weevil densities can suppress Eurasian watermilfoil populations; however, most infestations can potentially recover when weevils move to shore for overwintering. Augmentation with larvae and/or eggs has proven ineffective, but augmentation with adults increases weevil densities the year following release. Although this weevil does best on Eurasian watermilfoil, it feeds on native *Myriophyllum* spp. when densities are high. **Redistributions are recommended only for water bodies where native milfoil species are limited or absent. Caution should be used in redistribution, and an APHIS 526 permit is required for transporting *E. lecontei* interstate.**

Acentria ephemerella (Denis & Schiffermüller)
(Lepidoptera: Crambidae)

Acentria ephemerella winged female (Robert L. Johnson, Cornell University, bugwood.org)

DESCRIPTION AND LIFE CYCLE: Adults are 5-9 mm long and white to tan. Females are typically wingless and lay 100-300 eggs on host plants in early summer. Larvae are up to 12 mm long and greenish-transparent. Larvae mine plant leaflets until large enough to build shelters of plant material. 4^{th}-5^{th} instars feed on stem tips before pupating within cocoons attached to plant stems. There are two generations per year; new adults emerge in late summer and hatching larvae overwinter in various instars.

HISTORY AND CURRENT STATUS: This aquatic European moth was first found in QC, CAN in 1927 and MA, US in 1949. It was intentionally redistributed in NY, US from 1999-2002. Though now widely distributed, its abundance varies. High populations control Eurasian watermilfoil in some lakes by preventing weed canopy growth, but not in others; augmentative releases do not improve populations or control. Although testing indicated it prefers and does better on Eurasian watermilfoil, **it feeds on other aquatic species, including many native, and is not approved for redistribution in the US.**

Black swallow-wort

Vincetoxicum nigrum (L.) Moench

SYNONYMS: black dog-strangling vine, *Cynanchum louiseae* Kartesz & Gandhi

ORIGIN: Native to France, Spain, Portugal and Italy, it was intentionally introduced to North America in the late 1800s as an ornamental and subsequently naturalized.

DESCRIPTION: Herbaceous, perennial, twining vine with single or multiple stems growing from an extensive fleshy, fibrous root system with rhizomes. Stems are erect initially, but as plants mature they twine around adjacent vegetation or each other for support, often forming impenetrable thickets. Vines are typically 2-6.5 ft long (60-200 cm), though in shaded understories, plants often grow longer. Stems have hairs in longitudinal bands and are green but turn brown with age. Leaves are opposite, up to 4.8 in long (12 cm), elliptical with a pointed tip, and rounded or heart-shaped at their base. Leaves on some plants may appear glossy. Flowers are up to 0.25 in across (7 mm), star-shaped, and have 5 fleshy petals. Petals are purplish-black with white hairs and are wide at their base. Flowers appear in clusters of 6-10 at leaf axils. Fruits are thin pods up

Black swallow-wort a. climbing plants; b. infestation (Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

Black swallow-wort c. leaves and stems; d. flowers; e. mature fruit and splitting fruit (c-e Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

to 2.7 in long (7 cm) that often occur in pairs and at maturity split open along one side to release multiple tufted, wind-borne seeds.

HABITAT: Black swallow-wort has a temperate distribution, and germination rates are highest where seeds are subjected to cold winter temperatures. It tolerates a wide range of light and moisture conditions from sunny and dry to moist and wooded. It capitalizes on disturbance but can invade undisturbed plant communities. It is often found at upland sites such as rocky hillsides or forested slopes or in/along roads, fields, alluvial woods, forest understories, and riverbanks.

ECOLOGY: Black swallow-wort reproduces by seed and rhizomes. Seed production is greatly reduced under low light conditions. A single seed may yield up to 4 seedlings. In North America, seeds germinate throughout the growing season. Flowers appear from June to August, and fruits are produced from July through October. Seeds are transported by wind, and seed longevity is unknown. Plants die back in the fall and re-sprout from the root system in spring.

BIOLOGICAL CONTROL: As of 2016, *Hypena opulenta* has been approved by TAG for release on both black and pale swallow-wort, but a release permit has not yet been issued in the US. Releases in Canada to date have occurred only on pale swallow-wort. Additional species are being tested for potential future release in North America.

Pale swallow-wort

Vincetoxicum rossicum (Kleopow) Barbar.

SYNONYMS: dog-strangling vine, European swallow-wort, *Cynanchum rossicum* Kleopow

ORIGIN: Native to Ukraine and Russia, it was intentionally introduced to North America in the late 1800s as an ornamental and subsequently naturalized.

DESCRIPTION: Herbaceous, perennial, twining vine with single or multiple stems growing from an extensive fleshy and fibrous root system. Some plants produce short, horizontal, woody rhizomes. Stems are erect initially, but as plants mature they twine around adjacent vegetation or each other for support, often forming impenetrable thickets. Vines are typically 2-6.5 ft long (60-200 cm), though in shaded understories, plants often grow longer. Stems have hairs in longitudinal bands and are green but turn brown with age. Leaves are opposite, up to 4.8 in long (12 cm), elliptical with a pointed tip, and rounded or heart-shaped at their base. Leaves on some plants may appear glossy. Flowers are up to 0.25 in across (7 mm) and star-shaped with 5 narrow petals that are maroon,

Pale swallow-wort a. climbing plant (David Nisbet, Invasive Species Centre); b. infestation (John M. Randall, The Nature Conservancy)(a,b bugwood.org)

Pale swallow-wort c. leaves and stems; d. flowers (John M. Randall, The Nature Conservancy); e. mature, splitting fruit (c,e Leslie J. Mehrhoff, University of Connecticut)(c-e bugwood.org)

purple, or pinkish. They appear in clusters of 4-6 at leaf axils. Fruits are thin pods up to 2.7 in long (7 cm) that often occur in pairs and at maturity split open along one side to release approximately 20 tufted, wind-borne seeds.

HABITAT: Pale swallow-wort has a temperate distribution, and germination rates are highest where seeds are subjected to cold winter temperatures. It tolerates a wide range of light and moisture conditions, but does best in partial to full sun. It capitalizes on disturbance but can invade undisturbed plant communities. It is found in or along fields, fencerows, talus slopes, alluvial woods, forest understories, forest openings, and riverbanks.

ECOLOGY: Pale swallow-wort's short rhizomes do not significantly contribute to population spread. This species reproduces primarily by seed, and a single seed may yield up to 4 seedlings. Seed production is greatly reduced under low light. In North America, seeds germinate throughout the growing season. Flowers appear from May to June, and fruits are produced from June through August. Seeds are transported by wind, and seed longevity is unknown. Plants die back in the fall and re-sprout from the root system in spring.

BIOLOGICAL CONTROL: As of 2016, *Hypena opulenta* has been approved by TAG, but a release permit has not been issued in the US. It was released in Canada in 2013; evidence for establishment is encouraging. Additional species are being tested for potential future release in North America.

Hypena opulenta (Christoph)

Ukranian swallow-wort moth

DESCRIPTION: Eggs are small and pale yellow. Larvae are white initially but gradually turn green. At maturity, larvae are up to 2 cm long and have a yellow head capsule as well as black spots on their green bodies. Pupae are dark brown and up to 2 cm long. Adults are up to 1 cm long with a 3 cm wide wingspan. The forewings are light brown with dark brown centers while the hindwings are pale yellow with brown edges.

Hypena opulenta a. larva (Rob Bourchier, Agriculture and AgriFood Canada); b. adult (Jeem 123, voucher speciment provided by Naomi Cappuccino, Carleton University)

LIFE CYCLE: Pupae overwinter in soil and plant litter. Adults emerge in spring and lay an average of 400 eggs in small groups on swallow-wort leaf petioles or the undersides of leaves. Hatching larvae feed on swallow-wort leaves through five instars. Early instars skeletonize leaves while later instars feed on all leaf tissue between veins. Fifth instars prepare pupation sites in the soil either by tying leaves together or by constructing a silk chamber at the base of plants. Adults emerge in late summer, resume feeding, then overwinter in plant litter. In the native range, there are at least two generations per year, with generations overlapping.

DAMAGE: Defoliation by larvae reduces plant biomass and reproductive output. Repeated defoliation may lead to reductions in root biomass.

PREFERRED HABITAT: In its native range, *Hypena opulenta* is restricted to shady, forested habitats.

RELEASE HISTORY: Individuals from Ukraine were released on pale swallow-wort in Ontario, Canada in 2013 and 2014.

CURRENT STATUS: While this moth attacks both black and pale swallow-wort, it has thus far only been released on pale swallow-wort in North America. The 2013 release failed to result in establishment; however, following releases made in 2014-2016, subsequent generations were observed in the field. Though it is too early to confirm the field establishment of this species, initial observations are encouraging.

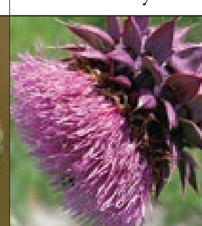
REDISTRIBUTION: Because populations are not currently confirmed to be established in the field, further releases are recommended. Any releases made should be done using laboratory colonies and under the guidance of appropriate authorities. In the future, should this biocontrol agent become established, field redistributions can be done by collecting larvae from foliage. Any instar can be collected, though larger, mature larvae are most conspicuous and easy to find. Gently remove larvae by hand or with soft forceps, and place them directly in a release container. Alternatively, clip vine sections infested with larvae. This species can be transferred in groups of 50-100 to uninfested swallow-wort patches. Establishment can be monitored by observing adults or larvae on swallow-wort foliage throughout the following growing season.

NOTES: Although *Hypena opulenta* is a biological control agent of both black and pale swallow-wort, releases in Canada to date have occurred only on pale swallow-wort. As of 2016, TAG has approved release of this insect on both pale and black swallow-wort in the US, but it is still within the US regulatory process and a release permit has not yet been issued.

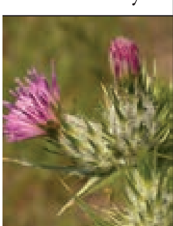
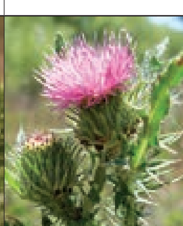
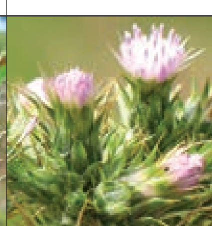
pale

Thistle species comparison

Bull, Canada and musk thistle are the primary targets of North American thistle biocontrol efforts. Weed descriptions and biocontrol agent distribution maps are given only for these three species. Below is a comparison of bull, Canada, and musk thistle, as well as six other exotic thistles that are occasional hosts to biocontrol agents.

Trait	Bull *Cirsium vulgare*	Canada *Cirsium arvense*	Musk *Carduus nutans*	Marsh *Cirsium palustre*
Life History	Biennial	Perennial	Biennial	Biennial
Preferred Habitat	Various light/ soil conditions; Mesic	Disturbed initially; Moist	Disturbed initially; Fertile soil; Mesic	Acidic soil; Moist
Avg Height	3' (0.9 m)	3' (0.9 m)	5' (1.5 m)	4' (1.2 m)
Basal Leaves	3-12" long (7.6-30 cm); Lobed; Coarsely hairy; Yellow spines from midrib and lobes	≤5" long (13 cm); Slightly downy lower surface; Lobed; Prickly, ruffled margins	≤20" long (51 cm); Hairless, waxy, white margins; Coarsely lobed; White spines on margins and lobe tips	≤8" long (20 cm); Deeply lobed, strong midvein; Prominent spines on margins but not leaf surfaces
Stems	Spiny along entire length	Not spiny	Spiny wings along lower sections, not upper	Spiny wings along entire length
Capitulum Diameter	1.5" (3.75 cm)	0.5" (1.25 cm)	3" (7 cm)	0.5" (1.25 cm)
Bracts	Spiny; Tipped in yellow	Not spiny	End in small spines; Wide, triangular; Purple at maturity	Not spiny; Purplish
Capitulum				

Credits: Bull: Jennifer Andreas, Washington State University Extension; Canada: Richard Old, XID Services, Inc, www.xidservices.com; Musk & Italian: Mary Ellen (Mel) Harte, bugwood.org; Marsh: © Malcolm Storey, www.bioimages.org.uk; Plumeless: Becca VanKampen, MIA Consulting; Slenderflower: Washington State Noxious Weed Control Board; Milk: Eric Coombs, Oregon Department of Agriculture; Scotch: Rachel Winston, MIA Consulting

ITALIAN *Carduus pycnocephalus*	PLUMELESS *Carduus acanthoides*	SLENDERFLOWER *Carduus tenuiflorus*	MILK *Silybum marianum*	SCOTCH *Onopordum acanthium*
Annual	Annual	Annual	Annual	Biennial
Disturbed, open; High pH soil; Dry	Disturbed; Well-drained soil; Mesic	Open areas; Fertile soil; Dry	Disturbed initially; Fertile soil; Mesic	Disturbed; Well-drained soil; Dry
4’ (1.2 m)	3.5’ (1 m)	3.5’ (1 m)	5’ (1.5 m)	7’ (2 m)
≤5” long (13 cm); Deeply lobed; Short matted hairs on undersides; Spines on lobe tips and margins	≤8” long (20 cm); Deeply lobed to midvein; Hairy underside; 1-3 spines on margins of each lobe	≤5” long (13 cm); Deeply lobed; Short matted hairs on undersides; Spines on lobe tips and margins	≤20” long (51 cm); Waxy, white marbling along veins; Lobed; Prickly, ruffled margins	≤24” long (61 cm); Woolly above and below; Gray-green; Yellow spines along wavy toothed margins
Slightly winged and spiny along entire length	Leaf-like spines covering stems entire length	Triangular-shaped stem wings tipped with spines along entire length	Not spiny	Spiny wings along entire length
≤ 1” (2.5 cm)	≤ 1” (2.5 cm)	<1” (2.5 cm)	2’ (5 cm)	2’ (5 cm)
Triangular; Long; Have stiff, forward-pointing hairs; Cobwebby	Spiny; Needle-like	Spiny; Triangular but narrow	Tipped in very long stiff spines; Leathery	Spiny; Needle-like; Tipped in yellow
				

Bull thistle

Cirsium vulgare (Savi) Ten.

SYNONYMS: spear thistle

ORIGIN: Native to Europe, Asia, and northern Africa; introduced to North America in the mid 1800s.

DESCRIPTION: An upright forb typically growing as a biennial, but can also behave as an annual or very short-lived perennial. Plants grow from 3-4 ft (1-1.2 m) tall on average. Leaves are long (3-12 in or 8-30 cm), lance-shaped, and lobed, with coarse hairs covering both surfaces. Long, yellow spines extend from the midrib and at each leaf lobe. Stems are stout, hairy, and have spiny wings. Capitula are 1.5-2 in (4-5 cm) in diameter, have rows of narrow, spiny bracts tipped in yellow, purplish pink florets, and are solitary at the ends of branches.

HABITAT: Bull thistle grows best on neutral soils rich in nitrogen and with moderate moisture. It is not typically found in sand, pure clay, or in soils with high humus

Bull thistle a. plant (Marianna Szucs, Colorado State University); b. infestation (Forest and Kim Starr, Starr Environmental, bugwood.org)

Bull thistle c. leaf (Dan Tenaglia, Missouriplants.com, bugwood.org); d. stem; e. flower head (d,e Jennifer Andreas, Washington State University Extension)

content, nor does it grow well in shade and drought. It can be found in almost any type of disturbed area including forest clear cuts, riparian areas, and pastures.

ECOLOGY: This species reproduces only by seed. Seeds are readily transported by water, wildlife, and human activity and may remain viable in the soil for many years. Seeds germinate and form rosettes whenever moisture is sufficient, but the majority of rosettes form during spring. Bolting occurs in late spring, and plants flower in early to mid-summer (typically June to July).

BIOLOGICAL CONTROL: While five species of thistle biocontrol agents are established on bull thistle in North America, *Urophora stylata* is the most effective. This fly reduces seed production which helps reduce bull thistle populations, especially where the plant is stressed by competition and other control methods. *Cheilosia grossa, Larinus carlinae, Rhinocyllus conicus,* and *Trichosirocalus horridus* preferentially attack other species, and their impact on bull thistle is minor. *Cheilosia grossa* and *L. carlinae* are established on bull thistle only in western North America. ***Larinus carlinae, R. conicus,* and *T. horridus* are no longer permitted for interstate redistribution in the US, and *C. grossa* is not approved for release in Canada.**

NOTES: Phenolic acids produced by this thistle have allelopathic effects against competing plants and (along with spines) serve as a defense against herbivory.

Canada thistle

Cirsium arvense (L.) Scop.

SYNONYMS: creeping thistle, field thistle

ORIGIN: Introduced from Eurasia in the 1600s.

DESCRIPTION: An upright perennial forb often found in dense infestations. Plants grow from 1-4 ft tall (0.3-1.2 m) from a rhizomatous root system. Leaves are irregularly lobed and have very prickly and ruffled margins. They are green on both sides with a slightly downy lower surface. Basal leaves are less than 5 in long (12.5 cm). Leaves grow alternately along the slender, grooved stems which can be finely haired but are not spiny. Upper branches are topped by clusters of small, compact (0.5 in or 1.25 cm diameter) capitula producing numerous tufted seeds. Receptacle bracts are not spiny. Florets vary in color from white to deep lavender.

HABITAT: This species rapidly colonizes disturbed moist sites including prairies, meadows, ditches, stream banks, lawns, and agricultural fields.

Canada thistle a. plants (Steve Dewey, Utah State University); b. infestation (Jan Samanak, Phytosanitary Administration)(a,b bugwood.org)

Canada thistle c. leaf (Jennifer Andreas, Washington State University Extension); d. stem (Rob Routledge, Sault College); e. flower head (Richard Old, XID Services, Inc, www.xidservices.com) (d,e bugwood.org)

ECOLOGY: Canada thistle reproduces both vegetatively through its roots and by seed. Seeds are readily transported by water, wildlife, and human activity and may remain viable in the soil for many years. Seeds germinate whenever moisture is sufficient, though the majority of rosettes are formed in spring. Stems bolt in late spring with flowering occurring from June to September.

BIOLOGICAL CONTROL: Four species successfully established on this weed. Of these, *Hadroplontus litura*, *Urophora cardui,* and *Larinus carlinae* attack Canada thistle in eastern North America. While both *H. litura* and *U. cardui* can reduce Canada thistle density and stature under favorable conditions, the impact of both is typically limited overall. **The impact of *L. carlinae* is often greater on native thistles than Canada thistle; it is not approved for redistribution in the US.** *Rhinocyllus conicus* is established on Canada thistle only in western states and provinces not included in this guide; **it preferentially attacks other thistle species and is not approved for redistribution in the US.** *Altica carduorum* and *Lema cyanella* both failed to establish in North America.

NOTES: This species is dioecious; the florets on all flowering shoots of a single clonal plant are either male or female. This trait is unique among North American exotic thistles. At some sites, infestations consist of plants of only one sex.

Musk thistle

Carduus nutans L.

SYNONYMS: nodding thistle, nodding plumeless thistle; *Carduus thoermeri* (Weinman)

ORIGIN: Native to Europe, Asia, and northern Africa; introduced to North America in the mid 1800s.

DESCRIPTION: Upright, herbaceous biennial typically growing 5-6 ft tall (1.5 to 1.8 m) from a fleshy taproot. Leaves are dark green, hairless, waxy and have characteristic white margins. Leaves are also coarsely lobed with white spines along margins and at lobe tips. Basal leaves are up to 20 in long (50 cm); stem leaves are smaller, grow alternately, and lightly clasp the stem. Stems are stout, highly branched, and have spiny wings along their lower sections but not their upper portions. Flower heads are up to 3 in (7 cm) in diameter, are solitary at stem tips, and produce numerous tufted seeds. They droop or “nod” when fully developed and have rows of wide, triangular bracts that end in small spines and are purple at maturity. Florets are magenta.

Musk thistle a. plant (Stefan Lefnaer); b. infestation (Marianna Szucs, Colorado State University)

Musk thistle c. leaf (Rachel Winston, MIA Consulting); d. stem; e. flower head (d,e Mary Ellen (Mel) Harte, bugwood.org)

HABITAT: This species readily invades pastures, roadsides, ditches, and meadows. It grows best in disturbed, neutral to acidic soils with moist conditions.

ECOLOGY: Musk thistle spreads only by seed. Seeds are readily transported by water, wildlife, and human activity and may remain viable in the soil for many years. Rosettes usually form in spring, with plants bolting by early summer. Flowering occurs throughout summer.

BIOLOGICAL CONTROL: *Urophora solstitialis* is established on musk thistle in eastern Canada, but only with low populations/impact. *Rhinocyllus conicus* and *Trichosirocalus horridus* are effective at some sites when used in combination and in conjunction with plant competition. **Both species are no longer approved for interstate transport in the US.** *Cheilosia grossa* and *L. carlinae* are established on musk thistle, but only with low populations/impact and only in western North America. ***Cheilosia grossa* is not approved for release in Canada, and *L. carlinae* is not approved for redistribution in the US.** The beetle *Psylliodes chalcomera* failed to establish in the US and was not released in Canada.

NOTES: *Carduus nutans* is part of a variable complex that has been treated as one to several species or, more recently, as a single species with several subspecies. Various intermediates are evident, and many specimens cannot be reliably assigned. In the US, subspecies include *nutans*, *leiophyllus* (= *Carduus thoermeri*), and *macrocephalus*.

Urophora stylata (L.)
Bull thistle seedhead gall fly

DESCRIPTION: Larvae are barrel-shaped, off-white, and have dark anal plates. They can reach lengths of 5 mm at maturity. Adults are brownish gray with a yellow head and brownish legs. Wings are clear and with a gray-brown "IV" marking, the "V" being near the tip of the wing. Adult males can be up to 5 mm long while females can be 7 mm.

Urophora stylata a. larvae in seed head; b. adult (a,b Peter Harris Agriculture and Agri-Food Canada, bugwood.org)

LIFE CYCLE: Overwintering larvae pupate in galls in spring when bull thistle plants are bolting. Adults emerge in early summer and deposit eggs on maturing bull thistle buds. Hatching larvae burrow into seed heads and feed on seed-producing tissue, inducing the formation of galls. There may be multiple larvae per seed head. Third (final) instars overwinter within galls. There is one generation per year.

DAMAGE: Larval feeding reduces seed production which can help reduce the rate of bull thistle spread. Seeds in infested seed heads are physically stuck to gall tissue, thereby reducing dispersal further. Galls from larval feeding act as metabolic sinks, diverting resources away from normal plant development.

PREFERRED HABITAT: *Urophora stylata* does best in open meadows with scattered plants. It does not do as well in dense stands of thistle or at sites with flooding and high winds.

RELEASE HISTORY: Individuals from Germany and Switzerland were released on bull thistle in Canada beginning in 1973 (NS, ON, QC). A second shipment from Austria and France was released in QC in 1976, but it failed to establish.

Individuals established in Canada were redistributed to bull thistle throughout the western US and MD, US beginning in 1983.

CURRENT STATUS: *Urophora stylata* attacks only bull thistle in North America. In the US, it is established only in western states where its abundance and impact on bull thistle vary. Most populations are cyclical or limited. From 60-90% of seed heads are attacked in some areas, which has reduced seed production by up to 60%. However, in general, it is difficult to maintain high fly populations on the short-lived bull thistle. In Canada, this fly naturally dispersed from all release sites and is now abundant on bull thistle. The weed has decreased at most sites, likely due to a combination of land use and attack by *U. stylata* and *Rhinocyllus conicus.*

REDISTRIBUTION: Sweeping adult flies is possible, though may be damaging. Instead, place capitula infested with galls into uninfested patches during fall or early spring. Transferring infested seed heads may also transfer unwanted parasitoids, insects, or bull thistle seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, adult flies can be transferred to uninfested bull thistle patches in groups of 50-100. Establishment can be monitored by observing adults on thistle foliage the following summer or by dissecting capitula for larvae from summer throughout the following spring. Alternatively, squeezing capitula between the thumb and forefinger from late fall through spring can quickly indicate larval presence. Those infested with galls will feel very firm, while uninfested capitula readily give when pressure is applied, and they easily fall apart.

NOTES: Bull thistle is short-lived and populations follow disturbance patterns, typically not lasting long in the same location. Consequently, it is difficult to maintain large populations of *U. stylata*. Very small numbers are occasionally reared from Canada thistle in western Canada.

bull

Hadroplontus litura (Fabricius)
Canada thistle stem weevil

SYNONYMS: *Ceutorhynchus litura* (Fabricius)

DESCRIPTION: Larvae are white, C-shaped, and may be pointed in the front end. They grow up to 3 mm long and have brown head capsules. Adults are mottled black and white with a "T"-shaped marking on their backs. The adults have long snouts and can be up 4 mm long.

Hadroplontus litura a. larvae in stem; b. adult (Laura Parsons, University of Idaho); c. stem-mining damage (a,c Norman E. Rees, USDA ARS)(a-c bugwood.org)

LIFE CYCLE: Overwintering adults emerge from plant litter and feed on Canada thistle leaf and stem tissue in early spring. Eggs are laid in spring in the mid-vein on the underside of new rosette leaves. Emerging larvae mine leaf veins, stems, and root crowns of target plants throughout spring and summer. They develop through three larval instars before pupating in the soil. Emerging adults overwinter in plant litter. There is one generation per year.

DAMAGE: Larval mining and adult feeding do not significantly impact weed populations directly as only non-essential tissues are typically consumed. Feeding does cause secondary damage, however, as pathogens and other organisms enter stems of targeted plants via holes made by exiting larvae.

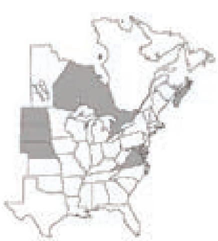
PREFERRED HABITAT: This stem weevil does well in moist, disturbed areas where target thistles are dense and not stressed by drought, grazing, or other control methods.

RELEASE HISTORY: Populations from Germany were released on Canada thistle in the eastern US from 1971 (MD, NJ, NY, SD). Populations from France, Germany, Italy and Switzerland were released in eastern Canada from 1965 (MB, NB, NS, ON, PEI, SK).

CURRENT STATUS: Attacks only Canada thistle in North America. In the US, some reports indicate this beetle is very effective due to reduced overwintering survival of the weed; however, most studies show a lack of impact, likely due to only non-essential parenchyma tissue being consumed by larvae, leaving vascular tissues untouched. Though this weevil is established at most release sites on Canada thistle in Canada, the weevil has low reproductive and dispersal ability so populations are typically small. Mining over multiple years decreases root biomass, when in conjunction with other stresses. Even in combination with other biocontrol agents, overall impact is limited.

REDISTRIBUTION: Adults can be collected with a sweep net and aspirator during spring when host plants are bolting. Releases of 200 adults should be made on on uninfested patches of Canada thistle. Establishment can be monitored the following spring by observing adults on thistle foliage, or during summer by checking for larvae feeding within plant stems.

NOTES: Some populations are infected with *Nosema* pathogens. Infected populations should not be used in redistribution efforts.



Canada

Urophora cardui (L.)

Canada thistle stem gall fly

DESCRIPTION: Larvae are barrel-shaped, white, and have dark brown anal plates. They can be up to 5 mm long at maturity. Adults have dark bodies and dark bands on their white wings that form a 'W'. Adults can be up to 8 mm long.

Urophora cardui a. larvae in gall (Eric Coombs, Oregon Department of Agriculture); b. adult (Laura Parsons, University of Idaho); c. gall (Jennifer Andreas, Washington State University Extension)

LIFE CYCLE: Larvae overwintering inside galls pupate in early spring. Adults emerge in late spring and early summer when new plants are flowering. Eggs are deposited on plant shoots in axillary buds throughout summer. Hatching larvae burrow into stems and cause galls to form. There are often multiple larvae in one gall. Larvae overwinter in the third (final) instar, with pupation occurring in early spring as plants start bolting. There is one generation per year.

DAMAGE: Larval feeding causes gall formation. Galls act as metabolic sinks, diverting resources away from normal plant development. Attacked plants produce fewer seeds, are less competitive, and may be more susceptible to pathogens and other insects.

PREFERRED HABITAT: This fly does well in moist, open and partially shaded areas where its host plant is scattered, especially areas with high grass competition. Areas subject to other means of control (grazing, mowing, chemical treatment, etc.) are not suitable for this fly's survival.

RELEASE HISTORY: Individuals from Austria and France were released on Canada thistle in the US beginning in 1977 (IA, MD, SD from 1981). Flies from Austria, France, and Germany were released on Canada thistle in Canada in 1974 (NB, NS, ON, PEI, QC beginning in 1975). An additional strain from Finland was released in western Canada in 1987.

CURRENT STATUS: *Urophora cardui a*ttacks only Canada thistle in North America. It is moderately abundant in the US, through primarily in western states not covered in this guide. Attacked plants may be stunted and produce fewer seeds, especially when galls occur at terminal growing tips; however, the overall impact is largely limited. The fly is often restricted to shaded infestations, close to riparian areas. In Canada, populations vary by location and year but are highest in areas with sheltering canopy, near water, and in climates with mild winter temperatures. Under favorable conditions this fly can reduce Canada thistle density and stature. In other areas, even in combination with *Hadroplontus litura,* this fly has no measurable impact.

REDISTRIBUTION: Sweeping adult flies is possible, though may be damaging. Instead, place gall-infested plants into uninfested patches during fall or early spring. Transferring infested plants may also transfer unwanted parasitoids, insects, or Canada thistle seeds. To avoid this, gall-infested plants can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, adult flies can be transferred to new Canada thistle infestations in groups of 50-100. Establishment can be monitored by observing adults on thistle foliage the following spring or by finding the characteristic large, swollen galls created by larval feeding throughout summer and fall.

NOTES: Galls and/or larvae within them are often preyed upon by rodents, birds, and an unidentified mite. Though *Urophora* larvae can be difficult to distinguish, the characteristic swollen galls help to easily differentiate *U. cardui* from other thistle-attacking *Urophora* species.

Canada

Urophora solstitialis (L.)

Musk thistle seedhead fly

DESCRIPTION: Larvae are barrel-shaped, off-white, and have dark anal plates. They can reach lengths of 4 mm at maturity. Adults are brownish-black with a yellow head and legs. Wings are clear and with two black "VII" markings, the "V" being near the tip of the wing. Adults are 3-5 mm long, and females have long, pointed, black ovipositors..

Urophora solstitialis a. larvae in seed head (Peter Harris Agriculture and Agri-Food Canada); b. adult (Eric Coombs, Oregon Department of Agriculture)(a,b bugwood.org)

LIFE CYCLE: Overwintering larvae pupate in galls in spring when their thistle host plants are bolting. Adults emerge throughout late spring and early summer and deposit eggs in developing thistle capitula. Hatching larvae burrow into seed heads and feed on seed-producing tissue, inducing the formation of hardened galls. There may be multiple larvae per seed head. Most larvae overwinter in galls during the third (final) instar, but early maturing larvae may pupate in early summer as a second generation. There are up to two generations per year.

DAMAGE: Larval feeding reduces seed production which can help reduce the rate of thistle spread. Seeds in infested seed heads are physically stuck to gall tissue, thereby reducing dispersal further. Galls from larval feeding act as metabolic sinks, diverting resources away from normal plant development.

PREFERRED HABITAT: Specific habitat requirements of *U. solstitialis* in North America are unknown.

RELEASE HISTORY: Individuals from Italy were released on plumeless thistle in the eastern US (MD) in 1993 and on musk thistle in MD and the western US beginning in 1993. Flies from Germany were released on plumeless thistle in

ON and western Canada in 1990. A second shipment from Austria was released on musk thistle in western Canada in 1991.

CURRENT STATUS: *Urophora solstitialis* attacks primarily musk thistle in North America. It failed to establish in the US. The fly is established on both plumeless and musk thistle in ON, Canada. Populations are limited on plumeless thistle, and its impact is considered low overall. The abundance and impact of *U. solstitialis* on musk thistle in ON are unknown.

REDISTRIBUTION: Where populations are sufficiently large, sweeping adult flies is possible, though may be damaging. Instead, place capitula infested with galls into uninfested patches during fall or early spring. Transferring infested seed heads may also transfer unwanted parasitoids, insects, or thistle seeds. To avoid this, plants with infested capitula can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, flies can be transferred to new thistle infestations in groups of 50-100. Establishment can be monitored by observing adults on thistle foliage the following summer or by dissecting capitula for larvae from summer throughout the following spring. Alternatively, squeezing capitula between the thumb and forefinger from late fall through spring can quickly indicate larval presence. Those infested with galls will feel very firm, while uninfested capitula readily give when pressure is applied, and they easily fall apart.

NOTES: In Canada, there is believed to be no conflict between *U. solstitialis* and *Rhinocyllus conicus.*

musk

Cheilosia grossa (Fallén)

Thistle stem hover fly

SYNONYMS: *Cheilosia corydon* (Harris)

DESCRIPTION: Larvae are tan maggots growing up to 19 mm long. Adults are fuzzy with orange-tan hairs, large black eyes, and clearish wings. Adults can be up to 15 mm long, including their wings.

Cheilosia grossa a. adult; b. larval mining damage; c. capitula death due to mining (a-c Eric Coombs, Oregon Department of Agriculture, bugwood.org)

LIFE CYCLE: Adults emerge in very early spring and deposit eggs on young leaves as host plants bolt. Larvae soon emerge and mine into shoots and stems. As the season progresses, larvae mine into roots and continue feeding. They develop through three instars. Pupae overwinter in roots or in plant litter. There is one generation per year.

DAMAGE: Larval mining interferes with water and nutrient transport and ultimately results in a decrease of seed production, sometimes even plant death.

PREFERRED HABITAT: This fly survives a wide array of climatic conditions throughout the range of its host thistles. It tends to do better in areas where host plants flower early.

RELEASE HISTORY: *Cheilosia grossa* was introduced from Italy and released on musk and slenderflower thistle in the eastern US beginning in 1990 (MD, NJ, TX) and Italian thistle in the western US in 1993. This fly was found feeding on bull thistle in the western US by 2001.

CURRENT STATUS: Attacks bull, musk, Italian, slenderflower, and (rarely) plumeless thistle in North America. In the eastern US, *C. grossa* is established only on slenderflower thistle in MD, though its abundance and impact are unknown. In the western US, *C. grossa* is established on bull, musk, Italian, and slenderflower thistle, though it is not very abundant on any of these species. *Carduus* species are preferred over *Cirsium*, but it is rarely found on plumeless thistle. Where established on any of the above species in the West, plants with large stem diameters (>10 mm) are most often attacked, reducing seed production and (infrequently) causing plant death. The overall impact of this biocontrol agent is typically minor.

REDISTRIBUTION: Sweeping adult flies is possible in spring when host plants are beginning to bolt, though this may be damaging. Alternatively, pupae can be collected by digging roots in late summer and early fall as host plants die back with lower temperatures. Infested roots can then be transferred to uninfested thistle patches. Or they may be stored overwinter at 39-46°F (4-8°C). Two to three weeks prior to normal emergence times, bring them to room temperature in rearing cages or breathable, clear containers. Once adults emerge, flies can be transferred to new thistle infestations in groups of 50-100. **Damage similar to that caused by this insect has been observed in several native thistles species (*Cirsium edule* group), thus caution should be used when considering introduction of this fly into new areas.** Establishment can be monitored the following summer through spring by dissecting stems and looking for larval damage. Note that feeding damage can be difficult to distinguish from other mining species if larvae are no longer present.

NOTES: **This species is not approved for release in Canada.**

bull

musk

Rhinocyllus conicus (Frölich)

Thistle seedhead weevil

DESCRIPTION: Eggs, laid on buds and stems, are covered with chewed plant material that becomes tan with age, appearing as part of the plant. Larvae are white with brown head capsules, C-shaped, and reach up to 4 mm long. Adults are dark brown or black with yellowish tufts of hair, giving them a mottled appearance in spring. As they age, adults lose some of these hairs and turn brownish-black. They can be up to 6 mm long.

Rhinocyllus conicus a. eggs (Whitney Cranshaw, Colorado State University); b. larvae and damage in capitula (Mark Schwarzländer, University of Idaho); c. adult (Eric Coombs, Oregon Department of Agriculture)(a-c bugwood.org)

LIFE CYCLE: Overwintering adults emerge in early spring and deposit eggs on bracts of thistle capitula and stems. Larvae hatch in late spring and early summer and develop through four instars. They burrow into seed heads and feed on receptacle tissue and developing seeds. Pupation occurs within seed heads in late summer as seeds mature. Adults emerge for a brief time before overwintering in sheltered areas. There is one generation per year.

DAMAGE: Adults feed on foliage and leave signature rounded feed holes over the entire leaf surface, though this damage is typically minor. Larval feeding destroys some seeds. Seed consumption does not kill existing plants, but does help reduce the rate of thistle spread.

PREFERRED HABITAT: This seed weevil does best in meadows and moist areas with moderate temperatures. In areas where summer arrives quickly, weevils are unable to utilize later-developing capitula.

RELEASE HISTORY: Three strains have been collected for use against exotic thistles in the US, originating from three host species in France and Italy; releases began in 1969 on musk, plumeless, Scotch (failed), Italian, slenderflower, and milk thistle. Releases on Scotch and slenderflower thistle occurred only in the western US. The weevil spread naturally to bull and Canada thistle in the western US. Weevils from France were released on plumeless and musk thistle in eastern Canada beginning in 1968 (MB, ON, QC). The weevil spread naturally and via intentional redistributions to bull, Canada, and marsh thistle in western Canada and bull thistle in eastern Canada (ON). Redistributions to Canada thistle in NS (1991) and Scotch thistle in western Canada (1998) failed to establish.

CURRENT STATUS: Attacks bull, Canada, musk, Italian, marsh, milk, plumeless, and slenderflower thistle in North America. This weevil typically prefers *Carduus* spp. (musk, plumeless, Italian, slenderflower) over other thistles. In the eastern US, it is abundant on musk thistle on which it is effective when combined with *Trichosirocalus horridus* and plant competition. It is established on plumeless thistle, though impact is typically low as only early capitula are attacked. In the US, the weevil is abundant on Italian and slenderflower thistle, but only in western states, where it can be effective on early-blooming plants, but only in combination with plant competition. It is established on Canada, bull, and milk thistle only in western states. On Canada thistle, it is largely ineffective because seed reduction doesn't hinder the plant's spread via roots. Its impact on bull and milk thistle in the western US is minimal. **This weevil attacks 22 of 90 *Cirsium* spp. native to the US, and redistribution permits were revoked in 2000.** In Canada, it attacks over 90% of musk thistle capitula, reducing seed production by ~50%. It has been credited with controlling this species especially when plant competition is present. It has limited impact on plumeless thistle in ON, as only the early capitula are attacked; populations and impact are believed to be higher in western Canada, especially in conjuction with other agents. Attack to bull, marsh, and Canada thistle throughout Canada is more minor.

REDISTRIBUTION: **This weevil is no longer approved for redistribution in the US.** In Canada, adults can be collected in spring with nets and aspirators and transferred in groups of 200 to new thistle infestations. Establishment can be monitored the following summer by dissecting capitula for larvae, or observing adults on foliage in late summer.

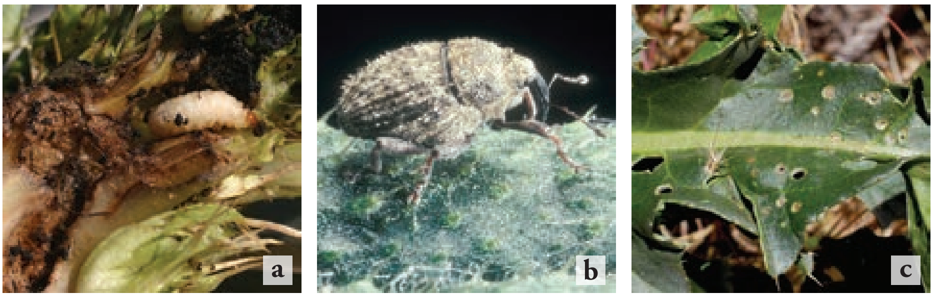
NOTES: Adults have shorter snouts than *Larinus carlinae*. Multiple larvae typically occur in the same capitula.

bull Canada musk

Trichosirocalus horridus (Panzer)
Musk thistle crown weevil

SYNONYMS: *Ceuthorhynchidius horridus* (Panzer)

DESCRIPTION: Eggs are opaque, white, and small. Larvae are creamy white with dark brown head capsules and can be up to 3 mm long. Adults are small (approximately 4 mm long), round, and brown with white mottling. They have obvious spines on their thorax and long snouts.



Trichosirocalus horridus a. larva and root crown damage; b. adult (Laura Parsons, University of Idaho); c. adult feeding damage (a,c Eric Coombs, Oregon Department of Agriculture)

LIFE CYCLE: Overwintering adults emerge in spring and feed on rosettes of host plants. Eggs are deposited on leaf undersides, along midrib and primary veins of young plants. Hatching larvae move down and feed on the tissue at the root-stem junction, developing through three instars. Pupation occurs in the soil in early summer. Adults emerge over the summer but are inactive until fall, when they feed superficially on host plant foliage. Adults overwinter in plant litter, emerging again in spring and often living until the next generation of adults begins to emerge. There is only one generation per year.

DAMAGE: Adult feeding in spring has minimal impacts, though larval feeding can weaken, reduce the seed production, and alter the growth of attacked plants.

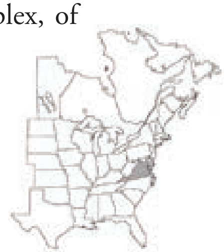
PREFERRED HABITAT: This crown weevil does best in open infestations of its target weed and on the perimeter of infestations where stems do not grow as tall. It is widely distributed throughout portions of North America, but does not do as well at high elevations or under marshy conditions.

RELEASE HISTORY: Individuals from Italy were released in the eastern US onto plumeless and musk thistle beginning in 1974. The weevil spread naturally and via intentional redistributions to bull thistle. In the western US, the weevil spread naturally and via intentional redistributions to Italian, Scotch (failed), and slenderflower thistle. In Canada, weevils from Germany were released on musk thistle beginning in 1975 (MB 1980) and plumeless thistle in 1975 (ON and QC beginning in 1977). It was later redistributed to marsh and Scotch thistle (failed) in western Canada (2007).

CURRENT STATUS: Attacks bull, musk, Italian, marsh, plumeless, and slenderflower thistle in North America. In the US, *T. horridus* prefers musk over plumeless thistle (established on the latter in KS, MD, MO, NJ, VA, WV). On both it can be effective when in combination with plant competition and other biocontrol agents, but it is ineffective at many sites. Its impact on bull thistle is minimal. The weevil is established on Italian and slenderflower thistle only in the western US, where it is moderately effective. In eastern Canada, *T. horridus* is established on musk and plumeless thistle on which damage is limited; attacked rosettes frequently survive to produce seed later in the season. It is established on marsh thistle in western Canada with unknown impact.

REDISTRIBUTION: Adults can be hand collected in spring from thistle rosettes. Alternatively, the summer generation can be collected in the adult stage using a sweep net and aspirator when host plants are flowering. Groups of 100-200 adult weevils can be released at uninfested thistle patches. Establishment can be monitored the following spring by observing adults on foliage or dissecting root crowns in summer in search of feeding larvae. **Due to observed nontarget attack, interstate transport is not permitted in the US, and some states have prohibited its redistribution within their borders. Where this biocontrol agent is approved for redistribution, it is imperative to refrain from making releases at sites where known related or susceptible species co-occur.** Contact your local county extension or land management agency for more information.

NOTES: In 2002, it was determined that *T. horridus* was in fact a complex of three species, each with distinct host plant preferences. A 2015 analysis concluded there are only two species in this complex, of which only *T. horridus* is established in North America.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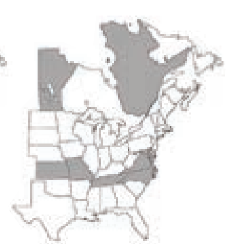

musk

Non-Established Biocontrol Agents

Altica carduorum Guérin-Méneville (Coleoptera: Chrysomelidae)

André Gassmann, CABI-Switzerland

DESCRIPTION AND LIFE CYCLE: Adults are metallic blue-black and 4 mm long. They emerge in late spring and feed on young thistle leaves. Oviposition occurs on the underside of thistle leaves. Larvae emerge in mid to late summer, and feed on thistle leaves. When mature, they drop to the soil for overwintering.

RELEASE HISTORY: *Altica carduorum* from France and Switzerland were released on Canada thistle in eastern Canada beginning in 1963 (NS, ON) and the eastern US starting in 1966 (DE, IN, MD, MN, NJ, SD, WI). Establishment failed at all sites. An additional strain from Italy released in MD, US also failed to establish, possibly influenced by predation.

Lema cyanella (L.) (Coleoptera: Chrysomelidae)

Alec McClay, McClay Ecoscience

DESCRIPTION AND LIFE CYCLE: Overwintering adults emerge in spring and oviposit on leaf undersurfaces and stems of Canada thistle. Larvae feed on the undersides of leaves, leaving the upper epidermis intact which forms a characteristic feeding window. Mature larvae drop to the soil in mid-summer, pupating within cocoons made of foam they secrete. Adults emerge in late summer and feed on foliage prior to overwintering in soil.

RELEASE HISTORY: *Lema cyanella* introduced from Switzerland was released on Canada thistle in NB and SK from 1983. After establishment failed, a population sourced from Switzerland and France obtained via New Zealand was released in western Canada from 1993. **One population initially established, but concerns over nontarget attack led to its eradication.** It is no longer considered established. **Not approved for release in the US.**

Psylliodes chalcomera (Illiger)
(Coleoptera: Chrysomelidae)

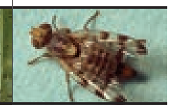
USDA ARS European Biological Control Laboratory (bugwood.org)

DESCRIPTION AND LIFE CYCLE: Overwintering adults emerge in spring and oviposit on musk thistle plant bases. Adults are shiny and dark with a metallic blue-green sheen. Larvae are slender and white with brown head plates. Adults and larvae can be up to 3 mm long. Larvae feed through three instars on leaves, buds, and flowers of musk thistle throughout the growing season. Pupation occurs in plant litter. There is one generation per year.

RELEASE HISTORY: *Psylliodes chalcomera* introduced from Italy was released on musk thistle in the US in 1997 (KS, TX) but failed to establish. It is not widespread in its native range; as a result, it has been difficult to collect large enough numbers for re-release and establishment in North America. **Not approved for release in Canada.**

Unapproved Non-Indigenous Natural Enemies

Six accidentally introduced species are established on exotic thistles in North America. Though some have been intentionally redistributed at different times, all six species are not approved for use. **It is illegal to intentionally move these species to new areas in the US.** Care should be taken when transferring approved agents to ensure that these unapproved species are not also included in transferred material.

Aceria anthocoptes	*Cassida rubiginosa*	*Cleonis pigra*	*Larinus carlinae*	*Puccinia carduorum*	*Terellia ruficauda*
					

Aceria: Eric Erbe, USDA ARS, bugwood.org, *Cassida:* Laura Parsons, University of Idaho, *Cleonis:* Ivo Tosevski, CABI-Switzerland, *Larinus:* Alec McClay, McClay Ecoscience, *Puccinia*: USDA ARS, bugwood.org, *Terellia*: Peter Harris, Agriculture and Agri-Food Canada

In addition to the above species, the rust *Puccinia punctiformis* is also widespread on Canada thistle in North America. Though believed to be present inadvertently, it is established throughout much of the world, and questions remain about its native range. **While not officially approved for general use in the US,** there is recent interest in gaining authorization within states to intentionally utilize state-specific US isolates.

Puccinia punctiformis (F. Strauss) Röhl.
(Pucciniomycetes: Pucciniales)

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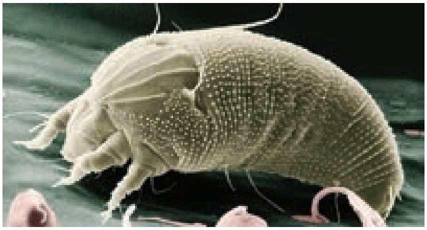
DESCRIPTION AND LIFE CYCLE: Teliospores germinate in spring and produce basidiospores. Aeociospores are then produced in a sweet, sticky nectar that attracts flies to disperse spores. Resulting urediniospores form dense yellow-brown pustules on upper leaf surfaces that are easily blown to uninfected plants to repeat the cycle. Teliospores form on senescing plants and drop onto rosettes in fall, overwintering and producing systemically-infected stems in spring.

HISTORY AND CURRENT STATUS: Likely introduced into North America by 1890 in diseased Canada thistle roots, this rust is now widespread throughout the US and Canada wherever its host occurs. Systemic infections can be lethal but are dependent on suitable conditions. Superficial foliar infections are more common; these have less impact on the plant by stunting growth and flowering but not reducing populations. **Not approved for general redistribution in the US.**

Unapproved Non-Indigenous Natural Enemies

Aceria anthocoptes (Nalepa)
(Acari: Eriophyidae)


Eric Erbe, USDA ARS, bugwood.org

DESCRIPTION AND LIFE CYCLE: Mites appear on foliage in spring as Canada thistle plants bolt. Larvae, nymphs and adults are white, tan, pink, or yellow, depending on the developmental stage. All are tiny (0.15-0.20 mm long). Females exist in reproductive (summer) and overwintering forms. Feeding mites suck out the contents of leaf cells. There are multiple generations per year; overwintering is likely on roots or root buds.

HISTORY AND CURRENT STATUS: This mite was discovered on Canada thistle in the US in 1998 (MD). It is now established in DE, KS, MD, MN, NE, ND, PA, SD, VA, WV in the eastern US and in AB, Canada. It can cause thinning and leaf deformation in the lab, but has not been properly evaluated in the field where it appears impact is minimal. It has been collected from numerous thistles native to North America. **Not approved for redistribution in the US.**

Cassida rubiginosa O.F. Müller
(Coleoptera: Chrysomelidae)


Laura Parsons, University of Idaho

DESCRIPTION AND LIFE CYCLE: Adults emerge in early spring and feed on new foliage. They are oval, have black undersides and a hard, green protective covering, and can be up to 7.5 mm long. Eggs are laid in spring and summer; emerging larvae feed on leaves. Larvae are green with spined margins, on which they accumulate molted skins and waste. They grow to 6 mm and pupate in late summer. Adults emerge and feed on young foliage until late fall and overwinter in plant litter. There is one generation per year.

HISTORY AND CURRENT STATUS: This beetle was recorded on Canada thistle in North America in 1901 and was intentionally redistributed in the US in the 1970s. It is currently established in DE, MD, MI, NH, NJ, NY, OH, SD, VA, WV (US) and MB, NB, ON, QC, SK (Canada). In some areas, it can significantly reduce biomass and survival, but its overall impact is typically minimal, likely hindered by predation and parasitism. It feeds on numerous native thistle species. **Not approved for redistribution in the US.**

Unapproved Non-Indigenous Natural Enemies

Cleonis pigra (Scopoli) (Coleoptera: Curculionidae)

Ivo Tosevski, CABI-Switzerland

DESCRIPTION AND LIFE CYCLE: Adults emerge in spring and feed on young leaves. They are up to 7 mm long and mottled brown with many shiny black lumps. Their wide snouts appear grooved. Larvae hatch in summer and bore to the stem base where they feed internally. They are white with brown head capsules and up to 3 mm long. Pupation occurs in plant litter. Adults emerge throughout fall and overwinter in plant litter. There is one generation per year.

HISTORY AND CURRENT STATUS: *Cleonis pigra* was recorded on Canada thistle in the US by 1919 and in Canada by 1933. It is established in IN, MI, NY, PA (US) and NB, ON, QC (CAN). Larval root mining may kill plants, but regeneration is typical. It feeds on several important species, but its overall impact to exotic thistles is minimal. **Not approved for redistribution in the US.**

Larinus carlinae (Olivier)(=*L. planus*) (Coleoptera: Curculionidae)

Alec McClay, McClay Ecoscience

DESCRIPTION AND LIFE CYCLE: Adults emerge in early spring and feed on young foliage, resulting in leaf holes and deformed bracts/seed heads. Adults are elongate (≤8 mm long), have black bodies with mottled tan-yellow hairs, and long snouts. Eggs are laid inside developing capitula. Larvae feed on developing seeds and receptacle tissue throughout summer. Larvae are white with brown head capsules and are up to 5 mm long. Pupation occurs within capitula; adults emerge in late summer and early fall and overwinter in plant litter. There is one generation per year.

HISTORY AND CURRENT STATUS: *Larinus carlinae* was recorded in the US by 1968 and Canada by 1988 and intentionally redistributed in both countries. It is established on Canada thistle in the eastern US (IN, MD, NY, OH, PA, WV) and in NS, CAN and on bull, Canada, musk, and plumeless thistle in western Canada. It attacks numerous native thistle species; damage to natives often exceeds damage to exotics. **Not approved for redistribution in the US.**

Puccinia carduorum Jacky
(Pucciniomycetes: Pucciniales)


USDA ARS, bugwood.org

DESCRIPTION AND LIFE CYCLE: Overwintering teliospores germinate in spring. Basidiospores infect rosettes and bolting plants. Urediniospores are the most characteristic, being gold brown, covered in short spines, round and tiny (25 µm). Spores occur in dense pustules on infected leaves. Pustules are reddish brown and powdery. Urediniospores are easily blown long distances to uninfected plants to repeat the entire cycle within two weeks.

HISTORY AND CURRENT STATUS: One strain was found present (inadvertently) on slenderflower thistle in CA, US by 1951. It is specific to that species and established in the western US, though its overall impact is unknown. A new strain was introduced on musk thistle in VA in 1987 for experimental field release. It spread naturally and now occurs as far west as CA (US) including the eastern states of DE, GA, IN, KY, MD, MO, OH, SC, TN, and VA. It is specific to *C. nutans* ssp. *leiophyllus* on which it reduces seed set and quality. **Neither strain is approved for redistribution in the US.**

Terellia ruficauda (Fabricius)
(Diptera: Tephritidae)


Peter Harris, Agriculture and Agri-Food Canada

DESCRIPTION AND LIFE CYCLE: Adults emerge in early spring, are up to 5 mm long, and yellow-orange with dark spotted abdomens. Wings have 3 black marks along leading margins and fainter marks on hind margins. Eggs are laid in immature female capitula. Larvae feed on seeds and receptacle tissue. They are white maggots up to 6 mm long. Pupa overwinter in capitula; there is one generation per year.

HISTORY AND CURRENT STATUS: *Terellia ruficauda* was discovered on Canada thistle in the US and Canada by 1873. Populations are widely distributed in eastern North America; the fly is abundant in Canada but generally limited in the US. Larvae destroy some seeds, but its overall impact on Canada thistle is minimal. **Not approved for redistribution in the US.**

WATERHYACINTH

Eichhornia crassipes (Mart.) Solms

SYNONYMS: water hyacinth, common water hyacinth, lilac devil, river raft

ORIGIN: Native to the Amazon basin of South America; believed to have been introduced to Louisiana, US by 1884.

DESCRIPTION: Upright, herbaceous, free-floating, and stoloniferous perennial typically growing 2 in to 3.2 ft tall (5 cm-1 m). Plants often form thick mats growing on open water, though seedlings and individual plants may also root in moist soil. In uncrowded situations, plants have short, spreading petioles with pronounced, buoyant swelling 1-2 in thick (2-5 cm). In dense stands, plants are taller and more erect with little or no swelling of petioles. Leaves are arranged in whorls of 6-10. Leaf blades are rounded or kidney-shaped, leathery, and up to 6 in across (15 cm). Flowers usually occur in clusters of 8-15 at the end of a single spike. Flowers are 1.5-2.5 in across (4-6 cm) and have 6 violet or bluish-purple petals. The top petal has a bright yellow spot. Flowers may have short, medium, or long styles, but only the short- and long-style forms occur in North America. Fruits are 3-celled capsules that contain up to 50 small, ribbed seeds.

Waterhyacinth a. plant (Chris Evans, University of Illinois); b. infestation (Karen Brown, University of Florida)(a,b bugwood.org)

Waterhyacinth c. leaves (Barry Rice, sarracenia.com); d. leaves and swollen petioles (Leslie J. Mehrhoff, University of Connecticut); e. flowers (Wing1990hk)(c,d bugwood.org)

HABITAT: Waterhyacinth grows best in still or slow-moving water bodies including lakes, rivers, marshes, and canals. It prefers full sun, warm temperatures, and high nutrient water. Cold and salt water limit growth of this weed.

ECOLOGY: Waterhyacinth spreads by seed and (primarily) by stolons. At maturity, flowering stalks bend and release seeds below the water surface. Seeds may remain viable for 15-20 years. Seedlings germinate in moist soil or shallow water. Once seedlings become buoyant, they separate from their roots and float to the surface. New roots form under each leaf and create a dense mass. Stems periodically produce stolons that grow horizontally for 4-20 in (10-50 cm) before establishing daughter plants. Huge, interconnected mats can develop rapidly, though connecting stolons eventually die. Flowering occurs year-round at warm locations and from late summer through autumn in cold climates. At cold sites, plants cease growth and stem bases overwinter, resuming growth in spring.

BIOLOGICAL CONTROL: Four species have been released in the US since 1972. *Megamelus scutellaris* is still increasing; heavily attacked plants produce fewer leaves, wilt, and die. *Neochetina bruchi* and *N. eichhorniae* have reduced waterhyacinth 50-66%. *Niphograpta albiguttalis* may have had high impact initially, but is now rarely seen in the field. **No species are approved for release in Canada.**

NOTES: "Establishment" at many northern sites is due to annual reintroductions. Plants do not survive heavy freezes.

Megamelus scutellaris Berg
Waterhyacinth planthopper

DESCRIPTION: Eggs are elliptical and milky white when laid but turn yellowish with reddish eye spots before hatching. Nymphs are similar to wing-less adults but are smaller (up to 2.5 mm long). Nymphs have yellowish bodies with mottled brown markings; their coloration darkens through each instar. Adults can be either wing-less or winged (with clear wings). Adults are 2.5-3.7 mm long and are mottled brown, gray, and yellowish.

Megamelus scutellaris a. adult (Jason D. Stanley, USDA ARS, bugwood.org); b. adults and nymphs; c. adults and damage to waterhyacinth (b,c Philip Tipping, USDA ARS)

LIFE CYCLE: At warm locations, both *M. scutellaris* and waterhyacinth develop throughout the year. At cold sites, immature stages overwinter in decaying mats of waterhyacinth. Adults lay eggs within leaves of waterhyacinth in spring; oviposition scars can be recognized by three parallel marks. Nymphs develop through five instars. Nymphs and adults feed on leaves and stems of waterhyacinth. Environmental cues determine whether adults will be winged or wing-less. When planthoppers are overcrowded or waterhyacinth plants are of poor quality, adults develop wings that enable them to disperse to more suitable waterhyacinth plants/infestations. There are multiple overlapping generations per year.

DAMAGE: Nymphs and adults pierce waterhyacinth lleaves and stems and feed on sap. Plants with heavy feeding produce fewer leaves and eventually wilt and die.

PREFERRED HABITAT: This planthopper appears to do best at sites with some cover or shading. Though the reasons for this are not currently known, shading may promote increased humidity which increases survival of the planthopper.

RELEASE HISTORY: The waterhyacinth planthopper was initially released in FL, LA, and TX in 2010 using populations from Argentina (releases were also made in CA from 2011). The first releases were believed to have failed establishment, though establishment was subsequently confirmed at FL release sites. A second release sourced from northern Argentina/Paraguay was released in FL beginning in 2012.

CURRENT STATUS: Both releases successfully established in FL and are no longer differentiated. Though it is too early to determine their overall impact, populations are spreading and slowly increasing. Parasitism may limit populations at some FL locations.

REDISTRIBUTION: Plants infested with planthoppers can be transferred to new waterhyacinth sites and placed against uninfested plants when waterhyacinth is actively growing, taking care not to also transfer unwanted parasitoids, other insects, or waterhyacinth seeds. Alternatively, late-instar nymphs and adults can be aspirated from plants and released at new waterhyacinth populations. Establishment can be confirmed the following year by observing nymphs, adults, or their piercing/sucking feeding damage on waterhyacinth leaves and stems.

NOTES: **This species is not approved for release in Canada.** Adult *Megamelus scutellaris* can be difficult to differentiate from other species of *Megamelus*.

Neochetina bruchi Hustache & *N. eichhorniae* Warner
Waterhyacinth weevils

DESCRIPTION: Both species are morphologically very similar. Eggs are white and oval. Larvae are C-shaped, white with yellow-orange heads, and up to 9 mm long. Pupae are white and enclosed in cocoons. Adults are somewhat rounded and have long snouts. Adult *Neochetina bruchi* are tan or brown and often have a lighter-colored v-shaped band on the lower parts of the elytra. Adult *N. eichhorniae* is usually a darker mottled gray and brown. Both species have two dark markings on their elytra. The markings are shorter for *N. bruchi* and located midway down the elytra while the markings for *N. eichhorniae* are longer and situated closer to the weevil's head (Figure b).

Neochetina spp. a. larva; b. adults: *N. bruchi* (left), *N. eichhorniae* (right)(a,b Willey Durden, USDA ARS); c. adult feeding scars on waterhyacinth (Katherine Parys, USDA ARS)(a-c bugwood.org)

LIFE CYCLE: Both species are continuously brooded, creating frequent overlap of generations. In warm areas where waterhyacinth remains present and does not freeze, all stages can overwinter. Adults may live longer than a year and can be found year-round. Adults feed on waterhyacinth leaves and stems, producing feeding scars 2-3 mm wide. Adults lay eggs (300-400 in a lifetime) embedded in waterhyacinth leaf and petiole tissue. *Neochetina bruchi* may deposit several eggs in the same site while *N. eichhorniae* deposits eggs singly. Larvae feed on plant tissue through three instars and mine the petioles towards the root crown. *Neochetina bruchi* larvae develop somewhat faster than *N. eichhorniae* larvae. Pupation occurs in cocoons attached to waterhyacinth roots below the water surface. Emerging adults climb on waterhyacinth tissue above the water surface to feed and mate.

DAMAGE: Adult feeding causes characteristic feeding scars on leaves and petioles. Larval feeding leaves mining tunnels in leaf petioles. Damage from adults and larvae stunts plant growth and reduces floral and vegetative reproduction. Heavy feeding and mining causes leaf petioles to become thin and brittle, and plants become waterlogged and gradually sink.

PREFERRED HABITAT: The specific habitat requirements of both species are unknown, though both appear to thrive wherever waterhyacinth populations remain persistent throughout the year.

RELEASE HISTORY: *Neochetina eichhornia* from Argentina was released in FL in 1972 and then redistributed to TX and LA beginning in 1974 and to CA in the western US in 2002. *Neochetina bruchi* was also introduced from Argentina and then released in FL, LA, and TX starting in 1974. It was redistributed to CA in the western US in 1982 and 2002.

CURRENT STATUS: In the southeastern US, both weevil species are well established in FL, LA, and TX. *Neochetina bruchi* is usually dominated by *N. eichhorniae.* Separating the two species based on their feeding damage is difficult, but they likely complement each other. Both weevils have had heavy impact on the weed and are credited with reducing waterhyacinth abundance from 1/2 to 1/3 of its original levels in Gulf Coast states. In managed systems, significantly less chemical controls are now needed much less frequently to manage the weed. Waterhyacinth still remains a problem in some parts of this region.

REDISTRIBUTION: Adults are most easily collected by aspirating or hand-picking individuals from within unfurled leaves and leaf sheaths and transferring them to new waterhyacinth infestations in groups of 200-300. When weevil populations are high, infested plants can be transferred to new waterhyacinth sites and placed against uninfested plants when waterhyacinth is actively growing, taking care not to also transfer unwanted parasitoids, other insects, or waterhyacinth seeds. Establishment can be confirmed the following year by observing adults feeding on waterhyacinth leaves, observing adult feeding scars on leaves, or by dissecting leaf petioles for evidence of larval mining.

NOTES: **Neither species is approved for release in Canada.** Spillover attack by *Neochetina eichhornia* adults (and possibly *N. bruchi*) was observed on the native *Pontederia cordata* L. and other native species intermixed with waterhyacinth, including *Canna* spp., though this attack was insignificant and temporary. More recently, no nontarget attack has been observed.

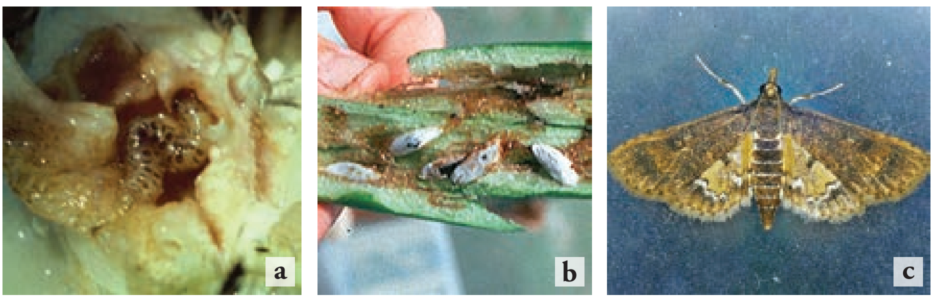
N. bruchi

N. eichhorniae

Niphograpta albiguttalis (Warren)
Waterhyacinth moth

SYNONYMS: *Epipagis albiguttalis* (Warren), *Sameodes albiguttalis* (Warren)

DESCRIPTION: Eggs are small, spherical, and creamy-white. First instars have a brown body with darker spots and a dark brown head. Later instars are cream-colored with scattered dark brown spots and a dark orange head and can be up to 2 cm long. Adults are variable in coloration, and females are often darker than males. Adult forewings range from golden to brown, while the hindwings are more consistently golden. Light-colored segments make their abdomens appear ringed. There is typically a distinct white spot midway along the leading edge of the forewing, and a distinct dark spot near the center of the hindwing. Adults are typically 6-10 mm long with wingspans of 17-25mm.

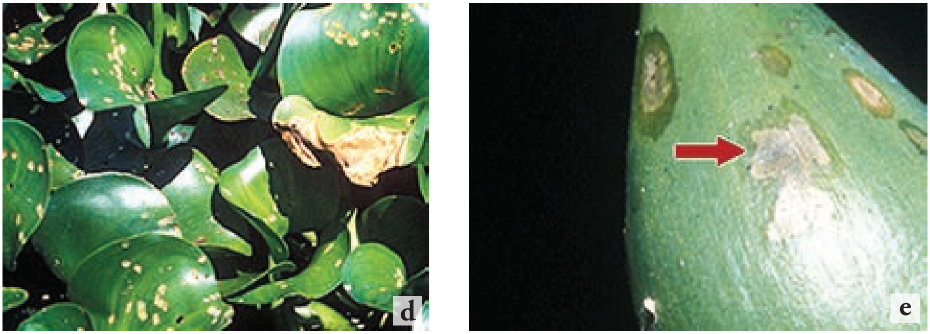


Niphograpta albiguttalis a. larva and damage (Willey Durden, USDA ARS, www.bugwood.org); b. pupae with larval damage (US Army Corps of Engineers, ERDC); c. adult (© Monica)

LIFE CYCLE: This species is continuously brooded, creating frequent overlap of generations. In warm areas where waterhyacinth remains present and does not freeze, all stages can overwinter. Adults lay eggs (350-600 in a lifetime) singly or in small groups in leaf and petiole tissue, usually in existing leaf injuries or feeding scars left by the *Neochetina* weevils. Larvae feed on leaf tissue through five instars, mining in petioles towards the root crown. Pupation occurs in cocoons within waterhyacinth petioles. Emerging adults are short-lived (up to 10 days), typically nocturnal, and can often be found resting on the undersides of waterhyacinth leaves. When adults emerge from leaf petioles, a glassy "window" is left covering the emergence tunnel.

DAMAGE: Larval tunneling in leaf petioles causes a characteristic curling and browning of the affected leaf. Tunneling destroys shoot tips, preventing future growth. Attacked waterhyacinth stems often die or lose buoyancy and sink.

PREFERRED HABITAT: The specific habitat requirements are unknown,



Niphograpta albiguttalis damage to waterhyacinth a. leaves; b. close-up (d,e US Army Corps of Engineers, ERDC)

though this species thrives wherever waterhyacinth populations remain persistent throughout the year. It appears to prefer young waterhyacinth plants with bulbous petioles, as are typically found in more open infestations with less dense populations of waterhyacinth.

RELEASE HISTORY: Individuals from Argentina were released in FL, LA, and TX beginning in 1977 and then redistributed to CA in the western US in 1983.

CURRENT STATUS: The waterhyacinth moth is supposedly established in the Gulf Coast states of FL, LA, and TX. It at times establishes quickly and causes significant damage to bulbous waterhyacinth stems locally before disappearing; however, is has rarely been observed in the most recent field surveys.

REDISTRIBUTION: Larvae may be collected by hand, but populations dense enough to make this worthwhile are hard to locate. Nonetheless, the best method for collection is typically the transfer of waterhyacinth plants infested with larvae and pupae. These can be placed against uninfested plants when waterhyacinth is actively growing, taking care not to also transfer unwanted parasitoids, other insects, or waterhyacinth seeds. Establishment can be confirmed the following year by observing adults resting on waterhyacinth leaves, observing windows covering adult emergence holes, or by dissecting leaf petioles for evidence of larval mining.

NOTES: **This species is not approved for release in Canada.**

Native Natural Enemies

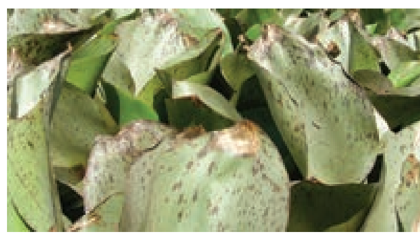
Bellura densa (Walker)(=*Arzama densa*) (Lepidoptera: Noctuidae)

Willey Durden, USDA ARS, bugwood.org

DESCRIPTION AND LIFE CYCLE: Adults are mottled tan, up to 17 mm long, and have a wingspan of 35 mm. Females lay eggs in spring in masses on waterhyacinth leaves. Larvae feed on waterhyacinth leaves and bore into stems. Late instars are olive green with dark horizontal bands and are up to 5 cm long. Pupation occurs in cocoons in plant stems. Adults emerge in summer and lay eggs; there are two generations per year in southern regions. Larvae overwinter in waterhyacinth stems.

HISTORY AND CURRENT STATUS: *Bellura densa* is native to SE North America. It was redistributed in southern states in the 1970s-80s. High populations significantly reduce waterhyacinth cover and biomass in some ponds, but have little impact in others. Populations are greatly hindered by parasitism, predation and disease. **This moth feeds on native and economically important species, so it is not safe for redistribution.**

Cercospora piaropi Tharp (=*C. rodmanii*) (Dothideomycetes: Capnodiales)



Infected leaves (Forest and Kim Starr, Starr Environmental, bugwood.org)

DESCRIPTION: This pathogen causes necrotic spots on waterhyacinth leaves. Infection kills leaf tissue from the tip to the stem. New leaves are often produced to combat leaf loss. Under severe disease conditions, new leaves are killed faster than they can be replaced, and the entire plant dies. Disease symptoms can be found year-round in warm climates.

HISTORY AND CURRENT STATUS: This pathogen was intentionally redistributed in FL and LA, US in the 1970s. Extensive research was conducted on economical applications of this fungus, though it was never formally registered as a bioherbicide. It is capable of decreasing waterhyacinth biomass, and in some instances has caused substantial decline of weed populations. Long-term success of this pathogen with only a single application is unlikely when waterhyacinth growth is rapid. Combined feeding by the *Neochetina* weevils and infection with this fungus has additive effects.

Orthogalumna terebrantis Wallwork (Acari: Galumnidae)

Adult *Orthogalumna terebrantis* (Willey Durden, USDA ARS, bugwood.org)

DESCRIPTION AND LIFE CYCLE: This species is continuously brooded, creating frequent overlap of generations. In warm areas where waterhyacinth remains present and does not freeze, all stages can overwinter. Adults lay tiny yellow eggs in damaged areas of waterhyacinth leaves. Nymphs and adults are brown, becoming shiny and nearly black with maturity. Adults are teardrop-shaped and less than 1 mm long, appearing as small black dots on waterhyacinth leaves. Feeding mites produce characteristic feeding tunnels that are long (5-10 mm) and thin, extending towards the tip of the leaf between leaf veins. There may be three generations per year.

HISTORY AND CURRENT STATUS: *Orthogalumna terebrantis* was recorded in FL and LA in the US by 1968. It is widespread in these states, but its populations are sporadic, and it provides no substantial control. In combination with *Neochetina eichhorniae*, the mite can significantly reduce size and density of waterhyacinth in natural situations locally. **Not approved for redistribution in the US or release in Canada.**

Tansy ragwort

Jacobaea vulgaris Gaertn.

SYNONYMS: ragwort, tansy, stinking Willy; *Senecio jacobaea* L.

ORIGIN: Native to Europe, Siberia, and Asia. Likely introduced to North America in contaminated ship's ballast; recorded as early as 1850s.

DESCRIPTION: Upright, herbaceous biennial (winter annual or short-lived perennial under certain conditions). Typically grows 1-3 ft tall (0.3-1 m) from one to several soft, fleshy roots. Leaves are deeply lobed to pinnately toothed, alternate, and 3-8 in long (7.5-20 cm). Stems arise singly or in clumps and branch near the top with multiple inflorescences. Flower heads consist of yellow disc (center) and ray (outer) florets. Ray flowers (usually 13) resemble petals and grow 0.3-0.75 in long (8-20 mm) long. Seeds are topped by a fine pappus.

HABITAT: Tansy ragwort is especially problematic in pastures, grasslands, and open forests, generally with moist soils.

Tansy ragwort a. plant (Jennifer Andreas, Washington State University Extension); b. infestation (Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

Tansy ragwort c. rosette (Jennifer Andreas, Washington State University Extension); d. stem leaf (Marianna Szucs, Colorado State University); e. flower head (Strobilomyces)

ECOLOGY: This species spreads only by seed, which are dispersed short distances by wind and longer distances by humans, other animals, and water. Seeds may remain viable in the soil for up to eight years. The life history varies depending on climatic conditions. Where winters are mild, the plant typically acts as a biennial. Rosettes grow during the winter, and bolting occurs early the following spring. Flowering occurs from July to September; it may occasionally occur the first year, but is usually delayed until the second. At locations with harsh winters and shorter growing seasons, the plant may behave as a short-lived perennial. Seeds typically germinate in spring. Seedlings increase in size throughout the summer, and only the largest successfully overwinter. Bolting typically occurs early the following summer, and flowers appear from July to October. Cutting or mowing the plant in either climate may cause it to grow as a perennial.

BIOLOGICAL CONTROL: The majority of releases on tansy ragwort have been made in western North America, where this weed is most problematic. Large *Longitarsus jacobaeae* populations effectively control tansy ragwort at many sites, especially those with cool, moist coastal climates. ***Cochylis atricapitana*** **is only approved in Canada,** where it stunts plant growth and reproductive output at some locations. *Botanophila seneciella* is established only in the West and has only limited impact. Defoliation by *Tyria jacobaeae* may kill ragwort in cold climates, but plants typically recover at mild coastal sites; **it is no longer permitted for interstate transport in the US.**

Longitarsus jacobaeae (Waterhouse)

Tansy ragwort flea beetle

DESCRIPTION: Three *L. jacobaeae* strains are presently established in North America; all are morphologically identical. Eggs are small (<1 mm diameter) and whitish-yellow, turning orange with maturity. Larvae are white and may be 1-4 mm long. Last instars have brown head capsules. Pupae are white and 2-4 mm long. Adults are golden brown, 2-4 mm long, and have enlarged hind legs.

Longitarsus jacobaeae a. eggs and hatching larva (Ken Puliafico, Montana State University); b. late instar (Eric Coombs, Oregon Department of Agriculture); c. pupa (Laura Parsons, University of Idaho)

LIFE CYCLE: The three strains established in North America differ genetically and in their life cycle timing. Only one strain (Italian CPNW) is established in eastern North America. Adults of this strain emerge in late spring and feed briefly on tansy ragwort rosettes before becoming dormant for the summer. They become active again and continue feeding in fall, causing a "shot-hole" pattern in attacked leaves. Adults mate and lay eggs around the bases of ragwort rosettes, sometimes laying eggs until early spring. Larvae mine leaf petioles and then root crowns of rosettes throughout winter and early spring, developing through three instars. In spring, larvae leave root crowns to pupate in the soil. There is one generation per year.

DAMAGE: Adult feeding may decrease plant size and even cause death in water-stressed plants. Larval mining of the root crown is generally the most destructive, reducing seed production and causing plant death.

PREFERRED HABITAT: The Italian CPNW strain thrives in dense, unshaded tansy ragwort infestations. Flooding interferes with the larval and pupal stages. This strain is best suited for low elevation sites (at or below 400 m or 1,300 ft) with climates characterized by warm summers and mild, moist winters.

RELEASE HISTORY: The Italian CPNW strain was introduced from Italy and released in the western US in 1968 and redistributed to BC in western Canada

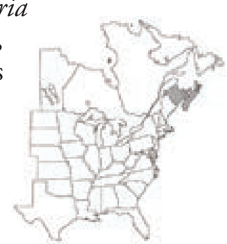
Longitarsus jacobaeae d. adult (Marianna Szucs, Colorado State University); e. adult feeding damage; f. larvae in roots (e,f Jeff Littlefield, Montana State University)

in 1971. A small shipment from England was also released in BC in 1972. The different populations in BC were later not differentiated and then redistributed (likely as a mix) to NB, NS, ON, and PEI from 1978.

CURRENT STATUS: All three strains are established in western states and provinces not covered in this guide. In eastern North America, only the Italian CPNW strain is established, and only in Canada where it is abundant at cool coastal climates. Establishment failed or is very limited at interior sites. Where populations are large, the beetle controls tansy ragwort well in conjunction with other biocontrol agents.

REDISTRIBUTION: Adults can be collected via sweep net (with or without an aspirator) or with an insect-collecting vacuum in the fall and then transferred to uninfested tansy ragwort patches in groups of 200. Establishment can be monitored the following year by observing adults on ragwort foliage along with the characteristic shot-hole feeding. Alternatively, plants can be dissected fall through spring for evidence of larval feeding. Note that larvae feeding within root crowns may be confused with early instars of *Cochylis atricapitana.*

NOTES: This beetle works well in conjunction with *Tyria jacobaeae*. For further information on the life cycles, habitat, release history, and current status of the strains established in western North America, refer to the sister guide "Field Guide for the Biological Control of Weeds in the Northwest."



Italian CPNW strain

Cochylis atricapitana (Stephens)

Ragwort stem and crown boring moth

DESCRIPTION: Larvae are creamy white to tan with small black heads and can be up to 8 mm long. Pupae are yellowish-brown, 7-8 mm long, and enclosed in a white cocoon. Adults are small and tent-winged with a wingspan of 7-16 mm. The forewings have irregular brown marks flecked with black and grey on a white or yellowish-white background. Females are more pink than males. A tuft of dark-colored scales extends from behind the head.

Cochylis atricapitana a. larva in rosette; b. adult (© Geoff Riley); c. feeding damage (a,c © Province of British Columbia. All rights reserved. Reproduced with permission of the Province of British Columbia)

LIFE CYCLE: There are 2-3 generations per year. Overwintering larvae resume activity in spring, feeding on tansy ragwort stems and root crowns through five instars. Pupation occurs either in the stem or in surrounding plant litter. Adults emerge in late spring as tansy ragwort is bolting and lay eggs on tansy ragwort crowns or undersides of leaves. Hatching larvae mine leaves and petioles while older larvae mine stems and root crowns. Mature larvae pupate within the plant. Emerging adults lay eggs in similar locations in mid- to late summer. Newly hatching larvae may overwinter, or a third generation may emerge from eggs laid in autumn and overwinter in plant stems.

DAMAGE: Larval mining suppresses flower formation, stunts plant growth, and may kill plants outright.

PREFERRED HABITAT: This moth is adapted to a wide variety of habitats where tansy ragwort grows, including high elevations and sites with early winters. To date, it is best established in mild coastal zones.

RELEASE HISTORY: Individuals from Spain were obtained via Australia and released in Canada in 1990 (NB, NS).

CURRENT STATUS: *Cochylis atricapitana* established readily in NS where it dispersed widely and contributed to control of the plant within five years at some locations. The moth did not fare as well in western Canada, where populations are small and restricted to coastal regions; introductions into interior climates failed.

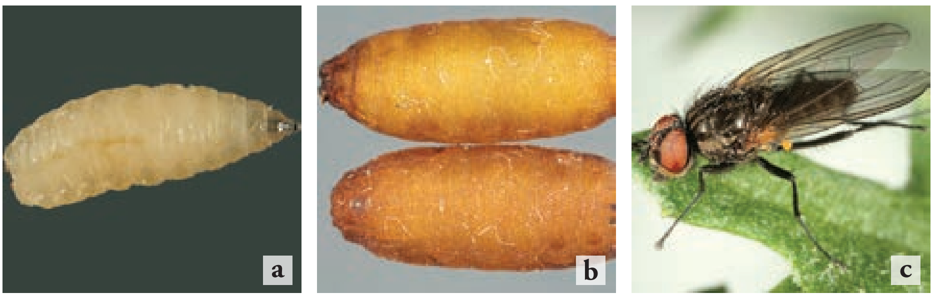
REDISTRIBUTION: Adults can be collected at night with the use of a black light; however, sufficient numbers can be difficult to find. Consequently, it is easier to redistribute larvae. Infested plants can be dug up and transferred to new sites in groups of 50 during spring, prior to flower maturation. Transplanting in fall is typically less successful for this biocontrol agent, and also creates the risk of spreading tansy ragwort seeds (from potentially different genotypes) which may make the tansy ragwort problem worse. Establishment can be monitored throughout the following season by dissecting stems and root crowns to find larvae. Note that early instars feeding in the root crown may be easily confused with *Longitarsus jacobaeae* larvae.

NOTES: **This species is not approved for release in the US.**

Botanophila seneciella (Meade)
Ragwort seedhead fly

SYNONYMS: *Hylemyia seneciella* (Hardy), *Pegohylemyia seneciella* (Meade)

DESCRIPTION: Eggs are small, oval in shape, and off -white in color. Larvae (maggots) are creamy white and narrowed at one end. Late instars can be up to 6 mm long. Pupal chambers are barrel-shaped and brown. Adults resemble house flies with reddish eyes, dark bodies, and slightly clouded wings that extend beyond their body. They are up to 6 mm long.



Botanophila seneciella a. larva; b. pupae; c. adult (a-c © Malcolm Storey, www.bioimages.org.uk)

LIFE CYCLE: Pupae overwinter in loose soil or litter. Adults emerge in spring when tansy ragwort is in the rosette to late bolting stage. Adults lay eggs in young flower buds in late spring and early summer. Hatching larvae burrow into capitula and feed on developing seeds (one larva per seed head). Attacked seed heads are easily identified—initially by a brown discoloration as florets die and later by the presence of frothy spittle. Final (third) instars exit seed heads in late summer, leaving behind characteristic exit holes, and pupate in the soil where they overwinter in puparia. There is one generation per year.

DAMAGE: Larval feeding destroys some or all seeds within attacked seed heads. Seed consumption does not kill existing plants, but does help reduce the rate of ragwort spread.

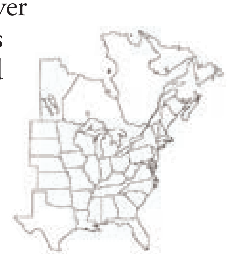
PREFERRED HABITAT: This fly does well in meadows and forest clearings. Where it is established alongside the cinnabar moth, the ragwort seedhead fly is often restricted to scattered tansy ragwort plants growing in habitats less suitable to the moth (e.g. shaded forests or narrow mountain valleys).

RELEASE HISTORY: Individuals from France were released in the western US in 1966 and redistributed from there to BC and PEI (CAN) starting in 1968.

Botanophila seneciella d. infested seed head; e. spittle on infested seed heads (d,e Jennifer Andreas, Washington State University Extension); f. exit hole (Marianna Szücs, Colorado State University)

CURRENT STATUS: *Botanophila seneciella* is established only in western states and provinces not covered in this guide. In the western US, the fly is moderately abundant. Infestation rates of up to 40% of available capitula have been documented in small, isolated tansy ragwort populations, though 5-10% attack rates are more typical. Only early seed heads are utilized; later-developing capitula generally escape attack. This agent is susceptible to resource competition from *Tyria jacobaeae,* which also consumes tansy ragwort seed heads, as well as tansy ragwort mortality caused by *Longitarsus jacobaeae*. Consequently, though the ragwort seedhead fly is the most widely distributed, it is usually the least abundant and least effective of the three agents established in the US. This fly is widely distributed in western Canada though abundance is low. Populations are often restricted to small relic populations of ragwort that are less desired by other biocontrol agents. It is unable to control the weed alone, but it contributes to partial control in combination with *Longitarsus* spp. and *Cochylis atricapitana*.

REDISTRIBUTION: Sweeping adult flies is often damaging. Moving fly-infested seed heads to uninfested patches is effective, but may inadvertently spread new tansy ragwort seeds (and from potentially different genotypes). The safest method is to collect pupae. Bouquets of infested plants can be placed in flasks of water (small-mouth jars prevent emerging maggots from falling in the water and drowning). Flasks are placed in open buckets amid a thick layer of fine sand or loose peat moss during late summer. Maggots exiting seed heads will burrow into the sand to pupate. Sand can be stored at 4-8 °C (39-46 °F) to overwinter and then be placed into uninfested patches of tansy ragwort in early spring. Establishment can be monitored the following season by dissecting capitula to find feeding larvae or observing frothy spittle on infested seed heads.



Tyria jacobaeae (L.)
Cinnabar moth

DESCRIPTION: Eggs are small (1 mm) and bright yellow when new, but turn black with age. First instars are light brown or orange; instars 3-6 are banded orange and black. Mature larvae are up to 25 mm long. Adults have black forewings with two red dots and red-lined borders. Hind wings are bright red. Wingspans may be up to 40 mm, and their coloring often fades with moth age.

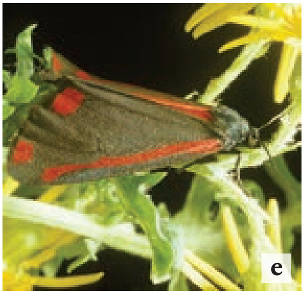
Tyria jacobaeae a. eggs (Jeff Littlefield, Montana State University); b. early instars (George Markin, USDA Forest Service); c. late instar (Mark Schwarzländer, University of Idaho)

LIFE CYCLE: Pupae overwinter in loose soil or plant litter. Adults emerge in late spring, mate, and lay eggs in clusters on the undersides of tansy ragwort rosette leaves. Hatching larvae feed on the undersides of rosette leaves. As plants bolt, later instars feed on stem leaves and developing buds, often in groups of 10-30. Final (sixth) instars leave plants in late summer and pupate in suitable locations before overwintering. There is one generation per year.

DAMAGE: Larvae may completely defoliate tansy ragwort plants, leaving behind only bare stems. In milder climates plants can recover. In colder, harsher climates, frost kills ragwort regrowth before plants can fully recover.

PREFERRED HABITAT: This species does best in warm, sunny areas with dense tansy ragwort infestations. It is less successful in shady habitats, narrow canyons, saturated soils, locations with harsh winters and little protective snow cover, or over-grazed areas. Because pupae overwinter in shallow soil or plant litter, they are highly susceptible to trampling or predation by rodents or other insects.

RELEASE HISTORY: Individuals from France were released in the western US in 1959. In Canada, moths from Sweden were released in NS in 1961, and moths established in the US were redistributed to PEI in 1966; both introductions failed to establish. Moths from Switzerland were released in NB, NS, ON, PEI released beginning in 1963.



Tyria jacobaeae d. pupa (George Markin, USDA Forest Service); e. adult (Mark Schwarzländer, University of Idaho); f. larvae feeding gregariously (Jeff Littlefield, Montana State University)

CURRENT STATUS: In the US, this moth is only established in western states not covered in this guide. In the West, populations fluctuate. High densities often completely defoliate plants. In mild regions, the weed often re-grows and recovers sufficiently to successfully overwinter and reproduce. In the colder, harsher Intermountain West, frosts usually kills regrowth before plants fully recover, so the moth is more effective at reducing weed populations. In Canada, the moth's overall impact is typically minimal. Its complete defoliation of tansy ragwort can lead to decreased winter survivorship and decreased seed production in some locations at some times; however, ragwort populations persist in all major infested areas despite even high cases of defoliation. Weather-induced fluctuations of the weed tend to control insect populations rather than the insect controlling the weed.

REDISTRIBUTION: This species is best collected in the larval stage by tapping or shaking plants over an open pan throughout the growing season. Larvae can be transferred to new sites in groups of 50-100. Establishment can be monitored the following year by observing feeding larvae throughout the growing season. **Due to observed nontarget attack, interstate transport is not permitted in the US, and some states have prohibited its redistribution within their borders. Where this species is approved for redistribution in the western US, it is imperative to refrain from making releases at sites where known related or susceptible species co-occur.**

NOTES: *Tyria jacobaeae* complements the effect of *Longitarsus jacobaeae*. The conspicuous colors of *Tyria* larvae serve as warnings to potential predators. Larvae are capable of sequestering alkaloids from their host for use as toxic defenses against birds and other animals.

Unapproved Non-Indigenous Natural Enemies

Longitarsus spp.
(Coleoptera: Chrysomelidae)

Adult *Longitarsus flavicornis* (Mark Schwarzländer, University of Idaho)

DESCRIPTION AND LIFE CYCLE: The four accidental or adventive tansy ragwort flea beetles (*L. flavicornis, L. ganglbaueri, L. gracilis*, and *L. succineus*) very closely resemble and are frequently mistaken for *L. jacobaeae*, especially *L. flavicornis* which differs only in the size of the male genitalia. Though less is known about the biology of the latter three flea beetles, *L. flavicornis* is a highly studied and successful tansy ragwort biological control agent in Australia. It has one generation per year. Larvae mine the petioles, lower leaves, and then root crowns of tansy ragwort where they overwinter. Larvae develop through three instars. They are white with brown head capsules, and may be 1.5-4 mm long. Pupation occurs in the soil in late spring or early summer. Pupae are white and 2-4 mm long. Adults emerge in early summer, feed on tansy ragwort leaves, and lay small yellowish eggs (<1 mm diameter) at the base of ragwort rosettes in late summer. Adults are coppery brown and 2.5-3.5 mm long. They have fully developed wings and are capable of flight, though they more often utilize their enlarged hind legs to jump. Newly hatching larvae feed on ragwort stems, root crowns, and roots where they overwinter; occasionally the egg stage overwinters in Canada.

HISTORY AND CURRENT STATUS: Since the 1970s, four species of *Longitarsus* have been observed in Canada as either adventive species or as successfully established populations after accidental introductions in contaminated releases of *L. jacobaeae*, likely from Europe. *Longitarsus flavicornis* was initially reported as established only on Vancouver Island in western Canada in mixed populations with *L. jacobaeae* where it reportedly had limited impact on the weed. Additional evaluation is needed to confirm its continued presence. *Longitarsus ganglbaueri* is only present in limited numbers in MB and NS, but it has reportedly been documented at some point in the western US. Its current status remains unknown. *Longitarsus gracilis* was identified in NS, most likely inadvertently introduced in mixed shipments of *L. jacobaeae* from Europe. What was believed to be a population of *L. jacobaeae* was redistributed from NS to BC in 2005. Subsequent monitoring of the BC release site yielded only *L. gracilis*. *Longitarsus succineus* is established only in NL. The current impact of *L. gracilis* and *L. succineus* in Canada is unknown. **These four flea beetles**

are not recommended for redistribution in Canada or the US due to their broad host range. Care should be taken to ensure adults or eggs of these unapproved species are not accidentally collected. Check with your local biological control experts for help with identifying flea beetle species.

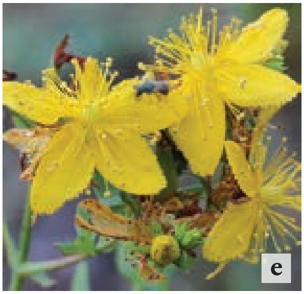
Common St. Johnswort
Hypericum perforatum L.

SYNONYMS: St. Johnswort, klamath weed, goatweed

ORIGIN: Native to Asia, Europe, northern Africa. Introduced to the United States on multiple occasions by European settlers interested in the plant's medicinal properties. First escaped cultivation in 1793.

DESCRIPTION: Perennial, upright forb typically growing 1-3 ft tall (0.3-1 m) with numerous stems that are somewhat woody at their base. Stems turn rust-colored later in the growing season. Roots produce short runners. Leaves are opposite, without stems or lobes, and are up to 1 in long (2.5 cm). Leaves have numerous transparent dots as well as tiny black glands along their margins. Flowers are numerous, bright yellow, 0.75 in (1.5 cm) in diameter, have many stamens, and have petals with additional black glands along margins. Seed pods are sticky, 3-celled, 0.25 in (0.6 cm) long, and filled with numerous seeds.

Common St. Johnswort a. plant (Catherine Herms, Ohio State University); b. infestation (John M. Randall, The Nature Conservancy)(a,b bugwood.org)



Common St. Johnswort c. leaves (Steve Dewey, Utah State University); d. mature plant in the fall (Norman Rees, USDA ARS); e. flowers (Rob Routledge, Sault College)(c,d bugwood.org)

HABITAT: This species prefers open sunlight and disturbance, such as in forest clear cuts, along roadsides, and in abandoned fields. It frequents sandy or gravelly soil.

ECOLOGY: Common St. Johnswort spreads by seed and root runners. Sticky seed capsules can be dispersed short distances by wind and longer distances by water and adhering to humans and other animals. First year plants do not produce flowers or seeds, and it may take two to several years to reach maturity. Flowering occurs from late spring through autumn. Seeds germinate throughout spring and summer or following autumn rains. Seeds may remain viable in the soil for several years. Vegetative reproduction is responsible for much of the growth in a common St. Johnswort population.

BIOLOGICAL CONTROL: This weed is most problematic in western states and provinces, though biocontrol has also proven beneficial on some infestations in the East. *Chrysolina hyperici* and *C. quadrigemina* are the most effective biocontrol agents, especially at open, sunny sites. *Agrilus hyperici* is established only in the West, where it is effective at some locations but has been displaced by *Chrysolina* spp. at others. *Aphis chloris* provides significant control in NS (Canada), though populations fluctuate due to weather and competition with *Chrysolina* spp.; **it is not approved for release in the US.** The low abundance and impact of *Aplocera plagiata* make it a low priority. High parasitism hinders *Zeuxidiplosis giardi*; redistributions are not warranted.

Chrysolina hyperici (Forster) & *C. quadrigemina* (Suffrian)
Klamathweed beetles

DESCRIPTION: Two species of klamathweed beetles are established in North America, both morphologically very similar. *C. quadrigemina* is slightly larger than *C. hyperici*. Eggs are orange and cylindrical. Larvae are initially orange and later gray and up to 6 mm in length. Adults are oval-shaped, robust, and are up to 6 mm long. They are shiny metallic with green, bronze, or blue undertones.

Chrysolina spp. a. eggs (Norman Rees, USDA ARS, bugwood.org); b. larva; c. *C. hyperici* adult (Laura Parsons & Mark Schwarzländer, University of Idaho); d. *C. quadrigemina* adult (b,d Eric Coombs, Oregon Department of Agriculture, bugwood.org)

LIFE CYCLE: Larvae emerge in early spring and feed on young foliage when the plant is bolting. Ingesting common St. Johnswort makes larvae photosensitive, so most feeding occurs before sunrise. They develop through four instars, and pupation occurs in the soil in late spring. Adults emerge in early summer as common St. Johnswort begins flowering. They feed and then often rest in the soil over summer. If fall rains are sufficient, adults return to plants and resume feeding on foliage in the fall, laying eggs on leaves as common St. Johnswort is senescing. Both species primarily overwinter as eggs. When fall rains are not significant, adults overwinter and lay eggs in spring. In mild climates, fall-hatched larvae can survive the winter. There is one generation per year.

DAMAGE: Larval feeding can decimate populations of common St. Johnswort. Summer defoliation by adults is also striking, but not as effective as larval feeding.

PREFERRED HABITAT: Both beetles do poorly in shaded, barren, or rocky areas. They prefer warm, sunny regions with wet winters. *C. quadrigemina* prefers more maritime conditions than *C. hyperici*, which is more cold and moisture tolerant.

RELEASE HISTORY: *Chrysolina hyperici* and *C. quadrigemina* were introduced from England and France (respectively) via Australia and released on St. Johnswort in the western US in 1945 and 1946, respectively. US-established

Chrysolina spp. e,f. adults and damage (e,f Jennifer Andreas, Washington State University Extension)

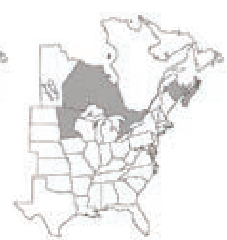
beetles were redistributed to eastern Canada beginning in 1969 (*C. hyperici* MB, NB, NS, ON, PEI, spread naturally to QC; *C. quadrigemina* NB, NS, ON).

CURRENT STATUS: In the US, both beetles are established primarily in western states where they can help reduce the weed by more than 97% at most open, sunny sites. In Canada, the beetles are also abundant and effective in the East. Both species are ineffective in shady habitats. Populations of both the weed and the beetles often follow a boom/bust cycle; when St. Johnswort control is high, beetle populations crash, leading to a St. Johnswort increase, but at lower than historical levels. Without improvement of land use, St. Johnswort will continue being a cyclical problem. *C. hyperici* and *C. quadrigemina* are often mixed in both the US and Canada, though *C. quadrigemina* is now typically considered to be more abundant and effective, especially at drier, warmer sites.

REDISTRIBUTION: Adults can be collected with a sweep net in summer and transferred to uninfested St. Johnswort patches in groups of 200 (adults often rest in the soil in late summer). Establishment can be monitored by observing larvae on St. Johnswort foliage the following spring (at night). Adults can be observed the following summer (daytime). Attacked plants appear stripped and wilty.

NOTES: In the US, *C. quadrigemina* attacks the native *Hypericum concinnum* and *H. punctatum* and the exotic *H. calycinum*. A third *Chrysolina* species, *C. varians* (Schaller), was introduced from Europe and released on common St. Johnswort in the western US from 1950 and western Canada from 1957, but failed to establish in either country.

C. hyperici

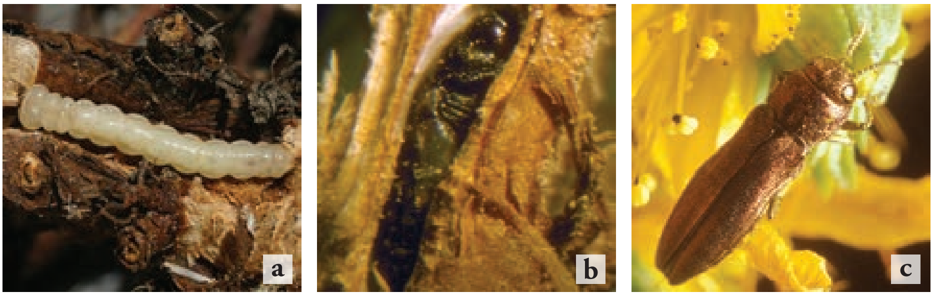


C. quadrigemina

Agrilus hyperici (Creutzer)

St. Johnswort root borer

DESCRIPTION: Larvae are white with brown mouthparts, have inflated segments, and reach 11 mm in length. Adults are a metallic brown color; females are all one color while males' heads are slighter greener than the rest of their bodies. Adults are flattened and tapered toward the rear and reach 5 mm in length.



Agrilus hyperici a. larva in root (Eric Coombs, Oregon Department of Agriculture); b. pupa in root (Norman Rees, USDA ARS); c. adult (Laura Parsons & Mark Schwarzländer, University of Idaho)

LIFE CYCLE: Larvae overwinter within common St. Johnswort roots, feeding again within roots the following spring as plants bolt. Pupation occurs in the roots after the fourth instar. Adults emerge through early summer as common St. Johnswort flowers. Adults are most active in the heat of the day. Oviposition occurs near the base of common St. Johnswort plants in late summer. Newly emerging larvae burrow into the roots to feed and then overwinter. There is one generation per year.

DAMAGE: When larvae feed within roots of common St. Johnswort, root tissue can be completely consumed. Stems arising from attacked roots and root crowns are stunted and produce fewer flowers; the attacked plant dies outright in some instances.

PREFERRED HABITAT: Common St. Johnswort is found mostly in mountainous regions in North America and drier, more southern portions of Europe. Damp sites are less suitable as larvae are often susceptible to fungal attack. This beetle prefers large plants with multiple stems. It will attack plants in shade, unlike some other common St. Johnswort biological control agents.

RELEASE HISTORY: This beetle was introduced from France and released on common St. Johnswort in the western US in 1950. Beetles established in CA, US were redistributed to BC in western Canada multiple times between 1955 and 1987.

CURRENT STATUS: *Agrilus hyperici* is established only in western states and provinces not covered by this guide. In the western US, its abundance and impact vary. It disperses widely, but populations are typically low until occasional explosions. This beetle initially displayed the ability to destroy common St. Johnswort at many locations, but was displaced by *Chrysolina quadrigemina* and persisted only in some areas. It contributed significantly to common St. Johnswort suppression in ID where it is still abundant. In western Canada, the beetle is typically less common. Its overall impact is unknown due to the lack of initial baseline data and the prolific occurrence of the *Chrysolina* beetles at *A. hyperici* release sites.

REDISTRIBUTION: Adults can be collected with a sweep net (with or without an aspirator) during summer when common St. Johnswort is in flower and can be transferred to uninfested St. Johnswort patches in groups of 50-100. Preference should be placed on new sites with no to minimal *Chrysolina* populations. Establishment can be monitored by observing adults on St. Johnswort foliage the following spring and summer during the heat of the day or by dissecting roots for evidence of larval mining from autumn through the following spring.

NOTES: This beetle has been observed attacking *Hypericum concinnum*, a forb/small shrub endemic to California.

Aphis chloris Koch
St. Johnswort aphid

DESCRIPTION: Eggs are yellowish at first, turning black with time. Nymphs and adults are lime green, tending to dark green in cooler climates. They are typically 1-2 mm long. Winged females have transparent wings.

Aphis chloris a. eggs (Peter Harris, Agriculture and Agri-Food Canada); b. adults and nymphs (© Province of British Columbia. All rights reserved. Reproduced with permission of the Province of British Columbia)

LIFE CYCLE: Eggs overwinter. Self-fertile females hatch in late spring and produce live young. 6-11 days are required for these immatures to reach the reproductive stage. Live young births continue until temperatures cool in the fall, though in warm areas, self-fertile females continue to be produced. Under crowded conditions from summer through fall, winged females disperse to start new colonies. Adults and nymphs congregate on common St. Johnswort stems, root collars, leaf axils, flowers and leaves. The onset of cool, short days in northern regions initiates the production of males and egg-producing females. Each female produces four eggs on average, depositing them onto basal winter foliage.

DAMAGE: Nymphs and adults attack common St. Johnswort stems and leaves, feeding on plant fluids. Under high aphid densities this feeding can cause individual plants to wither and die. In field studies, healthy potted plants were killed in one month when attacked by this species.

PREFERRED HABITAT: This aphid does best where summers are humid and temperatures are cool. Sufficient cold winter temperatures are required for egg development. It does not do well in hot, dry locations where common St. Johnswort plants wither and burn from heat.

RELEASE HISTORY: *Aphis chloris* was introduced from Austria, Germany, and Hungary and released in MB, NB, and NS, Canada beginning in 1990 (released in western Canada in 1979).

CURRENT STATUS: This biocontrol agent provides significant control at some sites in NS, Canada, though populations fluctuate due to weather and abundance/impact of *Chrysolina* spp. Low numbers of the beetles provide more suitable habitat for the aphid.

REDISTRIBUTION: Plant material infested with adults and nymphs can be transferred to uninfested common St. Johnswort patches throughout the growing season. Alternatively, foliage with eggs attached can be collected from fall through spring and transferred to new sites prior to egg hatch. In either case, infested plant material should be placed in direct contact with uninfested stems at new sites (taking care not to spread common St. Johnswort seeds to new sites). Establishment can be monitored throughout the same or following growing season by observing adults or nymphs on foliage of common St. Johnswort.

NOTES: **This species is not approved for release in the US.**

Aplocera plagiata (L.)

St. Johnswort inchworm

DESCRIPTION: Eggs are small, pearly-white ovals. Larvae resemble twigs and are reddish brown with weak gray stripes. They are up to 2.5 cm long. Pupae are greenish-golden and slender. Adults are triangular in shape and have gray wings with dark gray bands. Wingspans reach 3.75 cm (1.5 in).

Aplocera plagiata a. eggs (Norman Rees, USDA ARS, bugwood.org); b. larva (Eric Coombs, Oregon Department of Agriculture)

LIFE CYCLE: Overwintering larvae emerge in early spring and feed on common St. Johnswort foliage (typically at night) when the plant is bolting. They develop through four instars. Pupation occurs in the soil. Adults emerge in late spring and early summer and lay eggs on St. Johnswort foliage. Larvae of the first new generation emerge in midsummer as common St. Johnswort flowers, repeating the life cycle. Second generation larvae hatch in late summer, coinciding with the late flowering stage of common St. Johnswort, and feed on foliage and flowers. This generation overwinters in the larval stage within the soil. There are up to two generations per year, depending on winter temperatures.

DAMAGE: Larval defoliatily weakens but typically does not kill common St. Johnswort. Attack by large populations of this biological control agent can lead to a reduction of flower and seed formation.

PREFERRED HABITAT: This species prefers dry areas to those with high rainfall. It does well on rocky ground, open sandy places, and in limestone regions.

RELEASE HISTORY: Moths from Germany were introduced to western Canada in 1967. Eastern releases were made with individuals from Switzerland (NB 1977) and France (NS, ON beginning in 1984). Only the moths from France established

Aplocera plagiata c. adult (Eric Coombs, Oregon Department of Agriculture); d. defoliation (Norman Rees, USDA ARS, bugwood.org)

in eastern Canada. All three releases were successful in western Canada, from where the moths were redistributed (as a mix) to the western US in 1989.

CURRENT STATUS: In the US, *A. plagiata* is established only in western states not covered by this guide. Where it is locally abundant, defoliation hinders and may kill plants outright. However, its overall abundance is typically limited. It is most effective in warm, dry areas where the insect can complete two generations. In Canada, the moth's abundance and impact in ON are unknown. In western Canada, the moth disperses readily throughout southern interior BC. However, populations remain low and do minimal damage.

REDISTRIBUTION: Collecting adults is typically very damaging. The species is best collected in the larval stage using sweep nets. First generation larvae are available in midsummer as common St. Johnswort flowers. Second generation larvae hatch in late summer or early fall, coinciding with the late flowering stage of common St. Johnswort. Groups of 50-100 can be transferred to uninfested St. Johnswort patches immediately after collection. Establishment can be monitored by observing adults on St. Johnswort foliage the following spring/summer or larvae feeding on foliage (typically at night) in midsummer or early fall. Attacked plants appear stripped and wilty.

NOTES: Adults are usually fewer in number in the first generation compared to the second generation. Warm, dry, and long summers are needed to complete both generations. When cold temperatures arrive too soon, second generation larvae do not survive winter.

Zeuxidiplosis giardi (Kieffer)

St. Johnswort gall midge

DESCRIPTION: Eggs are elongated and pale red in color. Larvae are orange and can be up to 2 mm long. Pupae are a yellowish-red, becoming darker red as they mature. Adults are very small (3 mm long) and have dark red bodies with gray heads, wings, and legs. They have fine, delicate legs and antennae.

Zeuxidiplosis giardi a. adult; b. gall damage (a,b Norman Rees, USDA ARS, bugwood.org)

LIFE CYCLE: Larvae emerge in early spring and feed on common St. Johnswort leaf buds, causing leaves to grow into a spherical gall that is green with reddish markings. Larvae feed inside at the base of the gall through three instars; several larvae are often found within one gall. Pupation also occurs inside the gall. Adults are sexually mature upon emergence and live for up to five days. There may be up to seven generations per year, though there are usually fewer than five. Larvae and pupae overwinter inside galls.

DAMAGE: In suitable habitats, this insect can cause a loss of vigor and reduction of both root and foliage development. Heavily attacked plants are unable to obtain moisture and frequently die during drier seasons.

PREFERRED HABITAT: This midge does best with moderate to high humidity, thriving in damp locations and at high elevations. It does poorly in areas with dry summers and constant wind. It also does poorly with heavy livestock grazing.

RELEASE HISTORY: Midges collected in France were released in the western US in 1950. A second release attempt was made in the western US in 1992 utilizing individuals from Hawaii that were reportedly doing much better than individuals in the US. This second introduction failed to establish. Populations in the western US were redistributed to western Canada in 1955.

CURRENT STATUS: In North America, *Z. giardi* has established only in western US states not covered by this guide. In the West, the fly can reduce growth in heavily infested common St. Johnswort plants. However, *Z. giardi* is heavily parasitized, so populations are very limited. This midge did not establish in Canada. Populations thrived the first summer of release but were subsequently annihilated due to sudden sub-zero temperatures in mid-November.

REDISTRIBUTION: Sweeping adult midges is possible, though may be damaging. Instead, place plants infested with galls into uninfested patches throughout the growing season. Alternatively, galls infested with larvae may be hand-picked and transferred to uninfested patches of common St. Johnswort. When transferring galls, it is important to keep the galls moist to prevent dessication. Transferring infested galls may also transfer unwanted parasitoids, other seed head insects, or common St. Johnswort seed. To avoid this, galls can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, flies can be transferred to new common St. Johnswort infestations in groups of 50-100. Establishment can be monitored throughout the following season by observing galls on new common St. Johnswort foliage.

NOTES: This biocontrol agent is capable of forming galls on *Hypericum concinnum*, a forb/small shrub endemic to California. However, damage to this plant is insignificant.

Dalmatian toadflax
Linaria dalmatica (L.) Mill.

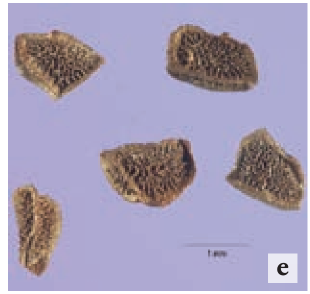
SYNONYMS: broad-leaved toadflax; *Linaria genistifolia* (L.) Mill., *Linaria genistifolia* (L.) Mill. ssp. *dalmatica* (L.) Maire & Petitm.

ORIGIN: Likely introduced from Eurasia by 1900 in horticultural trials.

DESCRIPTION: Upright, herbaceous perennial typically growing numerous upright and prostrate stems 1-4 ft tall (0.3-1.2 m) from a deep taproot with lateral branches. Leaves are alternate, thick (succulent to leathery), green to blue-green, and often with a waxy surface. Leaves are heart-shaped at the base, clasp the stem, and are typically 1-2 inches long (2.5-5.0 cm) and nearly as wide. Flowers are bright yellow and snapdragon-like with an obvious upper and lower lip and a long spur pointing downward. Each has a fuzzy, yellowish-orange throat. Flowers occur in spiked clusters emerging from leaf axils. Each flower produces a round capsule holding 60-300 small, somewhat triangular seeds.

HABITAT: Dalmatian toadflax is often found in or along disturbed areas such as railroads, roadsides, riversides, abandoned pastures and fields, and open forest slash piles. It does well in cool, semiarid climates and on coarse-textured soils.

Dalmatian toadflax a. plant (K. George Beck & James Sebastian, Colorado State University, bugwood.org); b. infestation (Jennifer Andreas, Washington State University Extension)



Dalmatian toadflax c. leaves; d. flower (c,d Bonnie Million, National Park Service); e. seeds (Steve Hurst, USDA NRCS PLANTS database)(c-e bugwood.org)

ECOLOGY: This species reproduces both by seed and root fragments. Severed root segments as small as 0.4 in (1 cm) can sprout new plants. Seedlings germinate in fall or (more often) in spring; bolting occurs in spring. Flowering occurs throughout the summer. Seeds may remain viable in the soil for up to 10 years.

BIOLOGICAL CONTROL: This weed is most problematic in midwestern and western states and provinces, though biocontrol may also prove beneficial on some infestations in the East. While both *Mecinus janthinus* and *M. janthiniformis* established, *M. janthiniformis* is highly effective on Dalmatian toadflax and redistributions of this species are warranted. *Brachypterolus pulicarius* and *Rhinusa antirrhini* were accidentally introduced, but later intentionally redistributed in both the US and Canada. Both prefer yellow toadflax; their abundance/impact on Dalmatian is minor. Populations of *Calophasia lunula* are typically low; in eastern North America, they are restricted to Canada. High densities can defoliate toadflax, though plants usually recover, and overall impact is limited. *Eteobalea intermediella, E. serratella,* and *R. linariae* failed to establish on Dalmatian toadflax in North America.

NOTES: Dalmatian and yellow toadflax are highly variable in North America and can hybridize. This manual uses the interpretation that *Linaria genistifolia* (L.) Mill. is distinct from *L. dalmatica* (L.) Mill. and that *L. dalmatica* consists of two subspecies, of which only *L. dalmatica* ssp. *dalmatica* is invasive and weedy in North America. The taxonomy of this group is under review.

YELLOW TOADFLAX
Linaria vulgaris Mill.

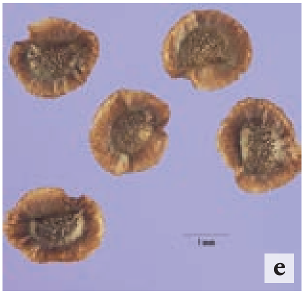
SYNONYMS: common toadflax, butter-and-eggs

ORIGIN: Possibly introduced from Eurasia as early as 1600s as an ornamental and medicinal plant, and as a source of textile dye.

DESCRIPTION: Upright, herbaceous perennial typically growing numerous stems 1-3 ft tall (0.3-1 m) from a taproot with spreading lateral roots. Leaves are alternate, green, pointed at both ends, and may have small stalks. Older leaves are narrow and typically 1-2 in long (2.5-5 cm) with a large central vein on the underside. Flowers are pale yellow and snapdragon-like with an obvious upper and lower lip and a spur pointing downward. Each has a fuzzy, bright orange throat. Flowers occur in spiked clusters at the top of the stem. Each flower produces an oval capsule fruit holding 10-40 viable, flat, disc-shaped seeds.

HABITAT: This species is often found along roadsides and railroads and in cultivated fields and pastures, but it can also invade undisturbed, healthy ecosystems. It is frequently found in more fertile and moist soil than Dalmatian toadflax.

Yellow toadflax a. plant (Tiffany Wax, Washington State University Extension); b. infestation (L.L. Berry, bugwood.org)



Yellow toadflax c. leaves; d. flowers (c,d Michael Shephard, USDA Forest Service); e. seeds (Steve Hurst, USDA NRCS PLANTS database)(c-e bugwood.org)

ECOLOGY: Yellow toadflax reproduces by seeds, creeping root systems, and root fragments. Seedlings typically germinate and bolt in spring. Lateral roots are capable of vegetative reproduction within three weeks of germination. Severed root segments as short as 4 in (10 cm) can form new plants. Flowering occurs throughout summer and fall, depending on location. Seeds generally have low viability (<50%), but some may remain viable in the soil for 8 years or more.

BIOLOGICAL CONTROL: This weed is most problematic in midwestern and western states and provinces, though biocontrol may also prove beneficial on some infestations in the East. While both *Mecinus janthinus* and *M. janthiniformis* established, *M. janthinus* prefers yellow toadflax; densities and impact can be high locally. It is too early to know if *Rhinusa pilosa* is established, though early results are encouraging. *Brachypterolus pulicarius* and *R. antirrhini* were accidentally introduced, but later intentionally redistributed. Both are widespread on yellow toadflax but have only minor impact. *Rhinusa linariae* is established only in the West and at such low densities impacts are limited. Populations of *Calophasia lunula* are typically low; in eastern North America, they are restricted to Canada. High densities can defoliate toadflax, though plants usually recover, and overall impact is limited. *Eteobalea intermediella* and *E. serratella* failed to establish on yellow toadflax in North America.

NOTES: Dalmatian and yellow toadflax are highly variable in North America and can hybridize. The taxonomy of this group is under review.

Mecinus janthiniformis Toševski & Caldara & *M. janthinus* Germar

Toadflax stem weevils

DESCRIPTION: Both species are morphologically very similar. Eggs are white and oval. Larvae are C-shaped, white with brown head capsules, and up to 5 mm long. Adults are bluish-black, elongate with long snouts, and up to 5 mm long. *Mecinus janthinus* is smaller than *M. janthiniformis.*

Mecinus spp. a. larva (Rosemarie De Clerck-Floate, Agriculture and Agri-Food Canada); b. pupa, c. adult (b,c Bob Richard, USDA APHIS PPQ)(a-c bugwood.org)

LIFE CYCLE: Overwintering adults emerge in early spring and feed on toadflax shoot tips, producing a shot-hole pattern in upper leaves (most obvious on Dalmatian toadflax). *M. janthinus* emerges a few weeks earlier on yellow toadflax than *M. janthiniformis* does on Dalmatian. Females chew holes into toadflax stems and lay eggs singly (up to 45 in a lifetime), covering eggs with chewed plant tissue. Larvae feed through three instars in short tunnels chewed into toadflax stems. *M. janthinus* tends to mine lower in toadflax stems than *M. janthiniformis*. Pupation occurs in mid-summer within chambers inside feeding tunnels. Adults overwinter inside pupal chambers. There is one generation per year.

DAMAGE: Adult feeding stunts shoots and roots and suppresses flowering. Larval mining severs water/nutrient conducting tissues, causing desiccation and death.

PREFERRED HABITAT: *Mecinus janthiniformis* is well adapted to a variety of conditions. Because overwintering sites are often above snow cover, populations do better in less fluctuating winter temperatures and above -18.5°F (-28° C). The optimal conditions for *M. janthinus* in North America are still being determined.

RELEASE HISTORY: What was originally released in the US and Canada as *Mecinus janthinus* was recently discovered to be a mixture of *M. janthinus* and the closely related *M. janthiniformis*. The true *M. janthinus* was sourced from France and Germany and released in 1991 on Dalmatian and yellow toadflax in western Canada and in 1995 on yellow toadflax in NS, Canada. Established individuals

Mecinus spp. damage d. (Jennifer Andreas, Washington State University Extension); e. (Gary Piper, Washington State University, bugwood.org); f. (Laura Parsons, University of Idaho)

were redistributed to Dalmatian and yellow toadflax in the western US in 1996. Eastern US releases occurred only on Dalmatian toadflax and began in 2010 (KS, ND, SD, WV). *Mecinus janthiniformis* was reportedly introduced from the Republic of Macedonia and released in western Canada on Dalmatian toadflax (1992) and yellow toadflax (2000). Redistributions of *M. janthiniformis* were made from Canada to both Dalmatian and yellow toadflax in the US post 1996 in mixes with the true *M. janthinus*. Most of these redistributions were made in western states; eastern releases started in 2000 (NE, ND, SD).

CURRENT STATUS: *Mecinus janthiniformis* prefers Dalmatian toadflax; *M. janthinus* prefers yellow. *M. janthiniformis* is established on Dalmatian primarily in northwestern US and Canada where it has reduced the weed dramatically at some locations. *M. janthinus* is established primarily in northwestern North America and NS (CAN). While currently not widely distributed, *M. janthinus* densities and impact on yellow toadflax can be high locally, and it appears to establish well in new areas.

REDISTRIBUTION: Adults can be tapped from toadflax foliage from spring through mid-summer when plants are bolting to flowering and transferred to uninfested toadflax patches in groups of 200. Establishment can be monitored by observing adults on toadflax foliage the following spring or by dissecting stems for larvae from late spring through late summer.

NOTES: As the identification of *M. janthiniformis* has only recently been made, sorting the release history and establishment status of *Mecinus* spp. on both toadflaxes is a work in progress.

Dalmatian

yellow

Rhinusa pilosa (Gyllenhal)

Yellow toadflax stem-galling weevil

DESCRIPTION: Eggs are pale yellow and oval-shaped. Larvae are C-shaped, creamy white with brown head capsules and up to 5 mm long. Adults are black, up to 4 mm long, and covered in upright hairs. They have a distinctive curved profile, and the snout gives this weevil a distinctive hook-nosed appearance.

Rhinusa pilosa a. adult; b. galls on yellow toadflax stems (a,b Ivo Toševski, CABI)

LIFE CYCLE: Overwintering adults emerge in early spring. Females lay eggs in actively growing tips of yellow toadflax stems, triggering the formation of large, obvious galls. Larvae feed on nutrient-rich inner gall tissues through three instars before pupating, also within the gall. New adults remain in the gall for a period of time in early summer-mid fall and feed on remnant gall tissues before chewing their way through the gall wall to exit. Feeding continues on host shoots for a brief period before adults move to the soil where they become inactive. Once temperatures cool consistently in late autumn, adults feed extensively on toadflax re-growth before overwintering in soil or plant litter. There is one generation per year.

DAMAGE: Stem galls reduce yellow toadflax height, number of stems, and biomass. Adult and larval feeding reduces nutrient reserves and photosynthetic tissue which may stunt plants and reduce reproductive output.

PREFERRED HABITAT: The habitat preferences of *R. pilosa* in North America are unknown because confirmed established populations are restricted to limited sites in AB and BC in western Canada. In its native Europe, *R. pilosa* does well in a variety of habitats throughout the range of yellow toadflax.

RELEASE HISTORY: Individuals from Serbia were released on yellow toadflax in western Canada beginning in 2014 and in MB, NS, ON, and PE in 2016.

CURRENT STATUS: This weevil attacks only yellow toadflax in North America and has thus far been released only in Canada. Following several releases of *R. pilosa*, successful galling of yellow toadflax was confirmed in multiple provinces. There also was successful overwintering survival of first generation adults produced from many releases. It is still too early to confirm establishment, especially in eastern Canada. Continued monitoring of new weevil populations is planned to determine population changes, spread, and impact.

REDISTRIBUTION: Any releases made should be done using laboratory colonies and under the guidance of appropriate authorities. In the future, should this biocontrol agent be further established, field redistributions can be done by collecting adults from toadflax stems in early spring using a sweep net and aspirator. They can be transferred in groups of 100-200 to uninfested yellow toadflax patches. Establishment can be monitored by observing adults on toadflax stems the following spring or by observing the obvious galls in stem tissue.

NOTES: As of 2016, TAG approval of this insect has led to its release in Canada, but in the US it is still within the regulatory process. Approval for release is expected in the near future.

Four species of *Rhinusa* are currently established on toadflaxes in North America. Adult *R. pilosa* are longer (4 mm) than *R. linariae* (2.5 mm), *R. antirrhini* (3 mm) and *R. neta* (3 mm). *Rhinusa pilosa* is black while *R. neta* is gray to brown, and *R. pilosa* is covered with longer, upright hairs while the hairs on *R. linariae, R. antirrhini,* and *R. neta* are short and more flattened. *Rhinusa pilosa* also differs from the other *Rhinusa* species by its location of attack; *R. pilosa* adults and larvae can be found on/in stems, while *R. linariae* adults can be found on stems and larvae on/in roots, and *R. antirrhini/R. neta* adults attack flowers and larvae attack seeds.

yellow

Brachypterolus pulicarius (L.)

Toadflax flower-feeding beetle

DESCRIPTION: Eggs appear milky white at first, becoming yellow just before hatching. Larvae are yellow with brown head capsules and are up to 7 mm long. Adults are shiny, dark brown to black, or sometimes black with brown mottling. They are 2-3 mm long and somewhat oval.

Brachypterolus pulicarius a. larva; b. adult (a,b Daniel K. MacKinnon, Colorado State University); c. adults (Susan Turner, British Columbia Ministry of Forests)(a-c bugwood.org)

LIFE CYCLE: Adults emerge in late spring and feed on young toadflax shoot tips. Females lay eggs singly into unopened toadflax buds, just beneath the folded petals. Larvae feed on pollen, anthers, ovaries, and immature seeds. They develop through three instars and drop to the soil in fall to overwinter as pupae in soil or plant litter. There is one generation per year.

DAMAGE: Adult feeding can delay flowering and reduce the number of healthy flowers (and thus seeds). Larval feeding is generally more significant, reducing seed output by more than 75% in attacked flowers. Decreasing seed output does not kill existing plants but can help reduce the rate of toadflax spread.

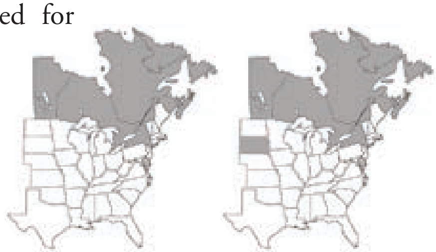
PREFERRED HABITAT: This flower beetle is well adapted to a variety of environmental conditions and can be found throughout the majority of toadflax infestations in North America.

RELEASE HISTORY: This species was initially an unintentional introduction documented on yellow toadflax in NY (US) in 1919. It spread naturally and via intentional redistributions throughout the US on both yellow and Dalmatian toadflax. It was first recorded on Dalmatian and yellow toadflax as an accidental introduction in western Canada in 1950. One population found feeding exclusively on Dalmatian in Canada was subsequently redistributed to the western US on Dalmatian toadflax (1992) and yellow toadflax (1997). The different groups of *B. pulicarius* in the US now overlap. Because they are not genetically different and are likely moving between the two weed species on their own, they can no longer be differentiated.

CURRENT STATUS: Attacks both Dalmatian and yellow toadflax in North America. It was initially believed different "strains" of *B. pulicarius* had evolved sufficiently to be suited differently to yellow and Dalmatian toadflax. Recent genetic studies have since found no evidence to support this. *Brachypterolus pulicarius* prefers and performs better on yellow toadflax, even for individuals collected from Dalmatian toadflax. Its use of Dalmatian toadflax remains incidental in both the US and Canada. Though it is established throughout the US, most information has been recorded from western states not covered in this guide. On Dalmatian in the western US, abundance is variable. High densities can stunt plant height, though its overall impact to flowering and seed production is minimal at most sites. The beetle is abundant on yellow toadflax in the western US on which it can delay flowering and reduce seed production by 80-90% at some locations. However, its overall impact is minimal. It is abundant on yellow toadflax in Canada, but its overall impact is limited. It delays flowering and seed production but has not truly changed the scope or prevalence of problems associated with yellow toadflax. It is found sporadically on Dalmatian toadflax in Canada but appears to be too rare to have any major impact on seed production.

REDISTRIBUTION: This beetle is already widespread throughout much of North America. Where necessary, adults can be collected by aspirating, tapping, or sweeping individuals from toadflax flowers. Adults should be collecting during spring when plants are in bud or flowering and transferred to uninfested toadflax patches in groups of 200. Establishment can be monitored by observing adults on toadflax stem tips the following spring. Alternatively, flowers can be dissected to reveal larvae feeding within during late spring and early summer.

NOTES: Competition between *Rhinusa antirrhini* and *B. pulicarius* prevents additive impact in many locations. Though *B. pulicarius* was first an accidental introduction in the US, it is approved for redistribution. It has been redistributed intentionally in both the US and Canada. **It is likely present in many more eastern states in the US than what have been officially documented.**



Dalmatian yellow

Rhinusa antirrhini (Paykull)

Toadflax seed capsule weevil

SYNONYMS: *Gymnetron antirrhini* (Paykull)

DESCRIPTION: Eggs are oval and flattened. Larvae are C-shaped, creamy white with dark brown head capsules, and up to 4 mm long. Adults are gray to black and covered in dense, short hairs. They have a long, curved, and pointed snout and a wide body. Adults collected from yellow toadflax are typically 2.5-3 mm long while those developing on Dalmatian are up to 5 mm long.

Rhinusa antirrhini a. larva in seed capsule; b. adult (a,b Ivo Toševski, CABI); c. adults on flowers (Eric Coombs, Oregon Department of Agriculture, bugwood.org)

LIFE CYCLE: Overwintering adults emerge in late spring and feed on toadflax shoot tips, leaf buds, and young leaves. As toadflax flowers open, adults feed on pollen and flower tissue. Females lay 40-50 eggs singly inside flower ovaries; this oviposition triggers the development of galls of enlarged seed tissue. Larvae feed on seed tissue through three instars. Pupation occurs within seed capsules, with adults emerging in late summer or early fall to overwinter in plant litter. There is one generation per year.

DAMAGE: Adult feeding is typically insignificant. Galls and larval feeding destroy the viability of affected seeds.

PREFERRED HABITAT: The habitat preferences of *R. antirrhini* are unknown. It is distributed throughout most yellow toadflax infestations in North America, indicating it is well adapted to a variety of conditions.

RELEASE HISTORY: This species was initially an unintentional introduction documented on yellow toadflax in the US (MA) in 1909 and in Canada (QC, ON) by 1917. It spread naturally and via intentional redistributions throughout the US and Canada on both yellow and Dalmatian toadflax. An additional strain was intentionally introduced from the former Yugoslavia and released on Dalmatian toadflax in western Canada in 1993 and the western US in 1996.

CURRENT STATUS: Attacks both Dalmatian and yellow toadflax in North America. On Dalmatian, *R. antirrhini* is established largely in western states and provinces not covered in this guide, and its impact on Dalmatian has not been studied. This beetle is well established on yellow toadflax throughout the US. Larval feeding destroys some seeds in attacked capsules, and seed reductions of 85-90% have been reported at some western sites; however, seed reduction is typically much lower and has minimal impacts on plant density. In Canada, the widespread distribution of *R. antirrhini* has yet to lead to satisfactory control of yellow toadflax. It is believed the overall impact of *R. antirrhini* on yellow toadflax is limited, and likely also limited on Dalmatian toadflax.

REDISTRIBUTION: This beetle is already widespread throughout much of North America. Where necessary, adults can be tapped from toadflax foliage during late spring when plants are bolting to flowering and can be transferred to uninfested toadflax patches in groups of 200. Establishment can be monitored by observing adults on toadflax flowers the following spring. Alternatively, seed capsules can be dissected to reveal larvae within them throughout the summer.

NOTES: Competition between *R. antirrhini* and *Brachypterolus pulicarius* prevents additive impact in many locations. Though *R. antirrhini* was first an accidental introduction in the US, it is approved for redistribution within North America. It has been redistributed intentionally in both the US and Canada and **is likely present in many more eastern states in the US than what have been officially documented.**

Four species of *Rhinusa* are currently established on toadflaxes in North America. Adult *R. antirrhini* have more pointed and curved snouts than *R. neta* and are dark grayish-black while *R. neta* are lighter gray to brown. *Rhinusa antirrhini, R. neta,* and *R. linariae* all have short hairs on their bodies while the hairs of *R. linariae* are longer and upright. *Rhinusa antirrhini* and *R. neta* adults attack flowers and shoot tips and larvae attack seeds, *R. linariae* adults attack stems and larvae attack roots, and *R. pilosa* adults and larvae attack stems.

Dalmatian

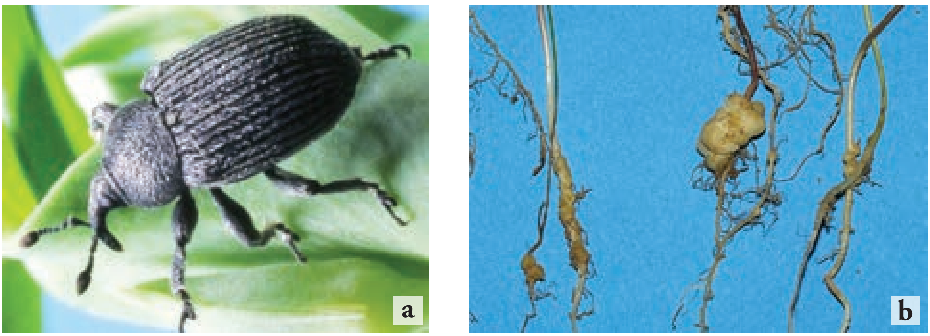
yellow

Rhinusa linariae (Panzer)

Toadflax root-galling weevil

SYNONYMS: *Gymnetron linariae* Panzer

DESCRIPTION: Eggs are pale yellow, smooth surfaced, and pear-shaped. Larvae are C-shaped, creamy white with brown head capsules and up to 4 mm long. Adults are small and black with pronounced, curved snouts. They are covered in dense, short hairs and up to 2.5 mm long.



Rhinusa linariae a. adult (Bob Richard, USDA APHIS PPQ, bugwood.org); b. galls on yellow toadflax roots (Ivo Toševski, CABI)

LIFE CYCLE: Overwintering adults emerge in spring and feed on new toadflax shoots. Females lay eggs singly into pockets chewed into toadflax roots and root crowns, triggering gall formation. Larvae feed on galled root tissue through three instars. Pupation occurs in galls with new adults emerging in mid- to late summer. Adults often feed briefly on toadflax stems and then overwinter in soil or plant litter. There is one generation per year.

DAMAGE: Root galls disrupt nutrient and water transport and may act as a metabolic sink. Adult and larval feeding reduces nutrient reserves which may stunt plants and reduce reproductive output.

PREFERRED HABITAT: The habitat preferences of *R. linariae* in North America are unknown because confirmed established populations are restricted to limited sites in BC in western Canada. In Europe, *R. linariae* does well in grassland habitats, is rarely found in subalpine habitats, and is absent from alpine zones.

RELEASE HISTORY: Individuals from Germany were released on Dalmatian and yellow toadflax in the western US in 1996. Populations from central and southern Europe and southern Russia were released on both Dalmatian and yellow toadflax in western Canada in 1996. After US introductions failed to establish, weevils established in BC in western Canada were redistributed to the western US in 2008 and again in 2015. The 2008 releases failed to establish.

CURRENT STATUS: This weevil attacks only yellow toadflax in North America. It has only been released in western North America, and is currently confirmed established only in CO (US) and BC (Canada). Adult foliage feeding and larval galling are known to reduce plant nutrient reserves. At some locations in BC, populations are reportedly having significant impacts; however, populations in CO and BC are generally limited. Because populations are slow to build, redistributions are made whenever possible.

REDISTRIBUTION: Populations are restricted to CO (US) and BC (CAN) where they are generally too small to redistribute. Where appropriate, adults could be collected from toadflax stems and flowers in spring using a sweep net and aspirator. They can be transferred in groups of 100-200 to uninfested yellow toadflax patches. Establishment can be monitored by observing adults on toadflax foliage the following spring or by digging up roots in summer to observe galls on root tissue.

NOTES: Four species of *Rhinusa* are currently established on toadflaxes in North America. Adult *R. linariae* have a more pointed and curved snout than *R. neta* and are black while *R. neta* are gray to brown. Adult *R. linariae* have short, dense hair on their bodies while *R. pilos*a have longer, upright hairs. *Rhinusa linariae* differs from *R. antirrhini* in its location of attack (adults on stems and larvae on roots compared to *R. antirrhini* adults attacking flowers and larvae attacking seeds).

yellow

Calophasia lunula (Hufnagel)

Toadflax moth

DESCRIPTION: Eggs are pale yellow, strongly ribbed, and slightly conical. Larvae are gray initially but have vivid black and yellow stripes with white spots at the final instar. They can be up 4.6 cm long. Pupae are reddish-brown or golden within green cocoons. Adults are mottled gray-brown with light and dark markings on the wings. They are 1-1.5 cm long with a wingspan of 2.5-3 cm.

Calophasia lunula a. larva, b. cocoon (Gary Piper, Washington State University, bugwood.org); c. adult (a,c Laura Parsons & Mark Schwarzländer, University of Idaho)

LIFE CYCLE: Adults emerge in late spring and feed on nectar of toadflaxes and other plants. Females lay up to 100 eggs singly on toadflax foliage. Larvae feed on young leaves, but will consume older, tougher lower stem leaves as plants become increasingly defoliated. Larvae nearing the end of the fifth and final instar move to the base of toadflax plants and spin cocoons of silk, chewed leaves, and soil that they attach to stem bases, plant litter, or soil. Adults emerge in mid-summer and repeat the process. There are 1-3 generations per year, depending on climate. The final generation overwinters as pupae within cocoons.

DAMAGE: Severe defoliation of seedlings and one-year-old plants can be fatal; older, larger plants can usually rebound from defoliation, although defoliated plants are less vigorous and may produce fewer flowers. Complete defoliation of an entire patch of toadflax by this moth has not been documented.

PREFERRED HABITAT: This species prefers warm, dry sites with coarse-textured soils and sparse toadflax populations. Establishment can be limited in cold climates, at northern latitudes, and at high elevations.

RELEASE HISTORY: Individuals from Switzerland were released in Canada beginning in 1962 on both Dalmatian toadflax (MB, NS, ON, SK) and yellow toadflax (MB, NB, NS, ON). After limited establishment only in ON, individuals from the former Yugoslavia were released in Canada in 1989 (NB,

Calophasia lunula d. larvae and damage (Laura Parsons & Mark Schwarzländer, University of Idaho); e. larval damage (Susan Turner, British Columbia Ministry of Forests)(d,e bugwood.org)

NS). Moths that established from the Swiss release were redistributed from ON to the US in 1968 and released on both Dalmatian and yellow toadflax, but only in western states.

CURRENT STATUS: Attacks both Dalmatian and yellow toadflax in North America. In the US, *C. lunula* is established only in western states not covered in this guide where its populations are limited on both Dalmatian and yellow toadflax (though some localized population explosions occur). At high densities it can lead to patch defoliation, but this does not have a significant impact on attacked plants. In Canada, both source populations established but are only moderately abundant, and the moth's impact is limited. Cold climates and parasitism may also limit populations in some parts of Canada.

REDISTRIBUTION: Adults are easily damaged by sweep netting and difficult to find so this species is best transferred in the larval stage. Larvae can be gently picked from toadflax foliage using flexible forceps in summer through fall and transferred to new sites in groups of 100. Later instars may regurgitate a dark liquid when handled; this is not harmful to the insect or collector. Establishment can be monitored by observing larvae on toadflax foliage throughout the following growing season.

NOTES: **There are reportedly some concerns regarding this species' host specificity; caution should be taken during redistributing to areas with desirable snapdragon species present.**

Dalmatian

yellow

Non-Established Biocontrol Agent

Eteobalea intermediella Riedl & *E. serratella* Treitschke
(Lepidoptera: Cosmopterigidae)

Eteobalea intermediella (Ivo Toševski, CABI)

DESCRIPTION AND LIFE CYCLE: Both species are very similar, differing mainly in their egg appearance, egg-laying behavior, and number of generations per year. Adults are slender, 8-10 mm long, and are black with white and yellow spots. Adults emerge in late spring, and females lay up to 180 eggs in loose strings of 3-8. *Eteobalea intermediella* lays eggs in the lower leaf axils or on the base of yellow toadflax and non-flowering Dalmatian toadflax stems. *Eteobalea serratella* lays eggs at the base of yellow toadflax stems or on the soil surface. at the base of toadflax stems. The pattern on the surface of *E. intermediella* eggs is net-like while the surface of *E. serratella* eggs has a ridged appearance, marked by fine parallel lines or furrows. Larvae bore into the root crown where they feed on tissue inside tunnels they carve and line with silk. Larvae are cream-colored with brown head capsules. They develop through five instars and are up to 12 mm long. *E. serratella* has one generation per year while *E. intermediella* has two; second generation adults emerge in mid-summer. Mature larvae of both species overwinter in roots then pupate in spring inside cocoons within the root crown.

RELEASE HISTORY: *Eteobalea intermediella* from former Yugoslavia and *E. serratella* from Italy were introduced against both Dalmatian and yellow toadflax in the western US in 1996. *Eteobalea intermediella* from Serbia was released on Dalmatian toadflax in western Canada in 1991. *Eteobalea serratella* from Italy was released on yellow toadflax in western Canada and NS beginning in 1992. All introductions are believed to have failed establishment in both the US and Canada.

Unapproved Non-Indigenous Natural Enemy

Rhinusa neta (Germar)
(=*Gymnetron netum*)
(Coleoptera: Curculionidae)

Rhinusa neta (Ivo Toševski, CABI)

DESCRIPTION AND LIFE CYCLE: Overwintering adults emerge in late spring and feed on toadflax shoot tips, leaf buds, and young leaves. Adults are gray or brown with a snout that is somewhat blunt and only slightly curved and not tapered or pointed. Adults are covered in dense, short hairs and are typically 3 mm long. As toadflax flowers open, adults feed on pollen and flower tissue. Females lay 40-50 eggs singly inside flower ovaries. Larvae feed on seed tissue through three instars. Larvae are C-shaped, creamy-white with light brown head capsules, and are up to 4 mm long. Pupation occurs within seed capsules, with adults emerging in late summer or early fall to overwinter in soil or plant litter. There is one generation per year.

HISTORY AND CURRENT STATUS: This beetle was unintentionally introduced and discovered on both Dalmatian and yellow toadflax in the eastern US in 1937 and in Canada by 1957. It has not been intentionally redistributed in either country. In the US, *R. neta* now occurs on both toadflaxes in several eastern states and at least WA in the Northwest, but only in scattered populations. In Canada, it is more widespread on yellow toadflax, but only found sporadically on Dalmatian toadflax. In both countries, *R. neta* prefers yellow toadflax over Dalmatian toadflax. Larval feeding destroys a high proportion of seeds in attacked capsules, though overall attack rates on yellow toadflax are typically limited in the US. Even in Canada, where yellow toadflax attack rates are higher, satisfactory control has yet to be achieved. **Not approved for redistribution in the US.**

Mile-a-minute weed

Persicaria perfoliata (L.) H. Gross

SYNONYMS: Devil's tearthumb, Asiatic tearthumb, devil's-tail tearthumb, giant climbing tearthumb, minuteweed *Polygonum perfoliatum* L.

ORIGIN: Native to Asia, it was introduced to North America in the 1930s, likely unintentionally mixed in with holly seeds.

DESCRIPTION: Herbaceous, annual climbing vine growing from a shallow and fibrous root system. The vines grow up to 20 ft long (6 m) in a single growing season, blanketing trees and surrounding vegetation. Stems are green but turn red with age. Stems, petioles, and the undersides of major leaf veins all have sharp, hook-like barbs that are distinctively curved backwards. Leaves are alternate, triangular, and 1.2-2.8 in long by 0.8-2 in wide (3-7 cm long and 2-5 cm wide). An ocrea (saucer-shaped sheath) up to 0.8 in across (2 cm) surrounds the stem at each leaf node. Flowers are tiny, greenish-white, and inconspicuous. They appear in clusters of 10-15 at vine tips or at the axils of upper leaves.

Mile-a-minute weed a. vines; b. infestation (a,b Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

Mile-a-minute weed c. leaves, barbs, and ocreae; d. flowers (Dalgial); e. fruit and ocrea (c,e Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

Fruits are green and berry-like, turning a deep purple-blue at maturity. Each fruit contains a single shiny black seed (achene).

HABITAT: Mile-a-minute weed prefers low, wet ground and full sun, but it can tolerate partial shade. In North America it is restricted to regions with cold winter temperatures and can be found in flood plains, parks, conservation areas, and orchards and along ditches, forest edges, roadsides, and rights-of-way.

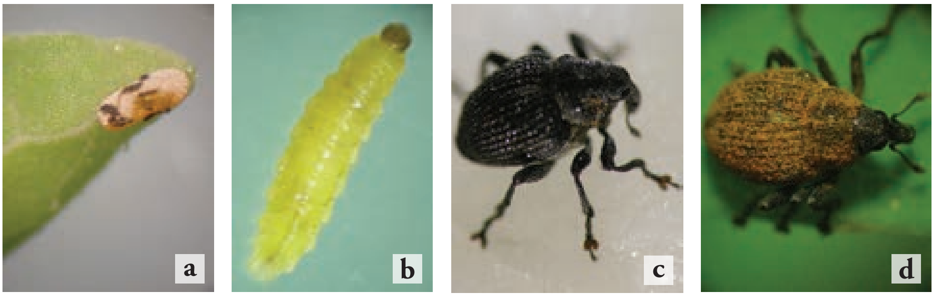
ECOLOGY: This species reproduces by seed only. In North America, most germination is in early spring from March through April. Flowers appear from June to July and fruits are generally produced from June through the first frost, depending on site conditions. Seeds are readily transported by water, humans, birds, deer, and other animals. Seeds may remain viable in the soil for up to 6 years.

BIOLOGICAL CONTROL: *Rhinoncomimus latipes* has been released throughout the northeastern and mid-Atlantic US since 2004 and has significantly impacted this weed by reducing weed density, cover, and seed production. Impacts are greatest under warm, dry conditions and with high plant competition. Additional species are being tested for potential future release into North America. No species are approved in Canada; the weed has not been recorded in Canada.

NOTES: Mile-a-minute weed is used in traditional Chinese medicine for its supposedly diuretic and anti-inflammatory properties.

Rhinoncomimus latipes Korotyaev
Mile-a-minute weevil

DESCRIPTION: Eggs are tan-colored, cylindrical, and covered with thin strips of frass. Larvae are up to 3 mm long and have a creamy-yellow body and brown head capsule. Adults are 2 mm long with longitudinal ridges in their elytra. They are black when they first emerge from pupation, but after a few days of feeding are covered in a rust-colored layer derived from plant sap.



Rhinoncomimus latipes a. egg on leaf tip; b. larva; c. black adult (Kelsey Paras, University of Delaware); d. rust-colored adult (a,b,d Amy Diercks)(a-d bugwood.org)

LIFE CYCLE: Overwintering adults feed on young leaves in early spring, leaving a characteristic "shot-hole" feeding pattern. Eggs are laid singly (40-130 per female) on buds, stems, and the undersides of leaves. Hatching larvae burrow into plant nodes to feed within mile-a-minute stems, developing through three instars. At maturity, larvae drop to the soil to pupate. Total development time from egg to adult is 3-4 weeks. There are 3-4 generations per year. Last generation adults overwinter in the soil or plant litter.

DAMAGE: Larvae mining in stems weakens the plant and stunts growth. Adult feeding at stem tips reduces growth and seed production while defoliation causes leaves and stems to curl and wither. At high densities, the combination of larval and adult feeding kills impacted vines.

PREFERRED HABITAT: This beetle prefers sunny habitats. While it survives in dry and moist conditions, its impact on mile-a-minute weed is highest at warm, dry locations.

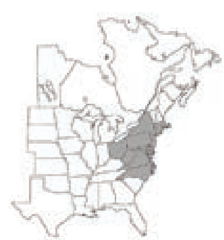
RELEASE HISTORY: Populations sourced from China were released in the northeastern and mid-Atlantic US from 2004 onward (CT, DE, MD, MA, NJ, NY, NC, PA, RI, WV, VA).

Rhinoncomimus latipes e. larva and damage (Amy Diercks); f. adult feeding damage (Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory)

CURRENT STATUS: The overall impact has been substantial, but varies from year to year. Populations have increased considerably and rapidly dispersed from most sites. In NJ, *R. latipes* has already spread to all known weed infestations. This species decreases mile-a-minute weed density, cover, and seed production. The greatest reduction in plant density and biomass occurs in communities with competing vegetation. Impact is highest in warm, dry years and lower in cool, moist years, especially when those conditions occur in spring.

REDISTRIBUTION: This species is best collected in the adult stage from mid-May through August. Adults can be tapped from mile-a-minute vines into collection containers. They can be transferred to new sites in groups of 250-500. Establishment can be monitored by observing adults or their distinctive shot-hole feeding pattern on mile-a-minute foliage the following summer. Alternatively, stems can be dissected throughout the growing season for evidence of larval mining.

NOTES: This beetle was initially misidentified as *Homorosoma chinensis* (Wagner) in the native range of China.



SPURGES

Cypress spurge

Euphorbia crassipes L.

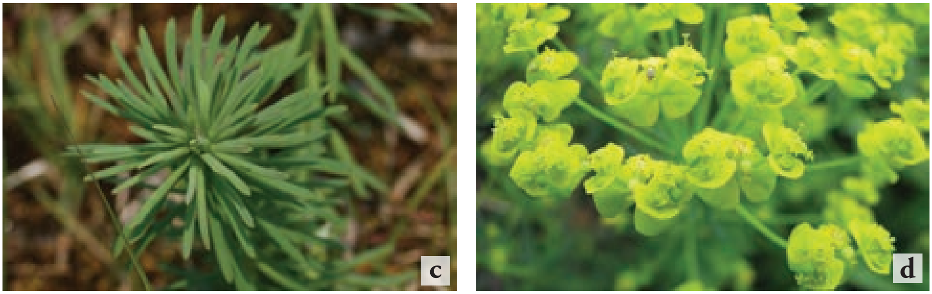
ORIGIN: Native to Eurasia. Likely introduced to North America as an ornamental; recorded present by the late 1850s.

DESCRIPTION: Herbaceous perennial with thickly clustered stems typically growing no higher than 16 in (40 cm) tall. The root system is rhizomatous. Roots are brown, have pinkish buds, and can be 10 ft deep (3 m). Leaves are green, alternate, stalkless, narrow (0.06 to 0.125 in or 1-2 mm wide), and 0.5-1.5 in (1-3 cm) long. They have smooth margins and are clustered tightly on plant stems. Flowers are tiny, lime green, and enclosed by showy, yellow-green bracts. They are arranged in clusters at stem tips. Seed pods contain three smooth, elongated, gray-brown seeds.

HABITAT: Cypress spurge capitalizes on disturbance and can be found in dry to moderately moist meadows, pastures, cemeteries, and gardens and along forest edges, roadsides, and rights-of-way.

ECOLOGY: This species reproduces both by seed and by its spreading root

Cypress spurge a. plant (Danny Steven S.); b. infestation (Leslie J. Mehrhoff, University of Connecticut, bugwood.org)



Cypress spurge c. leaves (Sander van der Molen); d. flowers (Leslie J. Mehrhoff, University of Connecticut, bugwood.org)

system. Root pieces as small as 0.5 in (1 cm) can develop into new plants under the right circumstances. Peak germination is in early spring from March through May with new seedlings usually not flowering the first year. Flowers appear from May to June. A second flowering often occurs in late summer or early fall. Seed pods shatter upon maturation, scattering seeds great distances. Seeds are also readily transported by water, humans, and other animals. Seeds may remain viable in soil for up to 20 years.

BIOLOGICAL CONTROL: Of the five *Aphthona* spp. established on cypress spurge, *A. nigriscutis* is most effective at reducing plant density. *Aphthona flava* is moderately abundanct, and its impact may be significant in combination with other species. *Aphthona lacertosa, A. cyparissiae* and *A. czwalinai* are believed to have limited abundance and impact. Populations of *Hyles euphorbiae, Spurgia capitigena,* and *S. esulae* are limited and have only minor impact, even at high densities. *Lobesia euphorbiana, Oberea erythrocephala,* and *Pegomya euphorbiae* failed to establish on cypress spurge in eastern North America. *Chamaesphecia empiformis* may have established, but additional confirmation is needed.

NOTES: North American cypress spurge is considered a complex of subspecies from multiple introductions. Cypress spurge is very similar to leafy spurge, but it grows shorter and less robust, has much smaller bracts, and narrower and denser leaves than leafy spurge. A toxic, milky latex oozes from damaged stems and leaves.

LEAFY SPURGE
Euphorbia esula L.

ORIGIN: Native to Eurasia. Likely introduced to eastern North America in contaminated ship's ballast and as a seed contaminant in the prairie states and provicnes; recorded as early as 1827.

DESCRIPTION: Herbaceous perennial with thickly clustered stems up to 3 ft tall (90 cm) and roots 9-21 ft deep (3-7 m). The root system is rhizomatous; roots are brown and have pinkish buds. Leaves are alternate, narrow, and 1-3 in long (2.5-7.5 cm). They have smooth margins and a deep midvein. Flowers are tiny, lime green, and enclosed by showy, yellow-green bracts. They are arranged in clusters at stem tips. Seed pods contain three smooth, elongated, gray-brown seeds.

HABITAT: This weed occupies many different habitats and soil types and can be found from grasslands to forests to riparian areas. It is dominant in pastures and abandoned fields, and along roadsides.

ECOLOGY: Leafy spurge reproduces both by seed and by its spreading root system. Root pieces as small as 0.5 in (1 cm) can develop into new plants. Peak

Leafy spurge a. plant (John M. Randall, The Nature Conservancy); b. infestation (Leslie J. Mehrhoff, University of Connecticut)(a,b bugwood.org)

Leafy spurge c. milky latex; d. leaves and stem (K. George Beck & James Sebastian, Colorado State University); e. flowers (c,e Norman E. Rees, USDA ARS)(c-e bugwood.org)

germination is from April through May with new seedlings usually not flowering the first year. Flowers appear from June to July. A second flowering often occurs in late summer or early fall. Seed pods shatter upon maturation, scattering seeds great distances. Seeds are also readily transported by water, humans, and other animals. Seeds may remain viable in the soil for up to eight years.

BIOLOGICAL CONTROL: This weed is most problematic in the Midwest and West, but biocontrol has also proven beneficial on some infestations in the East. Of the five *Aphthona* spp. established on leafy spurge, *A. lacertosa* and *A. nigriscutis* are effective at reducing plant density. *Aphthona flava* is moderately abundant, and its impact may be significant in combination with other species. *Aphthona cyparissiae* and *A. czwalinai* are believed to have limited abundance and impact. *Lobesia euphorbiana* has a moderate impact locally in Canada. Populations of *Hyles euphorbiae, Oberea erythrocephala, P. euphorbiae, Spurgia capitigena,* and *S. esulae* are typically limited, but even at high densities they have only minor impact. *Aphthona abdominalis, Minoa murinata,* and *Pegomya curticornis* failed to establish on leafy spurge in eastern North America. *Chamaesphecia* spp. also likely failed.

NOTES: Leafy spurge is a morphologically variable species believed to represent a complex of forms, species, and hybrids. It is very similar to cypress spurge, but grows taller and more robust, has larger bracts, and much wider leaves that are more sparsely spaced than cypress spurge. A toxic, milky latex oozes from damaged stems and leaves.

Aphthona lacertosa Rosenhauer
Brown-legged leafy spurge flea beetle

DESCRIPTION: Larvae are up to 5 mm long, slender, whitish and with a brown head capsule. Adults are shiny black and 3 mm long. Legs are largely reddish-brown in color. The top of the hind femurs sometimes have dark patches.

Aphthona lacertosa a. adult (Laura Parsons & Mark Schwarzländer, University of Idaho); b. adults and damage (Todd Pfeiffer, Klamath County Weed Control)(a,b bugwood.org)

LIFE CYCLE: Overwintering larvae resume feeding on young roots in early spring as cypress and leafy spurge are resuming growth. Pupation occurs in the soil. Adults are active from early to late summer as spurges bolt, flower, and mature. Each female lays 200-300 eggs into the soil throughout the growing season. Hatching larvae burrow into spurge roots to feed, developing through three instars. There is one generation per year.

DAMAGE: Larvae feed on root hairs and young roots, inhibiting root function and stunting spurge stem growth. Adults feed on leaves and flowers, decreasing photosynthesis and plants' sugar-making ability for root reserves.

PREFERRED HABITAT: This species does best in moderately-dense infestations of cypress and leafy spurge found growing in loamy soils. It can adapt locally to both dry and wet habitats in the US but does better at mesic to moist sites in Canada. It does poorly in soils with too much sand or clay.

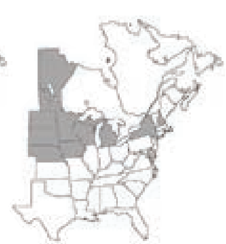
RELEASE HISTORY: Individuals from Austria, Hungary, and the former Yugoslavia were released on leafy spurge in the US beginning in 1993 (IA, MI, MN, NE, NH, NY, ND, RI, SD, WI) and redistributed to cypress spurge starting in 1995 (NH, RI). Many US releases contained a mixture of *Aphthona* species. In Canada, individuals from Hungary and the former Yugoslavia were released on leafy spurge in western provinces in 1987; eastern releases began on leafy spurge in MB in 1991. Beetles initially from Hungary were redistributed from the US and released in MB and western Canada beginning in 1995.

CURRENT STATUS: *Aphthona lacertosa* attacks both cypress and leafy spurge in North America. Its abundance is limited on cypress spurge in RI, US where it and *A. czwalinai* are being replaced by *A. flava* and *A. nigriscutis.* Its density and impact in NH are unknown. This beetle is widespread and abundant on leafy spurge in the US. Along with *A. nigriscutis,* it is significantly reducing leafy spurge density at the local level in most regions, though it is not effective at all sites. In Canada, this beetle is established only on leafy spurge, on which it is reducing plant density at most sites. *Aphthona lacertosa* appears to be displacing *A. czwalinai* at many locations. Resampling efforts are currently underway at initially pure *A. czwalinai* release sites and pure *A. lacertosa* sites throughout Canada for molecular analysis.

REDISTRIBUTION: This species is best collected in the adult stage using a net and aspirator in early summer when plants are bolting. They can be transferred to new sites in groups of 200-300. Establishment can be monitored by observing adults on spurge foliage the following summer during the heat of the day. Keep in mind flea beetles quickly jump away when disturbed. Alternatively, roots can be dissected for evidence of larval feeding from autumn through the following spring. Note that feeding larvae can be extremely difficult to distinguish from other leafy spurge *Aphthona* species.

NOTES: Five species of *Aphthona* are established on cypress and leafy spurge in North America. *Aphthona lacertosa* has lighter colored hind femurs than the other black spurge flea beetle, *A. czwalinai. Aphthona cyparissiae, A. flava,* and *A. nigriscutis* are all brown spurge flea beetles.

cypress



leafy

SPURGES

Aphthona nigriscutis Foudras
Black dot leafy spurge flea beetle

DESCRIPTION: Larvae are 1-6 mm long, slender, whitish (more translucent when young) and with a brown head capsule. Adults are usually just over 3 mm long. They are orangish-brown and typically have a black dot on the back near the leading edge of the wings.

Aphthona nigriscutis a. larva (Neal Spencer, USDA ARS, bugwood.org); b. adult (R. Richard, USDA APHIS)

LIFE CYCLE: Overwintering larvae resume feeding on root hairs in early spring as cypress and leafy spurge are resuming growth. Pupation occurs in the soil. Adults are active from early to late summer as spurges bolt, flower, and mature. Females lay numerous eggs in groups on spurge stems at or just below the soil surface. Hatching larvae burrow into spurge roots to feed, developing through three instars. There is one generation per year.

DAMAGE: Larvae feed on root hairs and young roots, inhibiting root function and stunting spurge stem growth. Adults feed on leaves and flowers, decreasing photosynthesis and plants' sugar-making ability for root reserves.

PREFERRED HABITAT: This species prefers relatively sparse cypress and leafy spurge patches at dry sites with sandier soil. It does poorly in soils with too much clay.

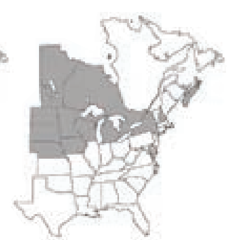
RELEASE HISTORY: In Canada, individuals from Hungary were released on leafy spurge beginning in 1983 (MB, NS, ON) and on cypress spurge in ON starting in 1986. After establishment in Canada, beetles were redistributed to leafy spurge in the US beginning in 1989 (IA, MI, MN, NE, NH, NY, ND, RI, SD, WI) and redistributed to cypress spurge in 1995 (NH, RI). Many US releases contained a mixture of *Aphthona* species.

CURRENT STATUS: *Aphthona nigriscutis* attacks both cypress and leafy spurge in North America. This species is considered abundant on cypress spurge in RI, US where, along with *A. flava*, it is replacing *A. lacertosa* and *A. czwalinai*. Under ideal conditions, stem density may decrease quickly, but unattacked roots help plants recover; numerous years are typically required for this biocontrol agent to decrease cypress spurge populations permanently. Its density and impact in NH are unknown. *Aphthona nigriscutis* is widespread and abundant on leafy spurge in the US. Along with *A. lacertosa*, it is significantly reducing plant density at the local level in most regions, though it is not effective at all sites. Impact may be hindered by a bacterium which causes high mortality in males, resulting in female-biased populations. In Canada, *A. nigriscutis* abundance and impact are variable. It helps control cypress spurge in the immediate vicinity of release sites at dry, open locations. It is extremely effective at reducing or removing leafy spurge in open, warm, very dry habitats with lighter soils. Populations are low or absent at moist, sheltered sites on heavy soil.

REDISTRIBUTION: This species is best collected in the adult stage using a net and aspirator in mid-summer when plants flower. They can be transferred to new sites in groups of 200-300. Establishment can be monitored by observing adults on spurge foliage the following summer during the heat of the day. Keep in mind flea beetles quickly jump away when disturbed. Alternatively, roots can be dissected for evidence of larval feeding from autumn through the following spring. Note that feeding larvae can be very difficult to distinguish from other spurge *Aphthona* species.

NOTES: Five species of *Aphthona* are established on cypress and leafy spurge in North America. The other brown spurge flea beetles (*A. cyparissiae* and *A. flava*) typically do not have the black spot on the back as does *A. nigriscutis*. *Aphthona flava* is also usually more orange in color than *A. nigriscutis*, though coloration differences among brown spurge flea beetles are often unreliable. *Aphthona czwalinai* and *A. lacertosa* are black spurge flea beetles. Spillover feeding by *A. nigriscutis* was observed on the native *Euphorbia robusta*; as leafy spurge density declined, so did feeding on *E. robusta*, and *E. robusta* populations increased.

cypress



leafy

Aphthona flava Guillebeau
Copper leafy spurge flea beetle

DESCRIPTION: Larvae are 1-6 mm long, slender, whitish (more translucent when young) and with a brown head capsule. Adults are orangish-copper in color and 3.5 mm long. Females are slightly larger than males.

Aphthona flava a. larva (Neal Spencer, USDA ARS); b. adult (USDA APHIS PPQ); c. adults and damage (Norman E. Rees, USDA ARS)(a-c bugwood.org)

LIFE CYCLE: Overwintering larvae resume feeding on root hairs in early spring as cypress and leafy spurge are resuming growth. Pupation occurs in the soil. Adults are active from early summer to early fall as spurges bolt, flower, and mature. Females lay numerous eggs in groups on spurge stems at or just below the soil surface. Hatching larvae burrow into spurge roots to feed, developing through three instars. There is one generation per year.

DAMAGE: Larvae feed on root hairs and young roots, inhibiting root function and stunting spurge stem growth. Adults feed on leaves and flowers, decreasing photosynthesis and plants' sugar-making ability for root reserves.

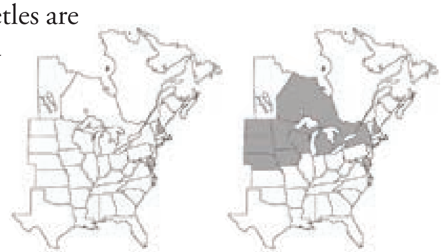
PREFERRED HABITAT: This species does best in moderately-dense infestations of leafy spurge found on more mesic, dry sites in alluvial soils above flood lines and light shade (US) and at mesic, dry sites with warm temperatures (CAN). It does poorly in soils with too much sand or clay. It is probably less likely to survive low temperatures than other *Aphthona* spp.

RELEASE HISTORY: Beetles from Hungary and Italy were released on leafy spurge in the western US beginning in 1985; eastern US releases began in 1986 (IA, MI, MN, NE, NH, NY, ND, RI, SD, WI). Established beetles were redistributed to cypress spurge in 1995 (NH, RI). Many US releases contained a mixture of *Aphthona* species. In Canada, indiviuals from Hungary and Italy were released on leafy spurge starting in 1982 (MB, NS, ON) and on cypress spurge in 1982 (NS, ON). Beetles established on leafy spurge were redistributed to cypress spurge within BC in western Canada in 2011.

CURRENT STATUS: *Aphthona flava* attacks both cypress and leafy spurge in North America. This species is considered abundant on cypress spurge in RI, US where, along with *A. nigriscutis*, it is replacing *A. lacertosa* and *A. czwalinai*. Under ideal conditions, stem density may decrease quickly, but unattacked roots help plants recover; numerous years are typically required for this biocontrol agent to decrease cypress spurge populations permanently. Its density and impact in NH are unknown. *Aphthona flava* is considered widespread on leafy spurge in the US, but overall it is much less abundant than other *Aphthona* spp. It persists at fairly low levels with little noticeable impact on infestations. In Canada, this beetle is only established on cypress spurge in western Canada where its abundance and impact are unknown. On leafy spurge, this species is moderately abundant in ON and western Canada. Leafy spurge density has declined where populations of *A. flava* are high; however, this is typically at sites that have been grazed by sheep and where *A. nigriscutis* is also present.

REDISTRIBUTION: This beetle is best collected in the adult stage using a net and aspirator in late summer when plants are flowering and beginning to mature. They can be transferred to new sites in groups of 200-300. Establishment can be monitored by observing adults on spurge foliage the following summer during the heat of the day. Keep in mind flea beetles quickly jump away when disturbed. Alternatively, roots can be dissected for evidence of larval feeding from autumn through the following spring. Note that feeding larvae can be extremely difficult to distinguish from other spurge *Aphthona* species.

NOTES: Five species of *Aphthona* are established on cypress and leafy spurge in North America. *Aphthona flava* is typically more orange than the other two brown spurge flea beetles, *A. cyparissiae* and *A. nigriscutis. Aphthona flava* also does not have the black spot on the back that *A. nigriscutis* has. However, coloration differences among brown spurge flea beetles are often unreliable. *Aphthona czwalinai* and *A. lacertosa* are black spurge flea beetles.



cypress leafy

Lobesia euphorbiana (Freyer)
Spurge leaf tying moth

DESCRIPTION: Eggs are translucent yellow and round. Larvae have brown head capsules and segmented bodies up to 12 mm long. Young larvae are pale yellowish-green, turning nearly black with maturity. Pupae are pale green initially, turning brown with time. Adults are mottled with yellow, brown, and rust tones and light-colored legs and antennae. Adults can be 9-11 mm long with wingspans up to 14 mm.

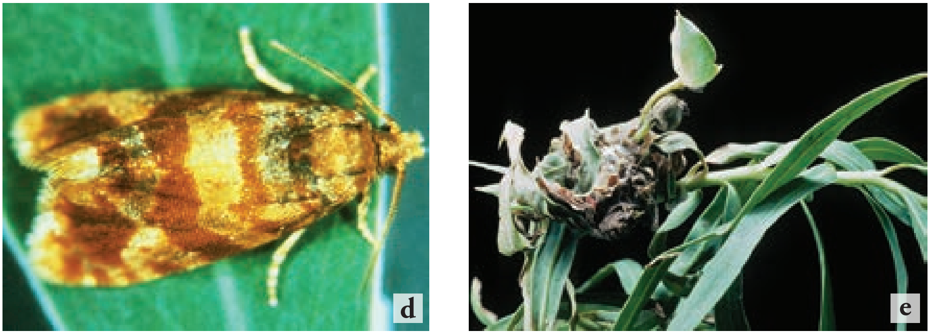
Lobesia euphorbiana a. larva; b. cocoon; c. pupa (a-c Laura Parsons, University of Idaho, bugwood.org)

LIFE CYCLE: Adults emerge in spring as spurge is bolting and flowering. Females lay eggs immediately (an average of 55 eggs each) and singly on the undersides of leaves. Hatching larvae move towards terminal leaf tips and tightly tie leaves with silky webbing. They feed on buds within ties, developing through four instars typically, but occasionally five when food is scarce. Prior to pupation, larvae move to leaf tips where they spin thick webs. Second generation adults emerge from mid- to late summer and repeat the process. Second generation pupae overwinter in plant litter within folded leaves. There are two generations per year, with three possible in suitable climates.

DAMAGE: Larval feeding of buds prevents flowering, and repeated heavy attack may eventually kill plants. When larvae vacate leaf ties, the sites often receive secondary attack from thrips and aphids.

PREFERRED HABITAT: This species does best at mesic sites where plants have high nutrient quality. Complete development requires high temperatures so sites that are warm to hot over summer are preferred. This moth often inhabits riparian areas as well as fringe forested areas, so shade is tolerated.

RELEASE HISTORY: Moths from Italy were released in Canada on leafy spurge in western provinces beginning in 1983; eastern releases began in 1987 (MB,



Lobesia euphorbiana d. adult (CABI, previously IIBC); e. damage (Laura Parsons, University of Idaho, bugwood.org)

NS, ON). Established individuals were redistributed to cypress spurge in ON in 1991, though this redistribution failed.

CURRENT STATUS: *Lobesia euphorbiana* is established only on leafy spurge and only in Canada where populations are dispersing well from release sites. Its impact is moderate and fluctuates with leafy spurge density and vigor. Repeated heavy attack kills target plants at some locations.

REDISTRIBUTION: The best stage for redistribution is larvae in leaf ties. In early to mid-summer, clip below infested leaves. Transfer material to new sites as soon as possible and ensure infested leaves touch the foliage of plants at the new sites. Establishment can be monitored the following season by observing leaf ties on new spurge foliage throughout the growing season.

NOTES: Gall terminals made by *Spurgia esulae* will occasionally be used by *L. euphorbiana*. **This species is not approved for release in the US.**

leafy

Aphthona cyparissiae (Koch)
Brown dot leafy spurge flea beetle

DESCRIPTION: Larvae are 1-5 mm long and have a white body and yellow head with a thick head capsule. Adults are usually just over 3 mm long. They are a light reddish-brown color and oval in shape.

Aphthona cyparissiae a. pupa (Neal Spencer, USDA ARS, bugwood.org); b. adult (R. Richard, USDA APHIS)

LIFE CYCLE: Overwintering larvae resume feeding on young roots in early spring as cypress and leafy spurge are resuming growth. Pupation occurs in the soil. Adults are active from early summer to late summer as spurges bolt, flower, and mature. Females lay numerous eggs into the soil throughout the growing season. Hatching larvae burrow into spurge roots to feed, developing through three instars. There is one generation per year.

DAMAGE: Larvae feed on root hairs and young roots, inhibiting root function and stunting spurge stem growth. Adults feed on leaves and flowers, decreasing photosynthesis and plants' sugar-making ability for root reserves.

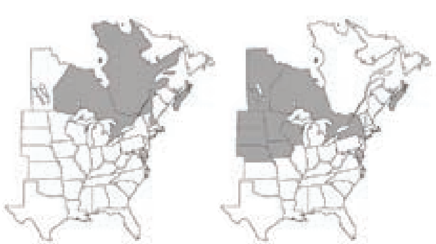
PREFERRED HABITAT: This beetle does best in moderately-dense infestations of cypress and leafy spurge found on dry to semi-moist sites. It does poorly in soils with too much clay.

RELEASE HISTORY: In the US, beetles from Austria, Hungary, Italy, and Switzerland were released on leafy spurge beginning in 1986 (IA, MN, NE, NH, NY, ND, RI, SD, WI) and redistributed to cypress spurge starting in 1995 (NH, RI). Many US releases contained a mixture of *Aphthona* species. In Canada, beetles from Austria, Hungary, and Switzerland were released on leafy spurge beginning in 1982 (MB, NS, ON, SK) and on cypress spurge starting in 1982 (ON, QC).

CURRENT STATUS: *Aphthona cyparissiae* attacks both cypress and leafy spurge in North America. In the US, it is present on cypress spurge in two states and abundant in at least one (RI). It is well established at a few leafy spurge release sites but is overall much less abundant on leafy spurge than other *Aphthona* spp. On both spurge species, *A. cyparissiae* populations are highest at dry, mesic sites with sandy loam soils. Under these conditions, stem density may decrease quickly, but unattacked roots help plants recover. Numerous years under the right conditions are required for this biocontrol agent to decrease spurge populations permanently. Damage is typically greatest in combination with other *Aphthona* spp. In Canada, high populations of *A. cyparissiae* effectively control cypress and leafy spurge at dry, open sites, but insect densities are too low and ineffective elsewhere.

REDISTRIBUTION: This species is best collected in the adult stage using a net and aspirator in mid-summer when plants are flowering. They can be transferred to new sites in groups of 200-300. Establishment can be monitored by observing adults on spurge foliage the following summer during the heat of the day. Keep in mind flea beetles quickly jump away when disturbed. Alternatively, roots can be dissected for evidence of larval feeding from autumn through the following spring. Note that feeding larvae can be extremely difficult to distinguish from other spurge *Aphthona* species.

NOTES: Five species of *Aphthona* are established on cypress and leafy spurge in North America. *Aphthona nigriscutis* typically has a black spot on the back while *A. flava* is generally more orange in color than *A. cyparissiae*. However, coloration differences among brown spurge flea beetles are often unreliable. *Aphthona czwalinai* and *A. lacertosa* are black spurge flea beetles.



cypress leafy

Aphthona czwalinai (Weise)

Black leafy spurge flea beetle

DESCRIPTION: Larvae are up to 5 mm long, slender, whitish and with a brown head capsule. Adults are shiny black. Middle and front legs are reddish-brown while the entire surfaces of the hind femurs are dark. Males are just under 3 mm long, while females are usually just over 3 mm.

Aphthona czwalinai a. pupa (Neal Spencer, USDA ARS, bugwood.org); b. adult (R. Richard, USDA APHIS)

LIFE CYCLE: Overwintering larvae resume feeding on young roots in early spring as cypress and leafy spurge are resuming growth. Pupation occurs in the soil. Adults are active from early summer to late summer as spurges bolt, flower, and mature. Females lay numerous eggs in the soil throughout the growing season. Hatching larvae burrow into spurge roots to feed, developing through three instars. There is one generation per year.

DAMAGE: Larvae feed on root hairs and young roots, inhibiting root function and stunting spurge stem growth. Adults feed on leaves and flowers, decreasing photosynthesis and plants' sugar-making ability for root reserves.

PREFERRED HABITAT: This species does best in moderately-dense infestations of cypress and leafy spurge found on more mesic sites. It does poorly in soils with too much sand or clay.

RELEASE HISTORY: Beetles from Austria and Hungary were released on leafy spurge in the western US beginning in 1987; eastern releases began in 1989 (IA, MI, MN, NE, NH, ND, RI, SD, WI). Established beetles were redistributed to cypress spurge in 1995 (NH, RI). Many US releases contained a mixture of *Aphthona* species. In Canada, beetles from Austria were released on leafy spurge in western provinces starting in 1985; eastern releases began on leafy spurge in

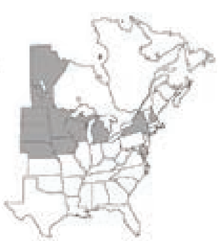
1986 (MB, ON) and on cypress spurge in 1987 (ON). Established indviduals initially from Austria and Hungary were redistributed from the US and released in MB and western Canada beginning in 1995.

CURRENT STATUS: *Aphthona czwalinai* attacks both cypress and leafy spurge in North America. In the US, it is established on both cypress and leafy spurge, though populations are very limited on cypress spurge. For many years it was believed that control of leafy spurge on the local level in the US was achieved primarily by *A. nigriscutis, A. czwalinai* and *A. lacertosa*. *Aphthona czwalinai* was thought to have been a major component in the early years of the leafy spurge biocontrol program, until it was discovered that most of what was being called *A. czwalinai* was in fact *A. lacertosa*. It was subsequently considered insignificant, until large populations were recently found in ND where this beetle does best at mesic sites. In Canada, *A. czwalinai* is established only on leafy spurge, and its distribution is limited. Release sites now appear to be dominated by *A. lacertosa.* Resampling efforts are currently underway at initially pure *A. czwalinai* release sites and pure *A. lacertosa* sites throughout Canada for molecular analysis.

REDISTRIBUTION: This beetle is best collected in the adult stage using a net and aspirator in mid-summer when plants are flowering. They can be transferred to new sites in groups of 200-300. Establishment can be monitored by observing adults on spurge foliage the following summer during the heat of the day. Keep in mind flea beetles quickly jump away when disturbed. Alternatively, roots can be dissected for evidence of larval feeding from autumn through the following spring. Note that feeding larvae can be extremely difficult to distinguish from other spurge *Aphthona* species.

NOTES: Five species of *Aphthona* are established on cypress and leafy spurge in North America. *Aphthona czwalinai* has solid dark hind femurs compared to the other black spurge flea beetle, *A. lacertosa. Aphthona cyparissiae, A. flava,* and *A. nigriscutis* are all brown spurge flea beetles. This species is occasionally referred to by the spelling of *A. czwalinae*.

cypress



leafy

Hyles euphorbiae (L.)
Leafy spurge hawk moth

DESCRIPTION: Larvae are up to 10 cm long. They change color upon maturation going from dark green, to brown and yellow longitudinally striped, to green with white spots, to red, black, yellow, and white with a horn at the back end. Larvae contain leafy spurge toxin and are poisonous. Adults have wingspans up to 5 cm and are white, pink, and brown.

Hyles euphorbiae a. larva; b. pupa (Whitney Cranshaw, Colorado State University, bugwood.org); c. adult (a,c R. Richard, USDA ARS)

LIFE CYCLE: There are up to two generations per year. Adults emerge in early to mid-summer when cypress and leafy spurge are bolting/flowering. Females lay 70-150 eggs in clumps on leaves and bracts. Hatching larvae feed on these parts as cypress and leafy spurge are flowering. Larvae feed through five instars, and then pupation occurs in the soil. Next generation adults emerge in late summer and repeat the cycle. New hatching larvae move to the soil to pupate; pupae overwinter.

DAMAGE: Larval feeding defoliates spurge, though this often does not kill the attacked plants.

PREFERRED HABITAT: This species does best in thick spurge infestations growing in open areas near trees. Pupae are heavily preyed upon so sites with low populations of rodents, ants, etc. are preferred.

RELEASE HISTORY: Moths from France, Germany and Switzerland were released in Canada on cypress spurge beginning in 1965 (ON) and on leafy spurge in 1966 (MB, ON). Established populations were redistributed to leafy spurge in the western US starting in 1966; eastern releases began in 1974 (MD, MN, NE, NY, ND, SD). The same Canadian source material was released on cypress spurge starting in 1976 (MD, NY, VA) and on the related invasive

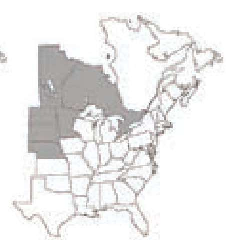
Euphorbia oblongata in the western US (failed) in 1974. Moths from Hungary were then released on leafy spurge in 1980 in the western US (ND, SD 1985).

CURRENT STATUS: *Hyles euphorbia* attacks both cypress and leafy spurge in North America. It is established on the fertile tetraploid form of cypress spurge in NY where initially high densities of this moth have since decreased due to high levels of predation. Even where high densities have resulted in total cypress spurge defoliation, impact is insignificant as plant populations can tolerate yearly defoliation. Both source populations established on leafy spurge in the US where they have since intermixed and can no longer be differentiated. Though moth densities may be locally high in some years, disease and predation typically prevent densities from developing to levels substantial enough to impact leafy spurge populations in some areas. Even where high densities have resulted in total plant defoliation, impact has been insignificant as this does not kill plants. In Canada, *H. euphorbia* abundance is typically limited to moderate on both cypress and leafy spurge due to predation. Even when moth populations are high, plants recover from defoliation. It has limited biocontrol value alone, but may stress the weeds when in combination with other biocontrol agents.

REDISTRIBUTION: Though this species can be collected in various stages, larval is the preferred stage to transport. Both generations are suitable for collection, either in spring/early summer as spurges are beginning to flower, or late summer/fall as spurges mature. Any instar can be collected, though larger, mature larvae are most conspicuous and easy to find. Gently remove larvae by hand or with forceps, and place them directly in a waiting container. Larvae may regurgitate liquid as a defense measure; this is not harmful to the insect or collector. They can be transferred in groups of 50-100 to uninfested spurge patches. Establishment can be monitored by observing adults or larvae on cypress or leafy spurge foliage throughout the following growing season.

NOTES: This biocontrol agent resembles native hawk moth species but is more active during daytime, while native hawk moths are more nocturnal.

cypress



leafy

Oberea erythrocephala (Schrank)
Red-headed leafy spurge stem borer

DESCRIPTION: Mature larvae are up to 20 mm long, slender, and white with a yellowish head and a head capsule. Bodies are obviously segmented with inflated segments. Adults are slender and 10-12 mm long with long, dark antennae, red heads, and black eyes. Adult bodies are dark grey above and lighter grey with reddish markings below. Their legs are yellowish-brown.

Oberea erythrocephala a. larva in root (R. Richard, USDA ARS); b. adult (Mark Schwarzländer, University of Idaho); c. damage (Eric Coombs, Oregon Department of Agriculture)(a-c bugwood.org)

LIFE CYCLE: Adults emerge in early to mid-summer and feed on spurge leaves and flowers. Females girdle a spurge stem, chew a hole, and deposit a single egg (up to 40 in a lifetime). Hatching larvae mine down the stem until reaching the root crown and nearby lateral roots. Larvae overwinter and pupate within the root crown in spring. Adults chew through remaining plant tissue and emerge from the soil. There is one generation per year in Europe, though two years may be required for full development in colder parts of North America.

DAMAGE: Adult feeding is insignificant. Larval mining kills shoots and reduces root reserves.

PREFERRED HABITAT: This species prefers mesic sites with tree cover. It is believed to do well in riparian areas and has been shown to survive winter temperatures below freezing.

RELEASE HISTORY: Individuals from Italy were released on leafy spurge in the western US in 1980. After these failed to establish, new individuals were sourced from Austria, Hungary and Italy and released on leafy spurge in the western US in 1982; eastern releases began in 1985 (IA, MI, MN, NE, NH, NY, ND, RI, SD, WI). In Canada, individuals from Switzerland were released on leafy spurge in eastern provinces starting in 1979 (MB, ON from 1981) and on cypress spurge in MB and ON beginning in 1986.

CURRENT STATUS: *Oberea erythrocephala* attacks only leafy spurge in North America. In the US, it was initially believed to have the potential to greatly depress leafy spurge populations, but beetle densities have remained too low to impart significant impact in the field. At some infestations, it may cause declines in larger plants. In Canada, *O. erythrocephala* is established only in the western province of AB where it is considered rare. At high densities, small plants can be killed, however field populations are too low to have a significant impact in Canada.

REDISTRIBUTION: Adults should be collected in early summer as spurge flowers. They often fly or drop when disturbed, so sweep netting is less efficient than for other species. Alternatively, the beetles can be collected by hand or with soft forceps and placed directly in containers. Collect during the heat of the day. They can be transferred to new sites in groups of 50-100. Establishment can be monitored by observing adults on spurge foliage the following summer during the heat of the day or by dissecting stems/root crowns for mining larvae from summer through the following spring.

NOTES: This species may attack only specific biotypes of leafy spurge, thus limiting its efficacy in many areas.

leafy

Pegomya curticornis (Stein) & *P. euphorbiae* (Kieffer)

Leafy spurge gall flies

SYNONYMS: *Pegomya argyrocephala* (Meigen)

DESCRIPTION: These two species are virtually indistinguishable. Larvae are light gray maggots. Adults are dark colored with maroon eyes and scattered black hairs on the head and thorax. Wings are dark and translucent and span up to 6 mm.

Pegomya euphorbiae adult (André Gassmann, CABI-Switzerland)

LIFE CYCLE: Adults emerge in early spring and lay eggs in leaf buds of new shoots after spurges have resumed growing. Hatching larvae tunnel down young shoots, which have less toxic milky latex than older shoots. Larvae develop through three instars. Larval vascular feeding induces the formation of galls in subterranean stems and in spurge roots. They overwinter as pupae within galls. There is one generation per year.

DAMAGE: Mined and galled cypress and leafy spurge stems wilt and eventually die.

PREFERRED HABITAT: Specific habitat requirements for both species are unknown.

RELEASE HISTORY: *Pegomya curticornis* and *P. euphorbiae* were collected from Hungary and released on leafy spurge in MB and western Canadian provinces in 1988. *Pegomya euphorbiae* from the same source was also released on leafy spurge in ON in 1990 and on cypress spurge in ON in 1989.

CURRENT STATUS: *Pegomya euphorbiae* is thought to be established only on leafy spurge in North America. It was initially believed that all introductions of *Pegomya* spp. failed to established on both cypress and leafy spurge in Canada. In 2014, however, establishment was confirmed at the original leafy spurge release sites in MB and SK. While there is still some uncertainty, it appears the established species is *P. euphorbiae*. Its abundance and impact on leafy spurge is unknown. It is still believed that *P. euphorbiae* failed to establish on cypress spurge in Canada.

REDISTRIBUTION: Populations are likely too limited to field collect, so releases should be made using laboratory colonies when available. In the future, should *Pegomya* spp. be further established, field redistributions can be done by gathering galled stems and roots in summer as spurges are actively growing and flowering. Bunch gathered plant material and transfer to new sites as soon as possible, and place them upright to help avoid predation. Establishment can be monitored the following growing season by cutting stems and observing mining larvae and galls.

NOTES: These two species were previously lumped together under the name *Pegomya argyrocephala*. ***Pegomya*** **spp. were approved in both the US and Canada but were released only in Canada.**

P. euphorbiae
leafy

Spurgia capitigena (Bremi) & *S. esulae* Gagné

Leafy spurge tip gall midges

SYNONYMS: *Bayeria capitigena* Bremi

DESCRIPTION: Both “species” are virtually indistinguishable (see Notes). Eggs are orange and cylindrical. Larvae are orange and 1-2 mm long. Adults are dark gray with reddish abdomens and tiny, dark heads. Adults are just under 2 mm long; males are slightly smaller than females. Males have forceps on the end of the abdomen while females have an exposed ovipositor.

Spurgia esulae a. eggs (L.L. Berry); b. larvae and pupae in galls (Norman Rees, USDA ARS); c. adult (USDA APHIS PPQ Archive)(a-c bugwood.org)

LIFE CYCLE: Adults emerge in spring when cypress and leafy spurge are resuming growth. They live only a number of hours. Eggs are laid in groups of 20+ among leaves on spurge growing tips. Hatching larvae feed on tips (through three instars), causing galls to form. Pupation occurs in silken cocoons within galls; adults emerge and repeat the cycle. There are two generations/year in cold climates, and 3-5 in warmer areas if new shoots are available. Last generation larvae overwinter and pupate in the soil.

DAMAGE: Larvae attacking spurge growing tips destroy the shoots’ ability to flower and produce seeds. Shoots eventually die and are replaced by new stems that are attacked by the next generation of midges.

PREFERRED HABITAT: These species prefer dense spurge infestations growing on south-facing slopes in cool climates, and can reportedly tolerate some shading.

RELEASE HISTORY: These two species were previously lumped together under the name *Bayeria capitigena.* After their introduction, *B. capitigena* was transferred to the genus *Spurgia* and split into two species. Consequently, the release history is convoluted. What is now *S. esulae* was introduced from Italy and released on leafy spurge in the US beginning in 1985 (IA, MI, MN, NE, NH, NY, ND, RI, SD, WI). These were redistributed to cypress spurge in the eastern US in 1995 (NH, RI). *Spurgia capitigena* is believed to have been a contaminant of one shipment of *S. esulae* released on leafy spurge in ND in 1986. Both species were redistributed to leafy spurge in Canada starting in 1987 (MB, NS, ON). Following establishment, both species were redistributed to cypress spurge in NS in 1990, and *S. capitigena* alone was also redistributed to cypress spurge in ON and QC in 1990. *Spurgia capitigena* from France was intentionally released on leafy spurge in ND, US from 2001-2002.

CURRENT STATUS: *Spurgia esulae* attacks both cypress and leafy spurge in North America. In the US, densities are generally low. Even where abundant, galls form after flowering, so its overall impact is insignificant. *Spurgia capitigena* (from both sources) is established only on leafy spurge in ND where its impact is largely unknown but assumed to be negligible. In Canada, *S. capitigena* is established on both cypress and leafy spurge in ON; to date *S. esulae* is confirmed established only on leafy spurge. Where established, galls from both species prevent flower formation and seed production, though their overall impact appears negligible.

REDISTRIBUTION: Midges are most safely collected by gathering galls infested with both larvae and pupae. The first generation is often best synchronized with its spurge host, so collect from mid-May to mid-June (depending on location) prior to spurge flowering. Clip at least 6 in (15 cm) below galls, bunch the clipped stems, and wrap the bottoms in damp paper towels. Transfer these to new sites as soon as possible, and place them upright to help avoid predation. Establishment can be monitored by observing galls on new spurge shoot tips throughout the following growing season.

NOTES: More recent studies with these midges revealed no evidence for two species. However, a revision of this group has not been published, so the two separate names are retained as valid at the time of publication of this field guide.

S. capitigena
cypress

S. capitigena
leafy

S. esula
cypress

S. esula
leafy

Non-Established Biocontrol Agents

Aphthona abdominalis Duftschmidt
(Coleoptera: Chrysomelidae)

Aphthona abdominalis adult (R. Richard, USDA APHIS, bugwood.org)

DESCRIPTION AND LIFE CYCLE: In Europe, overwintering adults emerge from plant litter in late spring and feed on leafy spurge foliage during bolting or flowering. Adults are 2 mm long and grayish-brown with a reddish-yellow head and transparent outer wings. Females lay eggs at or just below the soil surface. Hatching larvae burrow into spurge roots to feed, developing through three instars. Larvae are white with a yellow head and prominent head capsule and are 1-3 mm long. Pupation occurs in the soil near roots. There are up to 4 generations per year.

RELEASE HISTORY: Beetles from Italy were released on leafy spurge in ND and the western US from 1993, but failed to establish. **Not released in Canada.**

Chamaesphecia spp.
(Lepidoptera: Sesiidae)

Chamaesphecia crassicornis adult (R. Richard, USDA APHIS, bugwood.org)

DESCRIPTION AND LIFE CYCLE: Three *Chamaephecia* spp. have been released. All three have white larvae up to 15 mm long. In Europe, overwintering larvae resume feeding in root tunnels in early spring. They mine upwards in the plant stem, pupating within. Adults emerge from late spring and lay eggs on spurge plants. Adults are dark brown with yellow-white bands. Bodies are typically 10-14 mm long; wingspans are 16-22 mm. Each wing is brown with yellow markings and a few transparent windows with dark margins. Body and wing tips are fringed. Hatching larvae burrow into the stem, mine down, and feed on roots. There is one generation per year.

RELEASE HISTORY: *Chamaesphecia empiformis* from Europe was released on cypress spurge in ON, CAN (1970, 1989) and the western US (1975).

Non-Established Biocontrol Agents

Chamaesphecia tenthrediniformis from Europe was released on leafy spurge in ON (CAN) in 1971 and in the western US beginning in 1975. Starting in 1991, *C. crassicornis* and *C. hungarica* from Europe were released on leafy spurge, but only in western states and provinces not covered in this guide. It ws initially believed that all introductions of all species failed; however, what is believed to be an individual *C. empiformis* was photographed on cypress spurge in ON in 2015. Because the species in question could be *C. tenthridiniformis*, additional confirmation is needed before declaring either species established in North America. ***Chamaesphecia astatiformis* was released in western CAN (1993) but not released in the US.**

S P U R G E S

Minoa murinata (Scopoli)
(Lepidoptera: Geometridae)

Minoa murinata adult (Siga)

DESCRIPTION AND LIFE CYCLE: Pupa overwinter just beneath the soil surface. Adults emerge in late spring and lay eggs on spurge leaves. Adults are gray to tan with a metallic sheen. Wings are fringed and span 18-23 mm. Hatching larvae feed on the undersides of leaves. Larvae are grayish-pink with variable black markings, brown heads, pink warts, and an orange or yellow stripe along each side. They can be up to 13 mm long and develop through four instars before dropping to the soil in fall to pupate. There can be two generations per year in suitable climates. Adults of the second generation emerge in late summer.

RELEASE HISTORY: Moths from Germany and Austria were released on leafy spurge in Canada from 1988 (MB and western provinces), but eventually died out. **Not released in the US.**

Tree-of-heaven
Ailanthus altissima (Mill.) Swingle

SYNONYMS: Chinese sumac, stinking sumac, paradise tree, Brooklyn palm

ORIGIN: Native to China and Taiwan and intentionally introduced to Pennsylvania, US in 1784 as an ornamental.

DESCRIPTION: Deciduous tree typically growing 55-89 ft tall (17-27 m) with a trunk diameter of 3.3 ft (1 m) from a shallow, suckering root system. The bark is light gray and smooth, becoming rougher and fissured with age. The compound leaves are alternate, 1-3 ft long (30-90 cm), and have 10-41 leaflets arranged in pairs. Leaflets are 2-7 in long (5-18 cm) and 1-2 in wide (2.5-5 cm). Each leaflet is lance-shaped with smooth margins, a pointed tip, and squared base. Each leaflet base has 1-2 teeth with a prominent gland on the back of each tooth. Male and female flowers usually appear on separate plants (dioecious). Both flowers are small with 5 greenish-yellow petals and appear in large clustered infloresences 4-8 in long (10-20 cm) at the ends of new shoots. Leaves, branches, and male flowers all have a foul odor. Female flowers produce winged fruits (similar in appearance to maples) that are twisted, 1 in long (2.5 cm), and turn reddish in fall.

Tree-of-heaven a. tree (Robert Vidéki, Doronicum Kft.); b. infestation (Karan A. Rawlins, University of Georgia)(a,b bugwood.org)

Tree-of-heaven c. glands on back of leaflet teeth (Annemarie Smith, bugwood.org); d. inflorescence (H. Zell); e. mature fruits and foliage (Luis Fernández García)

HABITAT: Tree-of-heaven can thrive in a variety of climates from humid forests to arid mountainsides, but does best in full sun in temperate regions. It is a pioneer of disturbed sites, such as highway rights-of-way, fallow fields, vacant lots, and rail lines, but can move outwards into undisturbed native vegetation. It does well in a variety of soil conditions and can tolerate drought but not flooding. Prolonged cold and snow cover cause dieback, but the tree resprouts from roots.

ECOLOGY: Tree-of-heaven reproduces by seed and suckering roots. Seeds germinate throughout spring, with highest rates occurring in full sun. It is one of the fastest-growing trees in North America, growing 1-6.6 ft (0.3-2 m) per year. Plants can become reproductive in 1-2 years, and flowering occurs in late spring to early summer. A single plant can produce over 300,000 seeds per year. Seeds are readily spread by wind and water; some are retained on the parent plant over the winter. Seeds are typically viable for less than one year. The leaves are deciduous, falling from the tree in autumn and winter. New leaves emerge in late spring. The shallow root system readily produces suckers. These develop into new plants and create large tree-of-heaven infestations. Most trees live 30-50 years.

BIOLOGICAL CONTROL: As of 2016, there are no classical biocontrol agents approved for use in North America. The native wilt *Verticillium nonalfalfae* is currently being studied in experimental field tests. Additional species are being tested for potential future release in North America.

Tree-of-Heaven, Native Natural Enemy

Verticillium nonalfalfae (Inderbitzin et al 2011) (=*V. albo-atrum* Reinke & Berthold) (Plectosphaerellaceae: Phyllachorales)

Verticillum wilt on tree-of-heaven (The Pennsylvania State University)

DESCRIPTION AND LIFE CYCLE: Once spores penetrate vascular tissue of hosts, the pathogen spreads throughout the plant, causing shriveled/dead foliage and a yellowish-brown discoloration of the sapwood directly beneath the bark (healthy individuals have white sapwood). Wilt spores are spread by herbivorous insects. Resting stages overwinter in the soil.

CURRENT STATUS: This wilt is naturally occurring in North America. Since 2002, a strain believed to have evolved to be specific to tree-of-heaven has been observed killing large swaths of tree-of-heaven in PA, VA, and OH, US. Following extensive host range testing, inoculation techniques were developed, and the fungus is being distributed at various test sites in the US. As of 2016, this species is still under study in the US, and **it is illegal to move it across state lines.**

Alligatorweed

Alternanthera philoxeroides (Mart.) Griseb.

SYNONYMS: alligator weed, *Achyranthes philoxeroides* (Mart.) Standl.

ORIGIN: Native to South America, it was introduced to North America by 1897 in ship's ballast.

DESCRIPTION: This perennial species has two growth forms: aquatic and terrestrial. Both forms have opposite, stalk-less leaves typically 1-5.5 in long (2-14 cm). The aquatic form often creates dense floating mats. The aquatic form produces hollow stems emerging up to 20 in (50 cm) above water, and its leaves are long, lance-shaped, and smooth. The terrestrial form grows much shorter and produces stems that are less hollow with shorter, rounder leaves compared to the aquatic form. The flowers of both forms appear in ball-like clusters 0.6 in (1.5 cm) in diameter on long stalks during warm summer months. There are 6-20 flowers in each cluster. Individual flowers have five white, papery sepals

Alligatorweed a. plant (Graves Lovell, Alabama Department of Conservation and Natural Resources); b. infestation (Chris Evans, University of Illinois)(a,b bugwood.org)

Alligatorweed c. leaves, stems of the aquatic form; d. leaves, stems of the terrestrial form (c,d James H. Miller, USDA Forest Service); e. flowers (Rebekah D. Wallace, University of Georgia)(c-e bugwood.org)

that resemble petals. Seeds are smooth and lens-shaped, but are not typically produced (or viable) in North America.

HABITAT: Alligatorweed is most often found growing in shallow water along banks of all types of water bodies. The terrestrial form is also found in dried beds of water bodies as well as pastures, lawns, and some crops.

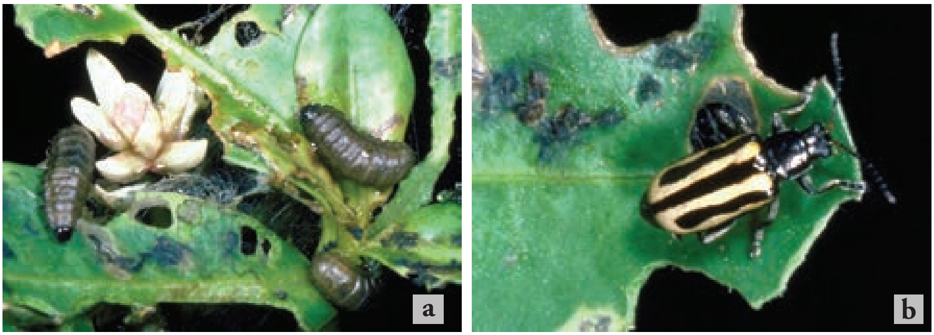
ECOLOGY: Alligatorweed grows year-round in warm climates; it primarily reproduces vegetatively in North America. Fragmentation of plants (e.g. from flooding or mechanical or chemical control) can yield numerous fragments with at least one node which are then moved from one place to another on currents, boats, machinery, etc., and take root in suitable habitat. The aquatic form produces dense floating mats from the hollow stems and may be rooted to the shoreline or free-floating. The terrestrial form produces an extensive rhizomatous root system from which new stems arise.
Flowering occurs in mid to late summer, but seeds are typically not produced in North America.

BIOLOGICAL CONTROL: *Agasicles hygrophila* and *Arcola malloi* are effective on the aquatic form of alligatorweed at warm locations in the US. Cold temperatures hinder their overwintering at inland sites, and they are ineffective on the terrestrial form. *Amynothrips andersoni* attacks both forms of alligatorweed, but has only minor impact. The weed does not occur in Canada.

Agasicles hygrophila Selman & Vogt

Alligatorweed flea beetle

DESCRIPTION: Eggs are pale yellow and cylindrical. Larvae are yellow initially, turning black as they age. Larvae can be up to 6 mm long. Pupae are cream-colored initially but darken with age. Adults are 4-6 mm long and black with four longitudinal stripes (2 on each elytra). Adults have enlarged hind femurs, enabling them to jump large distances. Females are slightly larger than males.



Agasicles hygrophila a. larvae and feeding damage; b. adult and feeding damage (a,b Gary Buckingham, USDA ARS, bugwood.org)

LIFE CYCLE: Adults emerge in early spring and begin mating and ovipositing; females lay an average of 1,100 eggs during their lifetime. Eggs are deposited in two rows (12-54 eggs per cluster) on the undersides of alligatorweed leaves. Larvae feed on leaf tissue, often leaving transparent feeding "windows". Larvae develop through three instars prior to chewing into alligatorweed stems. Pupation occurs within the plant stems. Adults emerge and feed on alligatorweed leaves and stems. There are 4-6 generations per year. Last generation adults overwinter among roots and stems of alligatorweed along water body margins.

DAMAGE: Larval and adult feeding on leaves and stems is often severe, leading to eventual submergence of the floating mat and clearing waterways.

PREFERRED HABITAT: This beetle attacks only the aquatic form of alligatorweed, though minor feeding has been observed on alligatorweed plants that have only recently become terrestrial (following a water drawdown). It overwinters only in warmer locations, but extends its range into colder locations during summer and autumn. Hot, dry summers reduce beetle populations at some locations.

RELEASE HISTORY: Beetles from Uruguay and Argentina were released on alligatorweed beginning in 1964 (AL, AR, FL, GA, LA, MS, NC, SC, TN, TX). Beetles sourced from the southernmost part of this species range in Argentina were released in the southeastern US in 1979 in an attempt to increase cold tolerance.

CURRENT STATUS: All releases of *A. hygrophila* are believed to have established in the southeastern US, though there is no evidence that beetles from the later release from cold portions of the insect's native habitat have performed any better than those released initially. Overall, the abundance of this flea beetle varies by season; populations decline during summer due to reduced fecundity associated with high temperature. The flea beetle's impact is likewise variable. It is highly successful in northern FL and warmer coastal areas where insects can overwinter, but populations are variable elsewhere. It is not effective against the terrestrial form of alligatorweed.

REDISTRIBUTION: This species is best collected in the adult stage using a net in early spring. Adults can be transferred to new sites in groups of 200. Establishment can be monitored by observing adults or larvae on alligatorweed foliage later in the season or the following year. Alternatively, stems of plants with heavy feeding damage can be dissected for evidence of pupation throughout the following growing season.

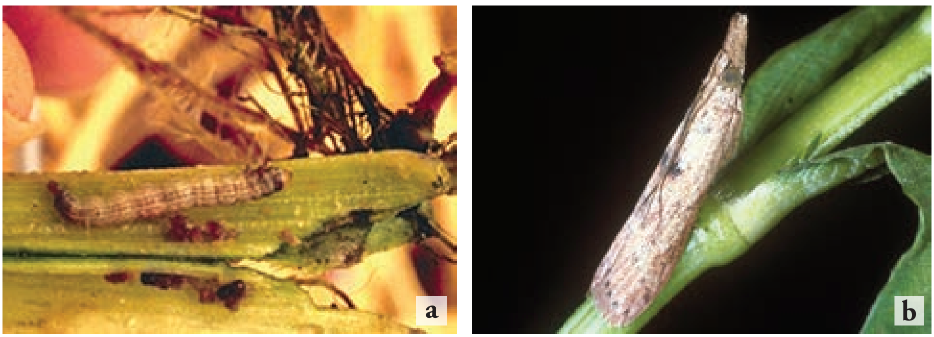
NOTES: **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Arcola malloi (Pastrana)

Alligatorweed stem borer

SYNONYMS: *Vogtia malloi* Pastrana

DESCRIPTION: Eggs are white and oval-shaped. Larvae are white to yellow initially, appearing brown at maturity because of several tan, longitudinal, wavy stripes. Last instars are up to 14 mm long. Pupae are found in silken cocoons and turn from yellow to dark brown with age. Adults hold their wings tightly against their bodies; they are 13-14 mm long with a wingspan of 20 mm. Forewings are tan to brown with mottled markings.



Arcola malloi a. larva (USDA ARS); b. adult (Willey Durden, USDA ARS, bugwood.org)

LIFE CYCLE: Adults emerge in spring, and females lay eggs singly at leaf axils or on the undersides of alligatorweed leaves. A single female may lay an average of 260 eggs in her lifetime. Larvae bore into stem tips and mine downwards, feeding on stem tissue through five instars. At maturity, larvae plug stem nodes beneath them with chewed tissue in order to seal out water and prepare adult exit "windows" by chewing stem tissue but leaving the epidermis intact. Larvae spin cocoons in which to pupate, and adults emerge through exit windows. In North America, the number of generations per year is unknown; 3-4 generations per year have been observed in the native range. Last generation larvae overwinter in alligatorweed stems and pupate the following spring.

DAMAGE: Larval mining causes stems to wilt and eventually die, turning yellow as they do so. Entire mats often turn yellow and submerge.

PREFERRED HABITAT: The moth is most commonly found on mats of the aquatic form of alligatorweed, though plants of the terrestrial form are also occasionally attacked. It overwinters only in warmer locations, but extends its range into colder locations during summer and autumn.

Arcola malloi damage to alligatorweed (c,d USDA ARS, bugwood.org)

RELEASE HISTORY: Motns from Argentina were released in FL, GA, NC, and SC beginning in 1971 (AL in 1972). This species subsequently dispersed naturally to AR, LA, MS, and TX.

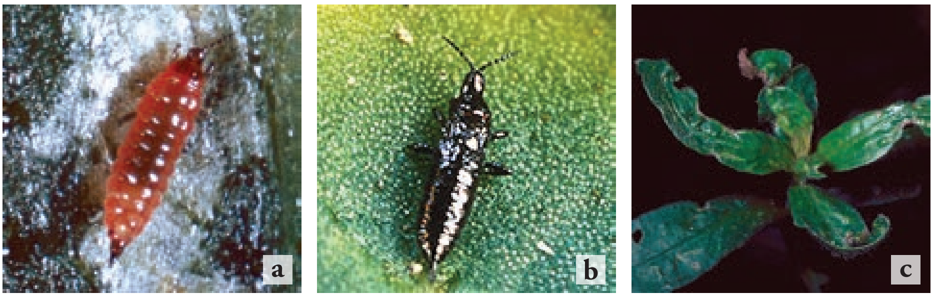
CURRENT STATUS: *Arcola malloi* is established throughout the southeastern US where larval burrowing causes stem collapse and waterlogging. The moth is a useful adjunct to (but possibly not as good a competitor as) *Agasicles hygrophila*. The moth contributes effectively to control in MS and FL, as well as in TX when populations are not limited by adverse conditions. It has an excellent dispersal ability with annual spread of up to 620 miles (1,000 km). It most likely overwinters in warmer coastal areas and migrates to inland infestations. This moth is most effective against floating plant mats; damage to the terrestrial form is minimal.

REDISTRIBUTION: Adults are easily damaged so sweeping is not recommended. Instead, place stems infested with larvae and pupae into uninfested alligatorweed. This can be done throughout the growing season, though the moth is most available from midsummer to early autumn. Take care to keep the collected stems cool and moist until they can be transferred. Establishment can be monitored by observing alligatorweed stems for evidence of larval mining later in the same season or in subsequent years.

NOTES: This moth has reportedly been collected from the native *Philoxerus vermicularis* (L.) Sm. (whose name has since been changed to *Blutaparon vermiculare* (L.) Mears) and the native *Alternanthera flavescens* Kunth. **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Amynothrips andersoni O'Neill
Alligatorweed thrips

DESCRIPTION: Eggs are elongated and yellow at first but turn reddish with age. Nymphs are up to 2 mm long. The first nymphal stage is pale yellow, but nymphs turn increasingly orange to red with black legs through subsequent stages. Adults can be either wing-less or winged (with fringed wings). Most winged forms have only short wings and are flightless; long-winged forms are uncommon. Adults are 2 mm long and black with black legs and antennae.



Amynothrips andersoni a. second instar (USDA ARS); b. adult (US Army Corps of Engineers ERCD); c. damage (Gary Buckingham, USDA ARS)(a,c bugwood.org)

LIFE CYCLE: Eggs are laid singly (an average of 200 per female) on hairs at stem nodes. Unmated females produce all males, but females that are fertilized produce equal amounts of male and female progeny. Adults and nymphs feed on new growth of alligatorweed leaves and stems. There are multiple overlapping generations per year; 4-5 generations have been observed in the native range. All stages can overwinter, though the most common overwintering stage is adult.

DAMAGE: Nymphs and adults pierce alligatorweed leaves and stems and suck out cell contents. Feeding causes leaf and tip deformation which stunts plants. This typically does not kill plants so the overall impact is not severe.

PREFERRED HABITAT: This thrips attacks both the aquatic and terrestrial forms of alligatorweed, and is the most cold tolerant of established alligatorweed biocontrol agents. Hot summers limit populations.

RELEASE HISTORY: Thrips from Argentina were released in the southeastern US beginning in 1967 (AL, CA, FL, GA, LA, MS, SC, TX).

CURRENT STATUS: *Amynothrips andersoni* successfully established on alligatorweed throughout the southeastern US. Though widely distributed, populations are usually limited. It is the least widespread of the alligatorweed biocontrol agents established in the US, but the most cold tolerant. Competition from the flea beetles limits populations on the aquatic form. It is the only established biocontrol agent to impact the terrestrial form of alligatorweed; however, damage to both the aquatic and terrestrial forms is usually only light (causing some leaf deformation). Predation limits populations in some areas.

REDISTRIBUTION: Due to the low impact of the alligatorweed thrips, this species is a low priority for redistribution. At cold locations where the other two alligatorweed biocontrol agents are limited, and/or where other control methods are not feasible, the thrips is best redistributed on infested plants transferred to alligatorweed mats at uninfested sites. Transfers are best made in spring and autumn, taking care to keep the collected stems cool and moist until they can be transferred. Establishment can be monitored throughout the following growing season by checking for adults or nymphs in the curled leaf tips of attacked alligatorweed.

NOTES: **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Scentless chamomile

Tripleurospermum inodorum (L.) Sch. Bip.

SYNONYMS: scentless false mayweed, *Matricaria perforata* Mérat, *Tripleurospermum maritimum* (L.) W. D. J. Koch ssp. *inodorum* (L.) Appleq., *Tripleurospermum perforatum* (Mérat) M. Laínz

ORIGIN: Native to Eurasia. Introduced to North America by the 1920s.

DESCRIPTION: An erect, branching annual or short-lived perennial growing 0.5-3.2 ft tall (15-100 cm) from a fibrous root system. Leaves are alternate and very finely divided, giving the plant a fern-like appearance. Flower heads are daisy-like with white outer ray florets and yellow inner disc florets. Flower heads are typically 1.25-1.6 in (30-40 mm) in diameter. Seeds are small (0.08 in or 2 mm long), elongate, brown, and ribbed, with no pappus.

HABITAT: Scentless chamomile is well adapted to many different habitats, thriving in disturbance typical of annual and perennial crops, pastures, wasteland, roadsides, and ditches. It germinates readily at sites with periodic flooding.

Scentless chamomile a. plant (Robert Vidéki, Doronicum Kft., bugwood.org); b. infestation (Alec McClay, McClay Ecoscience)

Scentless chamomile c. leaves (Caleb Slemmons, University of Wisconsin, Stevens Point, bugwood.org); d. flower heads (Alec McClay, McClay Ecoscience)

ECOLOGY: Scentless chamomile reproduces by seed only. Plants germinate throughout the growing season. Those germinating before mid-July often behave as annuals, bolting and flowering within the same growing season. Those germinating after mid-July behave as winter annuals, developing into an overwintering rosette which bolts and flowers the following summer. Most plants die after flowering and setting seed, though a small proportion overwinter and re-grow from the root crown to flower again in the following season. This species is a prolific seed producer; dense populations can yield up to 1.8 million seeds/m^2. Seeds are readily transported by water, birds, and other animals, and may stay viable up to 15 years.

BIOLOGICAL CONTROL: This weed is most problematic in midwestern and western states and provinces, though biocontrol has also proven beneficial on some infestations in the East. Both *Rhopalomyia tripleurospermi* and *Omphalapion hookerorum* are abundant in western Canada, and *O. hookerorum* has large populations in eastern provinces as well. Both species reduce scentless chamomile seed production. While this does not kill plants, they are useful in combination with other control methods or where some other control methods are not feasible. *Microplontus edentulus* is established only in western Canada and is rare in the field with no documented impact. **No species have been approved for use or released in the US.**

Omphalapion hookerorum (Kirby)

Scentless chamomile seed weevil

SYNONYMS: *Apion hookeri* Kirby

DESCRIPTION: Eggs are small and round, changing from white to brown with age. Larvae are white, C-shaped, and typically up to 2 mm long. Adult males are black and 1.5-2 mm long. Females have a metallic sheen in shades of blue, turquoise or purple and are typically 2-2.5 mm long. Both males and females have rounded bodies and curved snouts with bulging eyes.

Omphalapion hookerorum a. larva in damaged flower head; b. adult; c. adults on flower head (a-c Alec McClay, McClay Ecoscience)

LIFE CYCLE: Female adults emerge in spring and feed on scentless chamomile plants prior to laying eggs in young flower heads. Hatching larvae feed on florets and seeds, developing through three instars. Pupation occurs within the flower head. Adults emerge in late summer and mate, but females do not oviposit. They overwinter in soil or litter and will oviposit the following year. Males die before winter. There is one generation per year.

DAMAGE: Larval feeding destroys some seeds. Seed consumption does not kill existing plants, but does help reduce the rate of scentless chamomile spread.

PREFERRED HABITAT: The weevil is reportedly not restricted to any particular habitat in its native range, though it seems to prefer cold, dry continental climates.

RELEASE HISTORY: The weevils used for screening and initial releases were introduced from Germany and released in western Canada and MB beginning in 1992. An adventive population was discovered in NS in 1990, possibly introduced by fishing or pleasure boats or via dry ballast from Europe. Both intentional and adventive populations eventually intermixed.

CURRENT STATUS: *Omphalapion hookerorum* is established on scentless chamomile in MB and NS, Canada as well as in western provinces not covered by this guide. The weevil's abundance is high, and its overall impact is medium. In western provinces, up to 78% of scentless chamomile seed heads are attacked by *O. hookerorum,* and up to 32% by *Rhopalomyia tripleurospermi.* Estimated scentless chamomile seed production is reduced up to 19% by a combination of both species. Up to 17 *O. hookerorum* adults have been found in a single seed head (mean 3.9). It disperses up to 1.7 miles/year (2.8 km/year).

REDISTRIBUTION: Wherever it is not currently established, adults can be transferred in groups of 200. Releases can be made in spring or late summer. Adult females can be collected in spring, using an aspirator, from the young buds and shoot tips of scentless chamomile. In late summer, adults can be collected as they emerge from the mature seed heads. Releases should be made on patches of at least 2,000 m^2 (0.5 acres). Establishment can be monitored the following spring by checking for adults on shoot tips and flower buds, or in summer by dissecting capitula for evidence of feeding larvae.

NOTES: **This species has not been released in the US.**

CHAMOMILE

Rhopalomyia tripleurospermi Skuhravá & Hinz
Scentless chamomile gall midge

DESCRIPTION: Eggs are bright red and elongate. Larvae are bright red initially, changing to white at maturity. Male pupae are gray while female pupae are red to dark purple. Adult males and females also have distinct appearances. Males are approximately 2.5 mm long with a brown head and thorax and gray abdomen. Male legs are long and slender. Adult females are typically 2.5-3 mm long with a bright red abdomen and shorter, thicker legs. Females contain fully developed eggs; larger females contain more eggs.

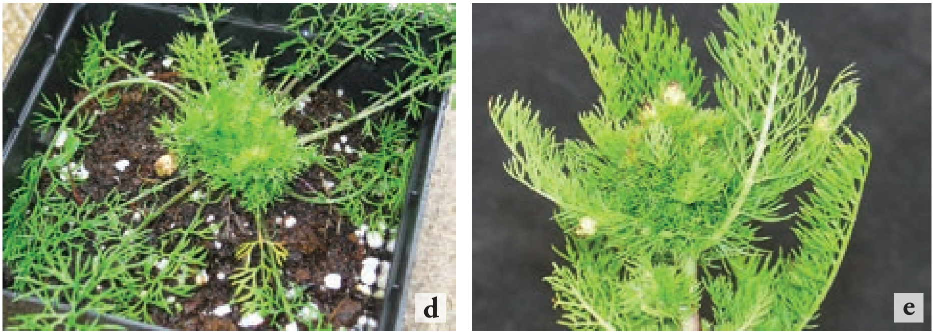
Rhopalomyia tripleurospermi a. eggs; b. male pupa; c. female adult (a-c Alec McClay, McClay Ecoscience)

LIFE CYCLE: Pupation occurs in spring. Adults emerge in spring, and females lay eggs into scentless chamomile leaf axils or unopened buds. Hatching larvae enter and feed on bud tissue, developing through three larval instars. Larval feeding induces the formation of galls, which appear as masses of crowded, leaf-like growths with a mossy appearance. Galls may develop on growing points, leaves, stems, or flowers. In AB Canada there are three generations per year, but two are expected in colder climates. Larvae overwinter in galls and pupate within galls the following spring.

DAMAGE: Larval-induced galls interrupt and stunt the normal growth of scentless chamomile, reducing flowering. High attack rates can kill overwintering rosettes.

PREFERRED HABITAT: The midge appears to thrive in all habitats where scentless chamomile occurs.

RELEASE HISTORY: Midges from Austria were released in Canada beginning in 1999 (MB and western provinces).



Rhopalomyia tripleurospermi d. gall on rosette; e. gall on shoot tip (d,e Alec McClay, McClay Ecoscience)

CURRENT STATUS: *Rhopalomyia tripleurospermi* is established on scentless chamomile only in western Canada provinces not covered in this guide (AB, BC, SK). In western Canada, its abundance is high, and its overall impact is medium. Up to 78% of seed heads are attacked by *Omphalapion hookerorum* and up to 32% by *R. tripleurospermi*. Estimated scentless chamomile seed production is reduced up to 19% by a combination of both species. Heavy galling stunts plants and decreases and/or delays flower production. Anecdotal reports suggest scentless chamomile populations are declining in areas (western provinces) with heavy attack. This fly disperses up to 3.2 miles per year (5.2 km/yr).

REDISTRIBUTION: Adults are small, short-lived, and delicate so sweeping is not feasible. Instead, place infested plants into uninfested patches from spring through midsummer. To avoid transferring unwanted parasitoids, other insects, or scentless chamomile seeds, gall-infested stems can be collected and adults reared out indoors. Refer to Additional Considerations in the Introduction for instructions on how to do so. Once they emerge in spring, midges can be transferred to new chamomile infestations in groups of 50-100. Establishment can be monitored by observing scentless chamomile foliage for galls later in the same season or in subsequent years.

NOTES: Galls are susceptible to parasitoid attack, but parasitism levels in the field are not high enough to prevent rapid population growth. **This species has not been released in the US.**

Microplontus edentulus (Schultze)
Scentless chamomile stem-mining weevil

SYNONYMS: *Ceutorhynchus edentulus* Schultze

DESCRIPTION: Larvae are white, C-shaped, and have brown head capsules. They are approximately 3 mm long. Adults are about 3 mm long and 2 mm wide. Females are slightly larger than males. Adults are mottled gray with lighter patches at the base and sides of wing covers. They have long, curved snouts.

Microplontus edentulus a. larva in flower head; b. adult (a,b Alec McClay, McClay Ecoscience)

LIFE CYCLE: Adults emerge in early spring and begin mating and ovipositing prior to chamomile flowering. Eggs are deposited singly into holes chewed by females in upper plant stems, near leaf bases. Hatching larvae mine stems and sometimes into flower bases, though they do not feed on or damage seeds. Larvae develop through three instars prior to dropping to the ground and burrowing into the soil to build cocoons out of soil particles. Pupation occurs within cocoons. Adults typically overwinter within cocoons, but some emerge in fall and overwinter in soil and litter. There is one generation per year.

DAMAGE: Larval stem mining causes plants to produce thin stems, which reduces plant mass and seed production. Large, healthy plants appear less affected.

PREFERRED HABITAT: Specific habitat requirements are unknown.

RELEASE HISTORY: Weevils from Austria were released on scentless chamomile in western Canada beginning in 1997 and in MB in 1998.

CURRENT STATUS: *Microplontus edentulus* has been confirmed established on scentless chamomile only at one site in western Canada (AB). To date there has been no evidence of impact in the field. Larval mining in stems occurs too late to

Microplontus edentulus c. larvae and mining damage in stem (Hariet Hinz, CABI-Switzerland); d. emergence hole in plant stem (Alec McClay, McClay Ecoscience)

impact plant fitness, and mining in receptacles does not destroy seeds. Parasitism may play a role in the low population levels.

REDISTRIBUTION: Populations are currently too limited to field collect so releases should be made using laboratory colonies when available. In the future, should this biocontrol agent become better established, field redistributions can be done utilizing a sweep net in early spring to collect adults from stems and foliage during the mating stage. These can be transferred to new, uninfested sites in groups of 100-200. Establishment can be monitored the following season by observing adults on plant foliage or dissecting stems to find larvae mining within.

NOTES: **This species has not been released in the US.**

Poison hemlock

Conium maculatum L.

ORIGIN: Native to Eurasia. Introduced to North America in the 1800s as a garden plant.

DESCRIPTION: An erect plant typically growing as a biennial but may behave as a winter annual or short-lived perennial. The plant often grows 3-6 ft tall (90-180 cm) from a deep taproot. Leaves are alternate and finely divided, giving the plant a fern-like appearance. Stems are hollow, smooth, and covered in purple spots or splotches. The inflorescence is a compound umbel with 12-16 umbellets. Individual flowers have five white petals. Seeds are brown, oval, flattened on one side, and have conspicuous wavy ribs.

HABITAT: Poison hemlock often grows in dense stands at shady or moist sites. It is frequently found along roadsides, field margins, ditch banks and in low-lying waste areas. It also invades native plant communities in riparian woodlands and open flood plains of rivers and streams.

Poison hemlock a. plant (Steve Dewey, Utah State University); b. infestation (Joe DiTomaso, University of California)(a,b bugwood.org)

Poison hemlock c. leaf; d. stem (Jeff Stachler, Ohio State University); e. inflorescence (c,e Pedro Tenorio-Lezama)(c-e bugwood.org)

ECOLOGY: Poison hemlock reproduces by seed only. Plants germinate throughout the growing season. Most plants are biennials, remaining as rosettes the first year and bolting/flowering only during the second year. Flowering typically occurs in mid- to late summer. Most plants die after flowering and setting seed, though a small proportion overwinter and re-grow from the root crown to flower again in the following season. Seeds are readily transported by farm machinery, vehicles, agricultural produce, mud and clothing, as well as being carried by water and, to a limited extent, wind. Seeds may stay viable up to three years.

BIOLOGICAL CONTROL: *Agonopterix alstroemeriana* was accidentally introduced to North America by 1973; it spread rapidly throughout the northwestern states by 1983. It has since been granted redistribution permits for use on poison hemlock in the US, and has been moved around extensively. It is widespread in the West, but eastern populations are more limited. High populations cause severe defoliation, but many plants recover after larvae pupate in midsummer, so overall impact is believed to be limited. **No species are approved for release in Canada for control of poison hemlock.**

NOTES: All parts of the plant contain alkaloids that are highly toxic to livestock and humans.

Agonopterix alstroemeriana (Clerck)

Defoliating hemlock moth

DESCRIPTION: Eggs are pale yellow and cylindrical. Early instars are predominantly yellow with black head capsules. Later instars are light green with three dark green longitudinal stripes. Mature larvae can be up to 12 mm long. Pupal cases are reddish-brown. Adults are approximately 10 mm long with 18 mm wingspans. Adults are speckled brownish-gray and have a distinctive dark brown spot on each wing.

Agonopterix alstroemeriana a. eggs; b. larva; c. adult (a-c Eric Coombs, Oregon Department of Agriculture, bugwood.org)

LIFE CYCLE: Adults emerge in early spring and begin mating and ovipositing. Eggs are deposited on the undersides of poison hemlock leaves. Hatching larvae feed on leaves, creating tubes of leaf particles. Leaf tubes are quickly abandoned when larvae are disturbed and drop to the ground. Larvae develop through five instars; late instars incorporate flower tissue into their tubes. They pupate in the soil with new adults emerging in midsummer. Adults overwinter in soil and plant litter. There is one generation per year.

DAMAGE: Larval feeding defoliates plants which can lead to reduced reproduction and sometimes plant death. Many plants recover and produce more foliage after larvae have pupated.

PREFERRED HABITAT: Specific habitat requirements are unknown.

RELEASE HISTORY: Accidentally introduced, this moth was first documented in the US (NY) in 1973. It spread rapidly to many additional states including those in the West by 1983. Despite being introduced accidentally, the USDA APHIS has granted permits for its redistribution, and it is currently commercially available.

Agonopterix alstroemeriana d. defoliated leaves; e. defoliated stand (a,b Eric Coombs, Oregon Department of Agriculture, bugwood.org)

CURRENT STATUS: This moth is established at high densities on poison hemlock throughout the western US and in portions of the East. It can reduce seed production and cause severe defoliation of poison hemlock, however many plants recover after larvae terminate feeding in midsummer. Changes in poison hemlock stand density have not been documented, so the overall impact is believed to be limited.

REDISTRIBUTION: *Agonopterix alstroemeriana* populations are widespread throughout the western US. Where eastern infestations of poison hemlock are sufficiently large to warrant releases of this moth, larvae can be hand-picked from other sites during late spring and transferred along with cut leaves of poison hemlock in groups of 50-100. As this weed is extremely toxic, gloves and protective clothing should be worn when cutting any foliage. Establishment can be monitored the following spring and summer by observing new larvae on poison hemlock foliage.

NOTES: Adults are nocturnal and hide during the day. **This species is not approved for release in Canada.**

HYDRILLA

Hydrilla

Hydrilla verticillata (L.) L.A.S. Johnson

SYNONYMS: Florida elodea, water thyme

ORIGIN: Native to Africa, Asia, Australia, and portions of Europe, hydrilla was intentionally introduced to North America in the 1950s as an aquarium plant.

DESCRIPTION: Submersed, aquatic perennial with roots typically buried in the hydrosoil. Roots are slender, white, and stoloniferous in the hydrosoil or may grow from stem nodes. Stoloniferous roots end in potato-like tubers up to 0.5 in long (13 mm). Stems are slender (<0.2 in or 4 mm wide), up to 33 ft (10 m) long, and become more branched at the surface, forming dense intertwined mats. Leaves occur in whorls of 3-8 all along the stem. Most leaves are <0.6 in (15 mm) long; they have serrated margins and small teeth on undersides of midveins. Swollen leaf buds (turions) are formed in leaf axils. In the US, male and female flowers may appear on the same plant (monoeocious) or on separate plants (dioecious). The dioecious form is more common in the southern US while the monoeocious is dominant in the North. Female flowers are tiny, have 6 white petals, and reach the surface on thread-like stalks; each produce 2-6 oblong seeds. Male flowers are tiny, green, and closely attached to leaf axils until they break off and free-float.

Hydrilla a. plant (David J. Moorhead, University of Georgia); b. infestation (Cleveland Metroparks) (a,b bugwood.org)

Hydrilla c. leaves; d. flowers and foliage (Cleveland Metroparks); e. tubers (c,e Robert Vidéki, Doronicum Kft.)(c-e bugwood.org)

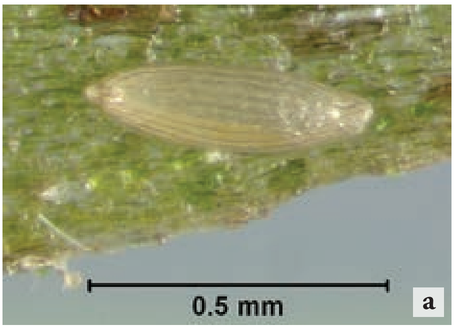
HABITAT: This aquatic species has been found growing in any type of freshwater, including lakes, springs, marshes, irrigation ditches, and rivers. It can grow in water depths from a few inches (7.5 cm) to 33 ft (10 m), and can tolerate moderate salinity (up to 33% of seawater). It can be found in both tropical and temperate climates and in a variety of nutrient and pH levels.

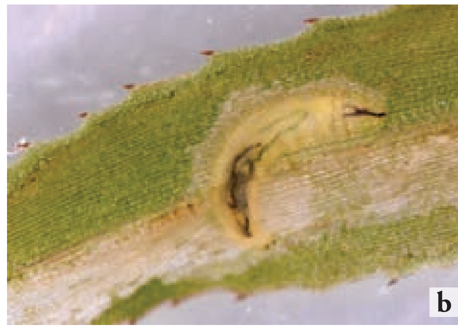
ECOLOGY: Hydrilla reproduces by seeds and (primarily) vegetatively. Throughout the growing season, new stems sprout from the root system and tubers as well as from stem fragments and turions that break from the parent plant. Stem fragments containing a single node (whorl of leaves) can sprout new plants. Flowering occurs from summer to fall. Male flowers break from the plant to free-float, fertilizing female flowers after bumping into them. In warm climates, the plant continues to grow over the winter. At cold sites, stems die back to the tubers, and new stems re-sprout the following spring. While turions die after one year, tubers may remain dormant in mud for many years.

BIOLOGICAL CONTROL: *Hydrellia pakistanae* is widespread and abundant; high fly densities are locally correlated with decreases in hydrilla. It was initially believed *Bagous hydrillae* failed to establish, but small populations were observed in 2009. To date, populations of *B. hydrillae* and *Hydrellia balciunasi* are too low to have significant impact. Despite multiple releases in the US, *B. affinis* failed to establish. Foreign exploration for additional biocontrol agents is still underway. The weed does not occur in Canada.

Hydrellia balciunasi Bock & *H. pakistanae* Deonier
Australian hydrilla leaf-mining fly & Asian hydrilla leaf-mining fly

DESCRIPTION: Both species are virtually indistinguishable; experts must use genitalia features to differentiate adults. Eggs of both species are yellow-white and elongate with longitudinal ridges. Larvae are yellow-green to white, have two anal spines, and are up to 3.5 mm long at maturity. Pupae are enclosed in cocoons that turn dark brown with age. Adults are dark gray with grayish-orange legs and typically bronze faces and are up to 1.5 mm long.





Hydrellia spp. a. egg; b. larva (a,b Lyle J. Buss, University of Florida)

LIFE CYCLE: At warm locations, both *Hydrellia* spp. and hydrilla develop throughout the year; larvae and pupae are the stages most often observed over winter. Adults emerge in spring and lay eggs singly or in small groups (though an average of 35 per lifetime) on leaves and stems at or just above the water surface. Larvae mine within leaves (4-12 per lifetime) through three instars. Leaves are mined completely before larvae exit to find another. Mature larvae attach themselves to leaf axils and pierce the stems with their anal spines while their skin hardens into cocoons. Pupae obtain air from the stems via the anal spines. Adults emerge and float to the surface in a bubble of air to repeat the cycle. There are multiple generations per year (up to 7) depending on site conditions.

DAMAGE: Leaves mined by larvae decay and fall. Stems with moderate to high amounts of *H. pakistanae* leaf-mining often sink and die.

PREFERRED HABITAT: Both species are restricted to warm climates but perform well in all warm water bodies where hydrilla mats are present.

RELEASE HISTORY: *Hydrellia balciunasi* from Australia was released in FL from 1989 and TX beginning in 1991. *Hydrellia pakistanae* from three different countries was released in the US: India starting in 1987 (AL, CA, FL, GA, LA, TX), Pakistan in 1990 (FL), China in 1992 (AL, FL, LA, TX) in an attempt to

Hydrellia spp. c. adult (Lyle J. Buss, University of Florida); d. abdomen comparison between males of introduced *Hydrellia* spp. (left) and native *Hydrellia* spp. (right)(USDA ARS, bugwood.org)

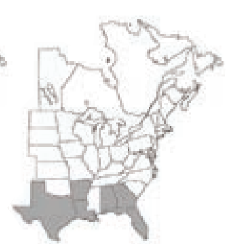
increase survival at cold locations. India and Pakistan releases were successful and subsequently not differentiated; it is unclear if the China releases were successful.

CURRENT STATUS: No major impact has been observed for *H. balciunasi* as populations have remained low and spread has been limited. *Hydrellia pakistanae* is much more widespread and abundant; larval mining decreases photosynthesis and reduces tuber numbers. High fly densities are locally correlated with decreases in weed populations. Some populations of both species are limited by parasitism and cold weather. Studies since 2004 indicate the monoecious biotype is not as suitable a host for introduced *Hydrellia* spp. as is dioecious hydrilla.

REDISTRIBUTION: *Hydrellia pakistanae* is a higher priority for redistribution. Hydrilla stems infested with larvae and pupae can be transferred to new hydrilla mats, taking care to keep the collected stems cool and moist until they can be transferred and to avoid transferring other insects or parasitoids. Establishment can be monitored the following growing season observing larvae mining leaves.

NOTES: Both introduced *Hydrellia* spp. closely resemble native *Hydrellia* spp. Introduced males can be differentiated by their abdomen being approximately the same size as their thorax, while the abdomen of a native male is 1.5 to 2 times as long as the thorax. Females of introduced and native species must be differentiated by their genitalia. **Neither species has been released in Canada where the weed is also reportedly not present.**

H. balciunasi



H. pakistanae

Bagous hydrillae O'Brien
Hydrilla stem weevil

DESCRIPTION: Eggs are white and oval. Larvae are C-shaped, white with brown head capsules, and up to 3 mm long. Adults are elongate with long snouts, up to 3 mm long, mottled, and tan to dark brown. In many individuals, 2-4 light coloration spots can be seen on the far ends of the elytra.

Bagous hydrillae a. larva ; b. pupa, c. adult, side view; d. adult, top view (a-d courtesy US Army Corps of Engineers, ERDC-EL)

LIFE CYCLE: Overwintering adults emerge in spring, fly from the shore to hydrilla mats, and feed on stems and leaves. Females lay eggs (average of 300 per lifetime) singly in hydrilla stems near plant nodes. Larvae bore into stems and feed through three instars. Adult and larval feeding causes stems to break apart, and fragments float to shore where they become stranded. Mature larvae exit stems of stranded fragments to pupate in the soil. Some pupate within stranded stems, though pupation does not occur in submersed hydrilla. Adults emerge, fly to new hydrilla patches, and continue the cycle. There are multiple generations per year in the native range (possibly 4-5). Adults overwinter in soil or among stranded hydrilla stems.

DAMAGE: Hydrilla stems turn black where larvae bore inside. Adult feeding externally on leaves and stem tissue and larvae boring internally in stems causes hydrilla stems to break apart, and fragments float to shore where they become stranded and die.

PREFERRED HABITAT: Specific habitat requirements are unknown.

RELEASE HISTORY: Weevils from Australia were released in AL, FL, GA, and TX from 1991-1996.

CURRENT STATUS: This weevil was temporarily recovered in FL and TX following the original releases; however, it was believed this species had failed to

Bagous hydrillae feeding damage (e-g courtesy US Army Corps of Engineers, ERDC-EL)

permanently establish in the field. Small numbers were recovered LA in 2009 (over 360 miles or 580 km from the nearest release), indicating populations persisted throughout the southeastern US. There have been no observed reductions to hydrilla mats, and the impacts of any existing weevil populations are believed to be negligible. New inventories are warranted to determine the overall distribution of this species in the US.

REDISTRIBUTION: Populations are currently too limited to field collect. In the future, should this biocontrol agent become better established, field redistributions can be done by hand-collecting adults from stranded hydrilla stems. These can be transferred to new, uninfested sites in groups of 100-200. Establishment can be monitored the following season by observing adults on plant foliage or dissecting stems to find larvae mining within.

NOTES: **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Non-Established Biocontrol Agent

Bagous affinis Hustache (Coleoptera: Curculionidae)

Bagous affinis adult (Michael Shillingburg)

DESCRIPTION AND LIFE CYCLE: Adults are elongate with long snouts, 3-4 mm long, and a mottled brown. Adults emerge in spring and feed on hydrilla stems and leaves exposed by receding waters. Females lay up to 230 eggs singly on emerged or drying hydrilla stems, moist wood, tubers, or soil. Eggs are white and oval. Larvae are C-shaped, white with brown head capsules, and up to 5 mm long. Larvae crawl through sediment searching for tubers, then feed on or within hydrilla tubers through three instars. Pupation typically occurs within tubers. There are multiple generations per year in the native range (possibly 2-3). Adults overwinter in soil or among stranded hydrilla stems.

RELEASE HISTORY: Individuals from India were released in FL from 1987-1990 and TX from 1994-1995. Though it was initially recovered in FL, permanent establishment has not been reported. Establishment has been limited by this species requiring extensive drawdown conditions which expose the sediment surface and allow immature weevils access to buried hydrilla tubers.

Cricotopus lebetis Sublette
(Diptera: Chironomidae)

Cricotopus lebetis adult (Jerry F. Butler, University of Florida, Professor Emeritus)

DESCRIPTION AND LIFE CYCLE: Adults are 3-4 mm long and green with multiple dark bands. Females have shorter antennae and thicker abdomens than males. Females lay 50-250 whitish eggs in long strings on the water. Larvae feed through four instars on the growing tips of hydrilla. Larvae are up to 4 mm long and translucent green with a dark band on the thorax. Pupation occurs within hydrilla stems. There are multiple generations (up to 11) per year.

HISTORY AND CURRENT STATUS: This midge was first recorded in LA, US in 1957; it is established in FL and LA. It damages hydrilla's stem tips, causing stunting and preventing hydrilla from growing to the surface. However, populations are limited and overall field impact is typically minor. **This midge attacks nontarget species and is not approved for redistribution in the US.**

Parapoynx diminutalis Snellen
(Lepidoptera: Crambidae)

Parapoynx diminutalis adult (Jonatan, Josve05a)

DESCRIPTION AND LIFE CYCLE: Adults are 8 mm long, white, with brown and tan markings and bands. Females lay ~200 yellow eggs in 30-egg masses on hydrilla stems and leaves. Larvae are up to 10 mm long, white to yellow, and have spotted heads, long hairs, and branched gills. Larvae feed on hydrilla leaves through seven instars. Late instars construct silk cases from plant tissue. Pupation occurs in cocoons within the cases. There are multiple generations per year.

HISTORY AND CURRENT STATUS: This moth was studied for its biocontrol potential but rejected. It was accidentally introduced (first recorded in FL, US in 1975) and is now established in AL, FL, GA, SC, TX. Larval feeding can heavily damage hydrilla populations locally. However, this biocontrol agent only occurs sporadically so overall impact is typically low. Populations are limited by cold weather. **This species is not approved for redistribution in the US.**

Bohemian knotweed

Fallopia ×*bohemica* (Chrtek & Chrtková) J.P. Bailey

SYNONYMS: *Polygonum* ×*bohemicum* (Chrtek & Chrtková) Zika & Jacobson
Reynoutria ×*bohemica* Chrtek & Chrtková

ORIGIN: Hybrid of *Fallopia japonica* and *F. sachalinensis* that is both intentionally cultivated and naturally occurring in the field where both parent species overlap. Backcrossing with parent species regularly occurs.

DESCRIPTION: Bohemian knotweed has features intermediate to its parent giant and Japanese knotweed species. It is an upright herbaceous perennial typically 3.2-14 ft (1-4 m) tall with a deep taproot and extensive rhizomes. Stems are hollow, smooth, jointed and swollen at the nodes (resembling bamboo), and often woody at their base. Leaves are alternate, 3-12 in (8-30 cm) long, and 2-10 in (5-25 cm) wide. Leaves may have an abruptly pointed or tapering tip; their base be flat, tapering, or heart-shaped. Hairs on the undersides of leaves are short with broad bases. Flowers are small, greenish to creamy-white, and grow in branched clusters from leaf axils near stem ends. Flower clusters are 3-6 in (8-15 cm) long. Fruits are papery, 3-winged, and up to 0.6 in (15 mm) long.

Bohemian knotweed a. plant (Sasha Shaw, King County Noxious Weed Control Program); b. infestation (Jennifer Andreas, Washington State University Extension)

Bohemian knotweed c. leaves (Robert Vidéki, Doronicum Kft.); d. flowers (Sasha Shaw, King County Noxious Weed Control Program); e. fruits (Leslie J. Mehrhoff, University of Connecticut)(c,e bugwood.org)

HABITAT: Bohemian knotweed is frequently found in riparian, wetland, or lowland plant communities. It can inhabit a variety of sunlight, soil moisture, and human disturbance conditions, but has become especially problematic in full sun locations along the banks and floodplains of rivers and streams and moist roadsides. It is found growing next to either/both parent species and in their absence.

ECOLOGY: North American Bohemian knotweed reproduces both vegetatively and by seed. Rhizome sprouting occurs from late spring through summer. Rhizome and stem fragments can give rise to new plants if sufficient moisture is present. Seeds are transported by wind, water, and wildlife. Seeds germinate during spring; their longevity in the soil is unknown. Flowering occurs in late summer to early fall. Leaves fall in winter, and plants die back to rhizomes.

BIOLOGICAL CONTROL: As of 2016, *Aphalara itadori* has been approved by TAG for release on Bohemian, giant, and Japanese knotweed, but it is still under review in the US. Releases were made in Canada in 2016, but only on Japanese knotweed.

NOTES: Bohemian knotweed plants and leaves are variable in size and shape compared to either parent species, making differentiation difficult. Hairs on the undersides of leaves are long and wavy for giant knotweed, short with broad bases for Bohemian knotweed, and reduced to barely visible bumps on Japanese knotweed.

Giant knotweed

Fallopia sachalinensis (F. Schmidt) Ronse Decraene

SYNONYMS: Sakhalin knotweed, *Polygonum sachalinense* F. Schmidt, *Reynoutria sachalinensis* (F. Schmidt) Nakai

ORIGIN: Native to Asia, it was introduced to North America in the late 1800s as an ornamental and for erosion control before it escaped cultivation.

DESCRIPTION: An upright herbaceous perennial typically growing from 3.2-13 ft (1-4 m) tall. It has a deep taproot and extensive rhizomes that may extend 50-65 ft (15-20 m) laterally. Clustered stems are hollow, smooth and pale green, jointed and swollen at the nodes (resembling bamboo), and often woody at their base. Leaves are alternate, 6-12+ in (15-30+ cm) long, and 4-10 in (10-25 cm) wide. They have a tapering tip, heart-shaped base, somewhat wavy margins, and long wavy hairs on their undersides. Flowers are small, greenish to creamy-white, and grow in branched clusters from leaf axils near stem ends. Flower clusters are up to 4 in (10 cm) long. Fruits are papery, 3-winged, and 0.6 in (15 mm) long.

Giant knotweed a. plants (Jennifer Andreas, Washington State University Extension); b. infestation (Robert Emanuel, bugwood.org)

Giant knotweed c. leaf; d. flowers (c,d Jennifer Andreas, Washington State University Extension); e. fruits (Barbara Tokarska-Guzik, University of Silesia,bugwood.org)

HABITAT: Giant knotweed is frequently found in riparian, wetland, or lowland plant communities. It can inhabit a variety of sunlight, soil moisture, and disturbance conditions, but has become especially problematic in full sun locations along the banks and floodplains of rivers and streams and moist roadsides.

ECOLOGY: North American Giant knotweed reproduces primarily vegetatively, but it spreads in limited amounts by seed. Rhizome sprouting occurs from late spring through summer. Rhizome and stem fragments can give rise to new plants if sufficient moisture is present. Seeds are transported by wind, water, and wildlife. Seeds germinate during spring; their longevity in the soil is unknown. Flowering occurs in late summer to early fall. Leaves fall in winter, and plants die back to rhizomes.

BIOLOGICAL CONTROL: As of 2016, *Aphalara itadori* has been approved by TAG for release on Bohemian, giant, and Japanese knotweed, but it is still under review in the US. Releases were made in Canada in 2016, but only on Japanese knotweed.

NOTES: Japanese knotweed grows shorter and has smaller leaves with flat or tapered bases, abrupt tips, and no hairs on their undersides. Use leaves from the middle of the stem for comparison as those at stem tips are most variable. Bohemian knotweed leaves are variable in size between both parent species; hairs on their undersides are short with broad bases.

Japanese knotweed
Fallopia japonica (Houtt.) Ronse Decraene

SYNONYMS: Japanese bamboo, Japanese fleeceflower, *Polygonum cuspidatum* Siebold & Zucc., *Reynoutria japonica* Houtt.

ORIGIN: Native to Asia, it was introduced to North America in the late 1800s as an ornamental and for erosion control before it escaped cultivation.

DESCRIPTION: An upright herbaceous perennial that grows 3.2-10 ft (1-3 m) tall from a deep taproot and extensive rhizomes that may extend 23-65 ft (7-20 m) laterally. Stems are hollow, smooth, purplish turning green with age, jointed and swollen at the nodes (resembling bamboo), and often woody at their base. Leaves are alternate, 3-6 in (8-15 cm) long, and 2-5 in (5-12 cm) wide; they have an abruptly pointed tip and a flat or tapering base. Hairs on the undersides of leaves are reduced to barely visible bumps. Flowers are small, creamy-white, and grow in branched clusters from leaf axils near stem ends. Flower clusters are 3-6 in (8-15 cm) long. Fruits are papery, 3-winged, and 0.4 in (10 mm) long.

Japanese knotweed a. plant (Jenn Grieser); b. infestation (Leslie J. Mehrhoff, University of Connecticut)(a,b bugwood.org)

Japanese knotweed c. leaves (John Cardina, Ohio State University); d. flowers; e. fruits (d,e Leslie J. Mehrhoff, University of Connecticut)(c-e bugwood.org)

HABITAT: Japanese knotweed is frequently found in riparian, wetland, or lowland plant communities. It can inhabit a variety of sunlight, soil moisture, and human disturbance conditions, but has become especially problematic in full sun locations along the banks and floodplains of rivers and streams and moist roadsides.

ECOLOGY: North American Japanese knotweed is believed to reproduce primarily vegetatively, though increasing attention has been given to its reproduction by seed. Rhizome sprouting occurs from late spring through summer. Rhizome and stem fragments can give rise to new plants if sufficient moisture is present. Seeds are transported by wind, water, and wildlife. Seeds germinate during spring; their longevity in the soil is unknown. Flowering occurs in late summer to early fall. Leaves fall in winter, and plants die back to rhizomes.

BIOLOGICAL CONTROL: As of 2016, *Aphalara itadori* has been approved by TAG for release on Bohemian, giant, and Japanese knotweed, but it is still under review in the US. Releases were made in Canada in 2016, but only on Japanese knotweed. It is too soon to determine if this psyllid has established in the field.

NOTES: Giant knotweed grows taller and has larger leaves with heart-shaped bases and long hairs on their undersides. Use leaves from the middle of the stem for comparison as those at the tips are most variable. Bohemian knotweed leaves are variable in size between both parent species; hairs on their undersides are short with broad bases.

Aphalara itadori Shinji
Knotweed psyllid

DESCRIPTION: Eggs are creamy-white and elongated. Early nymphal instars are pale yellow to tan and more closely resemble adults through each subsequent instar. Adults are typically 2 mm long and are mottled tan and orange at first, turning darker brown with age. Their wings have tan veins and are translucent with mottled brown markings.

Aphalara itadori a. nymph; b. adults on Japanese knotweed stem; c. damage to Japanese knotweed plant (deformed leaves and stunted growth)(a-c Rob Bourchier, Agriculture and AgriFood Canada)

LIFE CYCLE: Overwintering adults lay eggs singly or in small groups on knotweed leaves during spring. They frequently lay 600-700 eggs in their lifetime. Feeding nymphs secrete crystallized honeydew that form white strings or flakes on knotweed plant surfaces. Nymphs and adults feed by piercing and sucking knotweed leaf and stem cells. Nymphs develop through five instars. There are typically 2-3 generations per year, depending on site conditions. Adults overwinter in nearby vegetation, oftentimes beneath the bark of evergreen trees.

DAMAGE: Both adults and nymphs feed on knotweeds, but nymphal feeding is most damaging. Feeding causes defoliation, deformation of remaining leaves, stunted growth, and reduced biomass in both above- and below-ground growth. Heavy infestations may kill attacked plants outright.

PREFERRED HABITAT: This species is tolerant of a wide temperature range in its native Japan, and it is believed to do better under humid rather than dry conditions.

RELEASE HISTORY: Individuals of the Kyushu strain from Japan, obtained via England, were released on Japanese knotweed in Canada in 2016 (ON in the East and AB, BC in the West).

CURRENT STATUS: It is too early following release to confirm establishment in the field in Canada. Additional releases are planned for subsequent years.

REDISTRIBUTION: Because populations are not currently confirmed to be established in the field, further releases are recommended. Any releases made should be done using laboratory colonies and under the guidance of appropriate authorities. In the future, should this biocontrol agent become established, field redistributions can be done by transferring leaves and stems infested with psyllids to new knotweed sites and placing them against uninfested foliage, taking care to keep stems cool until the transfer is completed. Establishment can be confirmed the following year by observing nymphs and adults or the nymphs' white secretions on knotweed leaves and stems.

NOTES: There are two strains of this biocontrol agent currently under study; the Kyushu (southern) strain performs best on Japanese and Bohemian knotweed, and the Hokkaido (northern) strain performs best on giant knotweed.

Japanese

Melaleuca

Melaleuca quinquenervia (Cav.) S. T. Blake

SYNONYMS: broad-leaved paperbark, paperbark, punk tree, white bottlebrush

ORIGIN: Native to Australia, New Caledonia, New Guinea and intentionally introduced to Florida, US several times in the early 1900s as an ornamental, timber source, soil erosion inhibitor, and as a means to drain wetlands.

DESCRIPTION: Evergreen tree typically growing 49-80 ft tall (15-24 m) from an adapting root system with above- and below-ground roots. Trees in dense stands have a single, moderately straight trunk while those in open infestations may be multi-stemmed with wide canopies. Branches are ascending on young trees and somewhat drooping on older trees. The corky bark is thick, consisting of many layers. Outer layers often become ragged and partly unrolled. Leaves are alternate, lance-shaped, leathery, gray-green, and give a camphor-like odor when crushed. Numerous flowers occur on creamy white "bottle brush" inflorescences 1-3 in long (2.5-8 cm). Capsule fruits are arranged in tight clusters of 30-70; each capsule contains 200-350 tiny brown seeds.

Melaleuca a. tree (Forest and Kim Starr, Starr Environmental); b. infestation (Amy Ferriter, State of Idaho)(a,b bugwood.org)

Melaleuca c. leaves and bark (Fir0002/Flagstaffotos); d. flowers, fruits, and foliage (Forest and Kim Starr, Starr Environmental); e. seeds (Tony Pernas, bugwood.org)

HABITAT: Melaleuca is found in subtropical climates with alternating wet and dry seasons. In southern Florida, it can be found in moist habitats including sawgrass prairies, freshwater marshes, and cypress and mangrove swamps, as well as the drier zones of pine flatwoods and hardwood bottomlands.

ECOLOGY: Melaleuca reproduces by seed and re-sprouting from cut branches and stems. Seeds germinate in moist soil. The adaptive root system follows a receding water table, producing vertical sub-soil roots and thread-like “water roots” that extend from surface roots and submerged trunk portions during flooding episodes. Trees can become reproductive in one year, but most flower only by the third year. Flowering occurs primarily in fall and secondarily in summer, though some flowers can be observed all year, and some trees flower multiple times a year. Stems continue growing beyond fruits and produce leaves or additional flowers. Seeds are released after interrupting events such as fire, frost, or wind damage. Seeds may remain on trees for 10 years, but are typically only viable for two years in the soil. Some trees can live more than 100 years.

BIOLOGICAL CONTROL: In combination, *Boreioglycaspis melaleucae, Lophodiplosis trifida,* and *Oxyops vitiosa* reduce plant height, branching, and biomass of surviving coppices and increase seedling mortality; repeated attack enables other plant species to grow. *Fergusobia quinquenerviae* and *Fergusonina turneri* failed to establish in the US. Additional species are being tested for potential future release into North America. The weed does not occur in Canada.

Boreioglycaspis melaleucae Moore
Melaleuca psyllid

DESCRIPTION: Eggs are yellow, cylindrical, and have a spine-like projection on one end. Nymphs more closely resemble adults through each subsequent instar. Early nymphal instars are pale yellow with no markings. Mature nymphal instars have gray to black markings and have filamentous wax loosely covering their bodies. Adults are up to 3 mm long and pale yellow-orange to white in color with gray to black markings. Their wings are transparent with yellow veins. Two finger-shaped appendages extend outward and downward from below their eyes.

Boreioglycaspis melaleucae a. eggs on tip of a melaleuca leaf; b. adult; c. waxy flocculence produced by nymphs on melaleuca foliage (a-c Susan A. Wright, USDA ARS Invasive Plant Research Laboratory)

LIFE CYCLE: This species is continuously brooded, creating frequent overlap of generations. Female adults insert the spine-like projections of eggs into melaleuca stems and leaves. They lay eggs singly or in small groups, but up to 275 in their lifetime. Nymphs secrete waxy filaments that cover their bodies as a form of protection. Wax secretions form a dense, woolly mass on stems and leaves. Nymphs and adults feed by piercing and sucking out the cell contents of melaleuca leaf and stem cells. Nymphs develop through five instars, each secreting copious amounts of honeydew. There are multiple generations per year (up to 13) depending on site conditions.

DAMAGE: Both adults and nymphs feed on melaleuca, but nymphal feeding is most damaging. Their saliva is thought to be phytotoxic and cause premature leaf drop. Heavy infestations kill attacked leaves, young plants, and saplings.

PREFERRED HABITAT: This species is well adapted to most habitats throughout southern Florida. High summer temperatures (above 86°F or 30°C) reduce psyllid populations during the summer months.

RELEASE HISTORY: Psyllids from Australia were released in Florida, US beginning in 2002.

CURRENT STATUS: This psyllid is well established throughout Florida, though populations are seasonably variable and densities are greatest in the south. In combination with *Lophodiplosis trifida*, *Oxyops vitiosa,* and the adventive rust *Puccinia psidii*, it causes severe damage to mature melaleuca trees. Cumulative damage is reduced plant height, branching, and biomass of surviving coppices as well as increased fruit abortion and seedling/sapling mortality. Summer temperatures possibly reduce population growth. Predation by generalist species may reduce populations as well, though this is likely insignificant.

REDISTRIBUTION: Stems infested with psyllids can be transferred to new melaleuca sites and placed against uninfested foliage, taking care to keep stems cool until the transfer is completed. At sites with high summer temperatures (above 86°F or 30°C), populations will be low during summer and redistributions likely ineffective during that time. Establishment can be confirmed the same or following year by observing nymphs and adults or the nymphs' dense waxy secretions on melaleuca leaves and stems.

NOTES: The melaleuca snout beetle *O. vitiosa* cannot establish at permanently flooded melaleuca sites because of its requirement to pupate in soil. *Boreioglycaspis melaleucae* is a good complement at these types of sites because it completes its life cycle entirely in the tree canopy.

Lophodiplosis trifida Gagné
Melaleuca gall midge

DESCRIPTION: Eggs are elongated and red-orange in color. Larvae are yellow to orange and are up to 1.5 mm long. Pupae are a yellowish-orange, becoming darker orange as they mature. Adults are very small (3 mm long) and have dark red bodies, tan heads, and pale gray wings and legs. They have fine, delicate legs and antennae.

Lophodiplosis trifida a. adult female (Susan A. Wright, USDA ARS Invasive Plant Research Laboratory); b. galls on melaleuca foliage (Matthew F. Purcell, USDA ARS Australian Biological Control Laboratory)

LIFE CYCLE: This species is continuously brooded, creating frequent overlap of generations. Females lay up to 160 eggs singly or in small groups on young melaleuca stems, buds, and leaves. Larvae burrow into stem or leaf tissue, and enzymes in their saliva initiate the formation of galls. Though galls develop in stems, buds, and leaves, it is stems that are most heavily galled. Larvae feed within galls through three instars. Galls may have single chambers housing one individual or several chambers, each housing a single larvae. Larger galls can be a few inches (several cm) long. Pupation occurs within galls. Adults are sexually mature upon emergence and live for up to five days. There are multiple overlapping generations per year.

DAMAGE: Galling halts growth of infested stems on young stems of mature trees and kills small seedlings and saplings.

PREFERRED HABITAT: This midge does best with high humidity and at sites with prolonged flooding or near water. Populations are reduced in dry habitats.

RELEASE HISTORY: Midges from Australia were released in Florida, US in 2008.

CURRENT STATUS: Though this species was introduced more recently than all other melaleuca biocontrol agents, it quickly established at all release sites except one where biocontrol agents were killed by frost. Populations are moderately abundant overall. Populations are high in areas with a long hydroperiod (wetlands) but lower in upland systems where they are restricted to the lower canopy. Galling reduces melaleuca sapling height by 10.1%, leaf biomass by 42%, woody biomass by 42.7%, and root biomass by 30.3%. In conjunction with the other established biocontrol agents, *L. trifida* decreases plant growth and survival.

REDISTRIBUTION: Sweeping adult midges is possible, though may be damaging. Instead, transfer stems infested with galls to new sites and place against uninfested foliage. It is important to keep galled stems moist and cool to prevent dessication. Establishment can be monitored throughout the following season by observing galls on new melaleuca shoots.

NOTES: The melaleuca snout beetle *Oxyops vitiosa* cannot establish at permanently flooded melaleuca sites because of its requirement to pupate in soil. *Lophodiplosis trifida* is a good complement to this biocontrol agent because it does best at moist and humid sites.

Oxyops vitiosa Pascoe
Melaleuca snout beetle

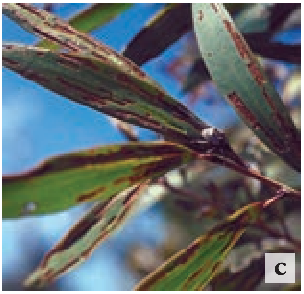
DESCRIPTION: Eggs are 1 mm long and yellow but are coated with a dark protective secretion. Larvae produce long, thin coils of feces and are covered in a protective oily secretion that turns dark with fecal matter. Early instars are small and yellow while mature larvae are up to 14 mm long, grayish, and slug-like in appearance. Adults are up to 9 mm long and reddish-brown initially but turn darker gray with age.

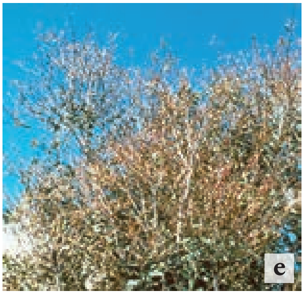
Oxyops vitiosa a. larvae, fecal coil, and feeding damage (Willey Durden, USDA ARS); b. adult (Gary Buckingham, USDA ARS)(a,b bugwood.org)

LIFE CYCLE: This species is continuously brooded, creating frequent overlap of generations. Females lay 500-1,000 eggs singly on young melaleuca leaves and expanding buds and twigs. Larvae are specialized feeders, feeding on the seasonal flush of young melaleuca leaves through four instars. They consume all layers of leaf tissue except the cuticle, leaving "window" feeding scars. At maturity, larvae drop from the host plant to burrow into the soil for pupation. Adults feed on melaleuca leaves, buds, and stems. Adult feeding damage to tough, older leaves is often superficial, resulting in narrow scars along the leaf surface. Adults are long-lived (over one year), and there are 2-3 generations produced per year in Florida's climate.

DAMAGE: Heavy larval and adult feeding causes defoliation and tip dieback which in turn stimulate new growth that acts as a nutrient sink and reduces reproductive output. New growth is subsequently attacked by continual generations of the beetle, increasing the impact further.

PREFERRED HABITAT: The snout beetle does best at sites with dry winter conditions and abundant young melaleuca foliage. Because this beetle pupates in the soil, persistent populations are rare in permanently flooded habitats.





Oxyops vitiosa damage c. feeding scars (Willey Durden, USDA ARS); d. normal undamaged branch (lower), defoliated branch (upper)(Peggy Greb, USDA ARS); e. severely defoliated (bare twigs) upper crown of trees (Ted D. Center)(c-e bugwood.org)

RELEASE HISTORY: Beetles from Australia were released in Florida, US from 1997.

CURRENT STATUS: This species is well established throughout Florida, though densities are greatest in the south. In combination with *Boreioglycaspis melaleucae, Lophodiplosis trifida,* and the adventive rust *Puccinia psidii,* it causes severe damage to mature melaleuca trees. Cumulative damage occurs as reduced plant height, branching, and biomass of surviving coppices as well as increased seedling mortality. Repeated attack enables other plant species to colonize sites.

REDISTRIBUTION: Despite being fairly widespread in Florida, it should be redistributed to sites where it is not yet established. Because beetles pupate in the soil, sites with prolonged flooding are not suitable for redistributions. Adults can be collected all year long but are most abundant in winter and spring. Adults can be tapped from foliage into collection trays or containers, or aspirated directly from the foliage. They can be transferred to new melaleuca sites in groups of 300-5,000. Establishment can be monitored the following year by observing adults or larvae on foliage, or by observing their characteristic feeding damage to young leaves and twigs.

Non-Established Biocontrol Agents

Fergusonina turneri Taylor (Diptera: Fergusoninidae) & *Fergusobia quinquenerviae* Davies & Giblin-Davis (Secernentea: Tylenchida)

Fergusonina and *Fergusobia* galls in melaleuca (Susan A. Wright, USDA ARS Invasive Plant Research Laboratory, bugwood.org)

DESCRIPTION AND LIFE CYCLE: *Fergusonina* gall flies and *Fergusobia* nematodes have a mutualistic relationship in that female flies oviposit both their own eggs as well as juvenile nematodes into melaleuca leaf and flower buds. Infection with the nematodes stimulates the formation of a gall, and fly larvae feed on gall tissue through all three instars. Female nematodes then invade third instar female fly larvae, laying eggs in and feeding on their hosts but not killing them. Third instars create "windows" in galls through which adults later emerge (following pupation within galls). All female flies contain nematodes. Juvenile nematodes migrate to the fly's oviducts in order to be oviposited in new melaleuca tissue along with fly eggs, thus repeating the cycle. Galls act as metabolic sinks, halting melaleuca stem elongation and preventing flower formation. Mature galls are green to reddish-yellow, 0.5 in (1.3 cm) in biology, and often appear as grape-like clusters of multiple fly chambers. Adult flies are 3-5 mm long and pale yellow with lateral stripes on the abdomen. They have iridescent green eyes and transparent wings. Larvae are white and up to 2.5 mm long. Adult nematodes are worm-like, unsegmented, and tiny (less than 1 mm long).

RELEASE HISTORY: Because *Fergusobia quinquenerviae* is a mutualistic nematode of *Fergusonina turneri,* both were released together. Individuals sourced from Australia were released in Florida, US from 2005-2007. This pair failed to establish despite multiple introductions and efforts to improve synchronization with the susceptible stage of melaleuca (buds). They temporarily colonized release sites, but disappeared completely after three generations.

Unapproved Non-Indigenous Natural Enemy

Puccinia psidii (G.Winter)
(Pucciniomycetes: Pucciniales)

Puccinia psidii infecting leaves of melaleuca (Forest and Kim Starr, Starr Environmental)

DESCRIPTION AND LIFE CYCLE: Though *Puccinia psidii* produces teliospores and basidiospores, urediniospores are the dominant spore form and most characteristic. Urediniospores are yellow gold, round, covered in short spines, and tiny (27 µm). Spores occur in powdery mass clusters (pustules) on both sides of infected leaves. Leaves become discolored shortly after infection. Even lightly infected leaves turn gray brown at the site of infection; severely infected leaves are heavily distorted and ultimately defoliated. Infected twigs develop lesions and localized swellings. Urediniospores are easily blown to uninfected plants to repeat the entire cycle within two weeks.

HISTORY AND CURRENT STATUS: This rust was first described in Brazil, but recorded from numerous host species throughout Central and South America and the Caribbean. It was first recorded on melaleuca in Florida (US) in 1997 and has since been found on melaleuca throughout southern Florida. Where infections are high, damage is significant. In combination with two insects, *Boreioglycaspis melaleucae* and *Oxyops vitiosa*, it causes reductions in plant height, branching, and biomass of mature melaleuca as well as causing increased seedling mortality. **Though it was studied upon arrival for its potential in biological control, this species was rejected and is not approved for redistribution in the US.**

Multiflora rose

Rosa multiflora Thunb.

SYNONYMS: baby rose, Japanese rose, many-flowered rose

ORIGIN: Native to Asia and intentionally introduced to North America on multiple occasions since the early 1800s as an ornamental. Between the 1930s and 1960s, it was widely planted for erosion control, wildlife cover, and as a living fence.

DESCRIPTION: Rambling shrub with multiple stems growing up to 15 ft tall (4.6 m) and 21+ ft wide (6.5 m) from an extensive fibrous root system. Stems are bright green to reddish, 0.6 in (1.5 cm) in cross-section, and usually covered with stiff, curved thorns. Stems are typically arching and can root when in contact with the ground; stems may occasionally climb among low tree branches. The compound leaves are alternate, deeply fringed where they attach to stems, and have 5-11 leaflets arranged in pairs with one terminal leaflet. Leaflets are elliptical, 1 in long (2.5 cm), and have toothed margins. The undersides of leaflets have tiny hairs. Flowers are 0.5-1 in (1.3-2.5 cm) across with 5 notched white or slightly pink petals and appear in large clusters. The small, clustered fruits (rose hips) each contain up to 20 tan seeds; fruits turn red and leathery in fall.

Multiflora rose a. shrub (Leslie J. Mehrhoff, University of Connecticut); b. infestation (Nancy Dagley, USDI NPS)(a,b bugwood.org)

Multiflora rose c. leaflets, fringed leaf base, thorns on stem (Rob Routledge, Sault College); d. flowers (Karan A. Rawlins, University of Georgia); e. mature fruits (James H. Miller, USDA FS)(c-e bugwood.org)

HABITAT: Multiflora rose does best in sunny areas with well-drained soils, but it tolerates a wide range of soil, moisture, and light conditions. It can form impenetrable thickets in open woodlands, prairies and fields, and along stream banks and roadsides.

ECOLOGY: Multiflora rose spreads by seed, root suckering, and by its arching branches rooting when they touch the soil. Seeds germinate throughout spring, with highest rates occurring in full sun. Plants may grow slowly for the first 1-2 years, followed by rapid expansion through root suckering and stem rooting. Flowering occurs in spring to early summer. A single mature plant can produce over one million seeds per year. Fruits remain on plants over the winter. Most new plants arise from seeds dropped near the parent plant, though birds and mammals also eat the fruits and disperse seeds large distances. Seeds may remain viable in the soil for 10-20 years. The leaves are deciduous, falling from the tree in autumn and winter. New leaves emerge in early spring.

BIOLOGICAL CONTROL: The native mite *Phyllocoptes fructiphilus* vectors the virus Rose Rosette Disease which can kill multiflora rose. Though the virus has been redistributed and studied extensively in the US, it is not an effective biocontrol agent and can decimate some commercial, ornamental and native roses. Redistribution of the mite and virus are not recommended, though both are widespread and are continuing to spread on their own. **There are no approved biocontrol agents in the US or Canada.**

Native and Unapproved Natural Enemies

Rose Rosette Disease
(Negative-strand RNA virus, genus Emaravirus)

& *Phyllocoptes fructiphilus* Keifer
(Acari: Eriophyidae)

DESCRIPTION AND LIFE CYCLE: Rose rosette disease is a virus that infects rose species (genus *Rosa*) and is transmitted both by grafting and by the mite *Phyllocoptes fructiphilus*. All stages of the mite are tiny and best viewed through a microscope. Adults are spindle-shaped, yellow to amber, 0.14-0.17 mm long, and have 4 legs. Females lay eggs on developing rose shoots in spring. Larvae and nymphs are translucent and resemble adults but are smaller in size. They develop within the leaf folds of new shoots or under leaf petioles. Larvae, nymphs, and adults all feed by piercing and sucking cell contents of tender growing tissue of multiple rose species. There are multiple generations per year, and adults overwinter under rose bark, old bud scales, and on living rose tissues. Mites can be distributed by the wind and by contaminated clothing and equipment. Symptoms of the virus are highly variable, depending on the rose species, cultivar, or even individual plant affected. Some of the more recognizable symptoms include leaves that are red for the entire growing season or have mosaic-pattern discoloration, leaves that are unusually long and thin, stems with excessive thorniness, thickening or flattening, a clustered mass of small branches (witch's broom), a mass of distorted flower buds, a dieback of shoots, and severe yellowing and stunting of plants.

HISTORY AND CURRENT STATUS: While the mite *P. fructiphilus* is native to North America, there is still debate on whether the virus is native as well. The virus

Rose Rosette Disease a. head of vector mite magnified (West Virginia University); b. virus-caused excessive thorniness and red foliage; c. virus-caused witch's broom branch and flower bud mass (b,c Jennifer Olson, Oklahoma State University)(a-c bugwood.org) was first identified in Manitoba, Canada in 1940 and in the US in 1941. Both the mite and the virus attack native, commercial, and ornamental roses in North America. In the absence of the virus, the mite produces no visible symptoms on rose plants. Mites can only effectively transmit the virus when feeding on rapidly growing tissue, which only occurs in the spring or after abundant rainfall. Dispersing mites do not infect many plants that are greater than ~330 ft (100 m) from heavily infested plants, so natural spread of the disease is relatively slow except within densely populated patches. Rose Rosette Disease has been credited with aiding the reclamation of some pastureland within 5-6 years of its introduction. The virus takes ~2-6 years to kill multiflora rose. Large infected plants can still successfully produce seed that can remain viable for up to 20 years. Even if new plants become infected with the virus, they will re-seed before they can be killed; therefore, the disease is not an effective natural enemy for this weed problem. The virus was intentionally redistributed on multiflora rose in IA, MD, and WV, and it has been studied extensively. Additional efforts to distribute the virus or mite have been curtailed because of public concern over the risk to commercial, ornamental and native roses. Both the insect and virus are widespread in eastern and mid-western North America and continue to spread on their own.

Brazilian peppertree

Schinus terebinthifolius Raddi

SYNONYMS: Christmas berry, Florida holly, pink pepper

ORIGIN: Native to South America and intentionally introduced to Florida, US in the 1800s as an ornamental; it became naturalized in the 1950s.

DESCRIPTION: Evergreen shrub or small tree typically growing 10-40 ft tall (3-12 m) from a shallow, suckering root system. Most plants have a short trunk hidden in a sprawling thicket of branches. Branches/stems have gray bark and are usually less than 4 in (10 cm) in diamter. The compound leaves are alternate, 3-6 in long (8-15 cm), and usually have 7-9 leaflets. Leaflets are arranged opposite each other with one terminal leaflet. Leaflets are 1-2.8 in long (2.5-7 cm) by 0.4-1.2 in wide (1-3 cm), oval to elliptical with smooth to toothed margins, and have obvious veins. They give off a strong turpentine odor when crushed. Male and female flowers usually appear on separate plants (dioecious). Both flowers are tiny with 5 white petals and appear in large clustered inflorescences up to 5 in long (13 cm) from leaf axils near branch ends. Each female flower produces a single dark red, berry-like fruit with a single seed.

Brazilian peppertree a. mature plant (Stephanie Sanchez); b. infestation (Forest and Kim Starr, Starr Environmental))(a,b bugwood.org)

Brazilian peppertree c. leaves and leaflets (Stephanie Sanchez); d. flowers (James H. Miller, USDA Forest Service); e. fruit (USDI National Park Service)(c-e bugwood.org)

HABITAT: Brazilian peppertree grows in tropical to subtropical regions and is a pioneer of disturbed sites, such as highway rights-of-way, fallow fields, and drained cypress stands, but can move outwards into undisturbed pinelands, mangrove forests, coastal shorelines, and marshes. It does well in mesic to wet locations below 650 ft (200 m) in elevation. Cold intolerance prevents its expansion into more temperate regions.

ECOLOGY: Brazilian peppertree reproduces by seed and by suckering roots. Seeds germinate throughout winter and spring. Seedlings can survive (but grow slowly) in shade; they can grow 12-20 in (30-50 cm) per year in full sun. Plants can become reproductive in three years. Flowering occurs primarily in fall with a small amount of flowering in spring/early summer. A single plant can produce thousands of ripe fruits that are retained on the plant for up to 8 months and are readily eaten/spread by birds and mammals. Seeds are typically only viable for up to 5 months after dispersal. Some trees can live up to 35 years. The shallow root system readily produces suckers. These develop into new plants, creating very dense Brazilian peppertree infestations.

BIOLOGICAL CONTROL: As of 2016, no biocontrol agents have been approved; *Pseudophilothrips ichini* and *Calophya latiforceps* are expected to be approved and released in the near future.

NOTES: The dried fruits of Brazilian pepper are used as a spice and are sold in gourmet shops in the US as "pink peppercorn."

Unapproved Non-Indigenous Natural Enemy

Megastigmus transvaalensis (Hussey) (Hymenoptera: Torymidae)

Megastigmus transvaalensis adult (Sergio Jansen Gonzalez)

DESCRIPTION AND LIFE CYCLE: Adults are 2-3.5 mm long and yellow-brown with clearish wings. Females lay up to 25 eggs singly within fruits. Eggs are white, smooth, and oval-shaped with a long stalk and tiny spur. Larvae are up to 3 mm long, white to yellow, and somewhat barrel-shaped. Larvae feed on fruit and seed tissue through five instars. Pupation occurs within fruits; pupae remain in diapause for several months, emerging during fall. There are two generations per year, synchronized with the fall and spring production of fruit.

HISTORY AND CURRENT STATUS: This wasp is likely of South African origin and spread to the US via the pink peppercorn trade. It was first found in CA, US before 1961 and in FL by 1988. Adults typically attack 22-76% of Brazilian peppertree fruits, preventing seed germination. Abundance and impact vary, however, by season and location. Despite being intentionally moved around in FL prior to 2011, **this species has not been officially approved in the US.**

Tropical soda apple

Solanum viarum Dunal

SYNONYMS: sodom apple, yu-a, tutia de vibora, joa bravo, joa amarelo pequeno

ORIGIN: Native to South America, it was introduced to North America by 1988, likely adhering to shoes or escaping cultivation.

DESCRIPTION: An herb or partially woody subshrub that grows as a perennial or an annual. Tropical soda apple has an extensive root system growing up to 1 ft deep (30 cm) with shallow, lateral branches extending outwards 3-6 ft (0.9-1.8 m). Mature plants are 3-6 ft tall (0.9-1.8 m) and have multiple sturdy, branching stems. Stems, branches, and leaves are covered in short, fine hairs. Leaves are broadly oval, 4-7 in long and 2-6 in wide (10-18 cm x 5-15 cm), and deeply lobed with lighter-colored veins. Rigid, yellow spines up to 0.8 in long (2 cm) are scattered on stems, branches, and leaf veins. Flowers are 0.6 in across (1.5 cm) with five white, recurved petals and occur in small clusters on stems below the leaves. Fruits are berries up to 1 in across (2.5 cm) that are mottled green when

Tropical soda apple a. plant (Florida Division of Plant Industry, Florida Department of Agriculture and Consumer Services); b. infestation (J. Jeffrey Mullahey, University of Florida)(a,b bugwood.org)

Tropical soda apple c. leaves (Karan A. Rawlins, University of Georgia); d. flower (Rebekah D. Wallace, University of Georgia); e. spines, young fruits, leaf (J. Jeffrey Mullahey, University of Florida)(c-e bugwood.org)

young (resembling watermelons) but turn yellow at maturity. Each contains up to 400 seeds. A single plant may produce more than 50,000 seeds annually.

HABITAT: Tropical soda apple capitalizes on disturbance to invade new areas, and can then spread into neighboring undisturbed sites. In the US, it is largely a weed of pastures and rangeland, but can also be found in conservation areas, cultivated fields, citrus groves, hammocks, roadsides, and ditch banks.

ECOLOGY: Tropical soda apple reproduces by seed and buds on its lateral roots. Both germination and flowering occur year-round but primarily in fall through spring. Though it is typically a perennial, this weed can sometimes grow as an annual germinating, flowering, and dying in the same year. In mild climates, the plant is green year-round. In temperate regions, the plant dies back with frost and re-sprouts from root buds the following spring.
Seeds are readily transported by cattle, wildlife, water, and hay, and may stay viable for two years.

BIOLOGICAL CONTROL: *Gratiana boliviana* was released in 2003 and is now abundant in southern and central FL, US where it is highly effective in reducing tropical soda apple plant density. Its northern distribution is limited by cold. The bioherbicide SolviNix® was registered in 2014 in the US for use in pastures and wooded areas. Infected plants die within ~6 weeks of inoculation. The weed does not occur in Canada.

Gratiana boliviana Spaeth
Tropical soda apple leaf beetle

DESCRIPTION: Eggs are oval-shaped, up to 1.8 mm long, and encased in two translucent, papery membranes. Larvae are pale green, up to 6 mm long, and have spines along their margins on which they accumulate molted skins and frass (used as camouflage). Adults are up to 6 mm long and 5 mm wide and have a hard protective covering. Females are slightly larger than males. Reproductive adults are green while adults in diapause are light brown.

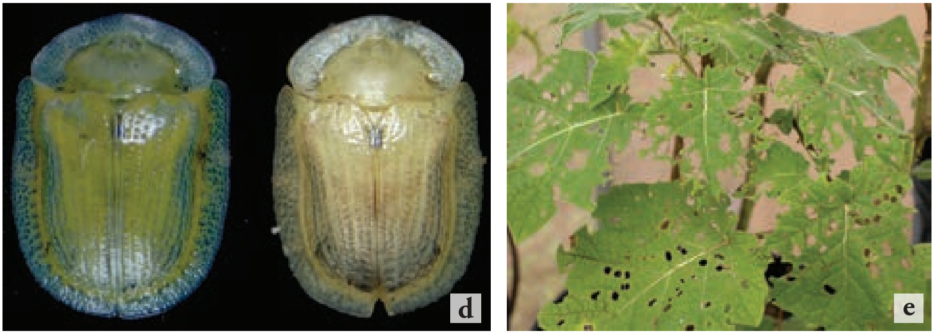
Gratiana boliviana a. egg; b. larva with frass and molted skin; c. adult (a-c Rodrigo Diaz, Louisiana State University)

LIFE CYCLE: Adults emerge in early spring and feed on tropical soda apple foliage, creating a distinctive "shot-hole" feeding pattern. Eggs are deposited singly (but up to 300 per female lifetime) onto tropical soda apple leaves. Larvae feed on the undersides of young leaves through five instars; their feeding also creates "shot-hole" patterns. Pupa are attached to the undersides of tropical soda apple leaves. The entire life cycle can be completed in a month; in Florida, there are 7-8 generations per year. Last generation adults enter diapause in leaf litter during winter, which allows them to survive cold temperatures and food scarcity.

DAMAGE: Larval and adult feeding reduces photosynthetic capabilities of attacked plants and facilitates secondary attack by plant diseases. These stresses reduce the growth and reproduction of tropical soda apple plants, decreasing competitive ability.

PREFERRED HABITAT: Beetle numbers are greater in open habitats, but feeding damage and beetle survivability are higher in shaded habitats. This species appears to be hindered by cold temperatures.

RELEASE HISTORY: Individuals from Argentina and Paraguay were released in the southeastern US beginning in 2003 (AL, FL, GA, TX).



Gratiana boliviana d. reproductive adult (left) and adult in diapause (right); e. adult feeding damage (d,e Rodrigo Diaz, Louisiana State University)

CURRENT STATUS: *Gratiana boliviana* is now widespread and abundant in south and central FL but is limited or absent in northern FL. Successful overwintering was initially observed in AL, GA, and TX, but permanent establishment has not been confirmed. In FL, larval and adult feeding cause defoliation and inhibit fruit production, though insect abundance is variable across the landscape. At high densities, beetles have been attributed with up to 90% decline in plant density within three years of release, and the weed is now limited at many sites.

REDISTRIBUTION: The prickles and spines of tropical soda apple impede sweep nets at most infestations. Instead, adults can be aspirated directly from plant foliage in spring through fall. These can be transferred to new, uninfested sites in groups of 100-500. Establishment can be monitored later in the same or subsequent year by observing larvae and adults on plant foliage or finding their distinctive shot-hole feeding patterns in tropical soda apple foliage.

NOTES: **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Tobacco mild green mosaic tobamovirus

SolviNix®

DESCRIPTION AND LIFE CYCLE: When this virus is inoculated on its host, tropical soda apple, it elicits a lethal hypersensitive response from the plant whereby the plant develops necrotic lesions on the leaves, followed by wilting and death. Plants of all ages are killed in 2-6 weeks. The virus becomes inactive in water and in soils after 6 months. This virus must be transmitted by physical contact, but it has no known insect vectors or other natural modes of transmission.

HISTORY AND CURRENT STATUS: This virus occurs naturally in many parts of the US and around the world. Following extensive host-specificity and safety testing, a select strain, U2, was approved and registered as the bioherbicide SolviNix® for use on tropical soda apple in the US in 2014. It is commercially available in liquid concentrate from the company BioProdex, Inc. When used according to label instructions, this bioherbicide kills tropical soda apple plants (including roots) within six weeks of inoculation. **This bioherbicide is not approved for use in Canada; the weed reportedly does not occur in Canada.**

Tropical soda apple a. leaf with tobacco mild green mosaic tobamovirus lesions; b. before (left) and after (right) inoculation with the virus (a,b Raghavan Charudattan, BioProdex, Inc.)

WATERLETTUCE
Pistia stratiotes L.

SYNONYMS: water lettuce, Nile cabbage, water cabbage, shellflower

ORIGIN: Native to the tropical Americas, Asia, Malesia, and Australia. It is present in fossil records from North America prior to the Pleistocene, but is believed to have been exterminated from the continent and then reintroduced (likely accidentally) in the 1700s during European colonization of Florida.

DESCRIPTION: Herbaceous aquatic that grows as a perennial but may behave as an annual in temperate regions where it is introduced. As indicated by the common name, waterlettuce consists of a rosette that resembles a floating head of lettuce. It has stolons and an abundance of feathery roots extending up to 20 in (50 cm). There are numerous wedge-shaped leaves per rosette. Each leaf has parallel veins and is fleshy, 1-6 in long (2.5-15 cm), green to gray-green, and covered with dense, white, water repellent hairs. The inflorescence is an inconspicuous spadix up to 0.6 in tall (1.5 cm) with 6-8 male flowers in a single whorl around the center and one female flower below. Flowers are enclosed by a

Waterlettuce a. plants b. infestation (a,b Forest and Kim Starr, Starr Environmental)

Waterlettuce c. leaves; d. flowers (Keisotyo); e. small plant with roots (c,e Forest and Kim Starr, Starr Environmental)

white, hairy, leaf-like spathe. There are up to 6 inflorescences per rosette, hidden among interior leaves. Fruits are small green berries.

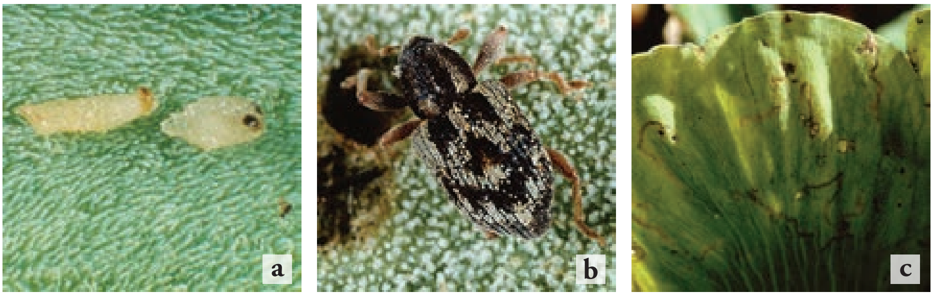
HABITAT: Waterlettuce prefers slow-moving or stagnant water and is frequently found in lakes, ponds, and canals.

ECOLOGY: This species reproduces both by seeds and stolons. Terminal buds on lateral stolons give rise to new rosettes. Up to 15 secondary rosettes may be attached to a primary plant and form large mats. Daughter plants break off and are carried by water currents, boats or wildlife to start new populations. Flowers may be found year-round in warm climates, but peak flowering occurs during summer. Seeds remain dormant for long periods in dry sediments when water levels recede in dry seasons, and readily germinate when rehydrated during rains or flooding. Waterlettuce is sensitive to frost and dies back in winter. In temperate regions, the plant behaves as an annual that regrows from the seed bank each year, or it is reintroduced annually by aquatic plant enthusiasts.

BIOLOGICAL CONTROL: *Neohydronomus affinis* was released in the southern US from 1987. It dispersed well but has had variable success. At some sites, it rapidly eliminated waterlettuce; at others, the weed persists. *Spodoptera pectinicornis* was released in the US from 1990 but failed to establish. The weed does not occur in Canada.

Neohydronomus affinis Hustache
Waterlettuce weevil

DESCRIPTION: Eggs are small, oval, and cream-colored. Larvae are up to 3 mm long and have a white or yellow body with a brown head capsule. Adults are approximately 2 mm long and have a nearly straight snout with an obvious constriction at the base. Adults range from golden-brown to bluish-gray. Bare patches form on the elytra where the scales are rubbed off, giving the adults a chevron-like pattern. Females are usually slightly larger than males.



Neohydronomus affinis a. larva (left) and pupa (right); b. adult; c. damage (a-c USDA ARS, bugwood.org)

LIFE CYCLE: At warm locations, both *Neohydronomus affinis* and waterlettuce develop throughout the year; adult and pupae are the stages most often observed over winter. Adult females lay eggs singly in holes they chew in the upper surface of leaves near leaf margins. Larvae mine into leaves and feed towards the spongy tissue of leaves through three instars. This leaves a distinctive mining trail clearly visible in thin leaf tissue. Pupation occurs within leaves. Emerging adults feed on waterlettuce leaves, creating round feeding holes and occasionally chewing into the leaf spongy tissue. There are three generations per year in the native range.

DAMAGE: Adult feeding and larval mining destroys leaf bouyancy, and attacked plants sink and die under high weevil densities.

PREFERRED HABITAT: This weevil develops fastest and feeds most actively in warmer temperatures and on large nutrient-rich waterlettuce plants.

RELEASE HISTORY: Weevils collected in Brazil were released in Australia, and from Australia were redistributed to the US (FL 1987, TX 1991).

CURRENT STATUS: *Neohydronomus affinis* disperses well and within 18-30 months of its release, waterlettuce was eliminated from three of four original release sites in FL. Though it has proven effective at many sites in the southeastern

US, establishment has not been universal, and long-term suppression of waterlettuce has not been achieved.

REDISTRIBUTION: Where the weevil has been released and failed (and/or in cold climates), further introductions may not prove successful or may be required annually. At warm locations where the weevil is not already present, it can be introduced by transferring plants infested with larvae and pupae, taking care to keep the collected plant material cool and moist until they can be transferred and to avoid transferring other insects or parasitoids. Establishment can be monitored later in the same or subsequent year by observing larval mining scars or adult feeding scars, or by observing actively feeding larvae and adults.

NOTES: Some early release literature listed their target biocontrol agent as *Neohydronomus pulchellus.* Subsequently it was clarified the early material was *N. affinis* and not *N. pulchellus.* **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Waterlettuce, Non-Established Biocontrol Agent

Spodoptera pectinicornis (Hampson) (Lepidoptera: Noctuidae)

Spodoptera pectinicornis adult (USDA ARS, bugwood.org)

SYNONYMS: *Namangana pectinicornis* (Hampson), *Epipsammea pectinicornis* (Hampson)

DESCRIPTION AND LIFE CYCLE: Adults have mottled brown forewings with light and dark markings and have creamy-white hindwings. They have a wingspan of 19-23 mm; females are slightly larger than males. Adults are generally only active (and mate) at night. Females lay up to 1000 eggs in their lifetime, depositing these in masses of up to 150 on both sides of waterlettuce leaves. Eggs are tiny, round, and yellow-green. Larvae feed on the spongy tissue within leaves and on leaf buds. Larvae are yellow-green initially but become green intermixed with brown by the final instars. They can be up 25 mm long and feed through six instars. Pupation occurs within leaves. Adults are short-lived and do not feed on waterlettuce. This species is continuously brooded throughout the year, creating frequent overlap of generations.

RELEASE HISTORY: Individuals from Thailand were released in FL and TX, US beginning in 1990. The moth was initially believed to have established following multiple and varying release attempts. Populations have since dwindled and are no longer detectable. **This species has not been released in Canada; the weed reportedly does not occur in Canada.**

Air potato
Dioscorea bulbifera L.

SYNONYMS: air potato, air yam, bitter yam

ORIGIN: Native to Africa, Asia, and Australia. Introduced to North America intentionally in 1905 (as a possible food crop or ornamental), it quickly became invasive.

DESCRIPTION: Herbaceous, perennial twining vine growing from persistent subterranean tubers that resemble small, oblong potatoes (up to 6 in or 15 cm in diameter). Vines are non-spiny and grow 66 ft (20 m) or longer, blanketing trees and surrounding vegetation. Leaves are alternate, smooth-margined, heart-shaped, attached by long petioles, and up to 8 in long (20 cm) and nearly as wide. Leaf veins are deep; all arise from the same point and terminate at the same point. Bulbils (aerial tubers) arise from leaf axils. There are two bulbil morphotypes: brown and tan; bulbils are typically round or angled, 0.4-5 in wide (1-13 cm), and give the plant its common name of "air potato". Male and female flowers (rarely present in North America) occur on separate plants on small hanging spikes arising from leaf axils in summer. Flowers are white to pale green, fragrant, and small. Seeds are tiny and partially winged.

Air potato a. vines growing up a tree; b. infestation (a,b Forest & Kim Starr)

Air potato c. leaves (James H. Miller, USDA Forest Service, bugwood.org); d. flowers, infrequent in the field (Karen Brown, University of Florida, bugwood.org); e. brown bulbil (Forest & Kim Starr)

HABITAT: Air potato can be found growing in moist, mesic, and/or hardwood forests. It is frequently found in disturbed areas, forest gaps, and along roadsides. Air potato is less common in coastal areas and pine forests.

ECOLOGY: Subterranean tubers and bulbils sprout in spring. Vines can grow outwards or climb into the canopy by twining around trees (up to 8 in or 20 cm per day in summer). While air potato can reproduce by seed, it rarely flowers in North America. Reproduction usually occurs vegetatively when bulbils fall to the ground and produce new stems. Up to 200 bulbils are produced per plant throughout summer and autumn, and these fall to the ground in autumn and winter months. Vines die back in winter. Bulbils are carried long distances by water and are frequently transported on machinery and equipment.

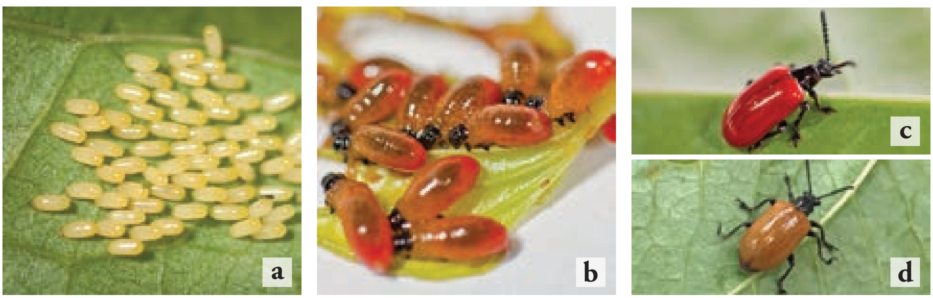
BIOLOGICAL CONTROL: *Lilioceris cheni* was released in the US in 2011 and is already having significant impacts by reducing vine density and bulbil production. Redistribution of this species is recommended, and it is being mass reared and released in Florida. One additional species is being tested for potential future release into North America. The weed does not occur in Canada.

NOTES: Some varieties of air potato are edible and cultivated as a food crop, especially in West Africa.

Lilioceris cheni Gressitt & Kimoto

Air potato leaf beetle

DESCRIPTION: Two biotypes have been released: Chinese and Nepalese. Eggs are pale yellow, cylindrical, and up to 1 mm long. Early instars of the Chinese biotype are reddish while those of the Nepalese biotype are more yellowish; both become gray in later instars. Late instars are up to 7 mm long and have a black head capsule. Larvae are frequently coated in a sticky secretion to which fecal matter adheres. Pupae are pale orange, up to 7 mm long, and enclosed in a foam-like matrix covered with soil and other particles. Adults are up to 9 mm long with bulging eyes and black heads, legs, abdomens, and antennae. The elytra of the Chinese biotype are typically red, while the Nepalese biotype is a rusty orange.



Lilioceris cheni a. eggs; b. larvae (Chinese biotype); c. adult (Chinese biotype)(a-c Melissa C. Smith, USDA ARS Invasive Plant Research Laboratory); d. adult (Nepalese biotype, Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory)

LIFE CYCLE: Overwintering adults emerge in spring, feed on air potato foliage and lay eggs (700-1900+ during their lifetime) in loose clusters on the undersides of expanding air potato leaves. Beetles chew through the veins of a young leaf prior to ovipositing, causing leaf edges to cup or curl inwards. Larvae feed on air potato leaves and occasionally newly forming bulbils through four instars, skeletonizing leaves from the undersides. At maturity, larvae enter the soil and orally secrete a foam-like substance in which to pupate. The foam-like substance becomes covered with soil and other particles and hardens. Many pupae can often be found in the same foam matrix. Emerging adults feed on air potato foliage and occasionally newly forming bulbils. There are multiple overlapping generations per year, and adults overwinter in soil and plant litter.

DAMAGE: Adult and larval feeding on air potato leaves reduces photosynthetic capacity and may stunt growth and limit bulbil production. Damage to growing tips inhibits vine elongation and may reduce the plant's ability to climb vertical structures.

Lilioceris cheni e. pupal foam-like matrix covered with soil and other particles (William A. Overholt, University of Florida); f. oviposition damage resulting in leaf cupping; g. heavy feeding causing skeletonization of air potato leaves (f,g Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory)

PREFERRED HABITAT: Specific habitat requirements are unknown.

RELEASE HISTORY: In FL, the Chinese biotype was released in cages in 2011 and in the open from 2012 onward. Releases of the Chinese biotype were made in GA beginning in 2015. The Nepalese biotype was first released in FL, GA, and LA in 2016.

CURRENT STATUS: Following very large mass-rearing and distribution programs, leaf beetle populations are now well established and very effective in Florida. At many sites, vine density and bulbil production have been reduced by 25-70%, and impact is still increasing.

REDISTRIBUTION: The beetles are being mass reared in Florida, and most releases are currently made from these laboratory colonies. As populations increase, field redistributions can be done by tapping adults from stems and foliage into cachement containers throughout the growing season. These can be transferred to new, uninfested sites in groups of 50-100. Establishment can be monitored the following season by observing adults or larvae feeding on air potato foliage.

Old World climbing fern

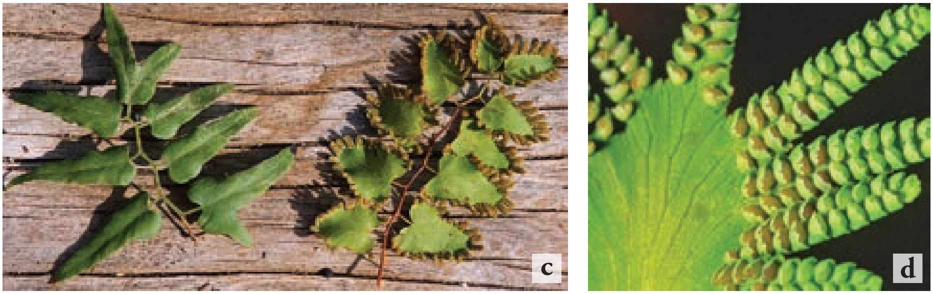
Lygodium microphyllum (Cav.) R. Br.

SYNONYMS: Lygodium, climbing maidenhair fern, small-leaf climbing fern

ORIGIN: Native to the wet tropics and subtropics of Australia, Africa, Asia, and Oceania, Old World climbing fern was introduced to the US as an ornamental in the mid 1900s. It was first found naturalized in Florida in 1965.

DESCRIPTION: Herbaceous, perennial climbing fern growing from brown, wiry rhizomes. The rachises (midribs) of fronds are twining and grow up to 90 ft long (27 m), blanketing trees and surrounding vegetation; old rachis material can form dense mats (3.3 ft or 1 m deep) on the ground. Rachises are green or brownish when alive and dark brown and wiry when dead. Leafy branches off the main stem are 2-5 in (5-12 cm) long and each contain several pairs of leaflets. Leaflets are either sterile or fertile. Both types are 1-2.4 in (2.5-6 cm) long, triangular-shaped, and attached by small stems. Sterile leaflets generally have smooth margins and may be lobed while fertile leaflets are fringed with tiny lobes of enrolled leaf tissue that cover the reproductive (spore-producing) parts.

Old World climbing fern a. plant (Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory); b. infestation (Tony Pernas, NPS, bugwood.org)



Old World Climbing Fern c. sterile leaflet (left), fertile leaflet (right)(Peggy Greb, USDA ARS); d. fertile leaflet close-up (Amy Ferriter, State of Idaho)(c,d bugwood.org)

HABITAT: This species is frequently found in moist tropical zones and is capable of establishing without disturbance. In Florida, it is found invading hardwood and hydric hammocks, mesic and wet flatwoods, forested and strand swamps, sawgrass prairies, as well as weedy communities.

ECOLOGY: Old World climbing fern spreads vegetatively via its creeping fronds and rhizomes and via spore dispersal. Vegetative growth and spore production occur year-round in Florida. Fertile leaflets are usually produced in exposed locations where the plant receives sufficient sunlight. Spore production is prolific, and spores are easily spread by wind and contaminated hay and equipment and may remain viable for more than four years after their release. Germinating spores give rise to young Old World climbing fern plants (sporelings).

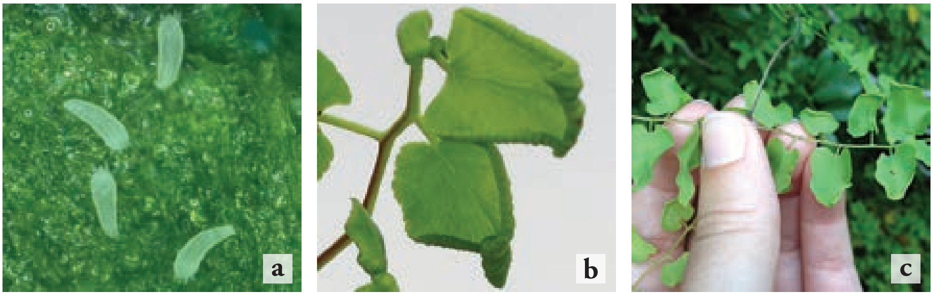
BIOLOGICAL CONTROL: Releases of the mite *Floracarus perrepae* and the brown lygodium moth, *Neomusotima conspurcatalis,* began in the US in 2008. Both species established, and both are having variable impacts on the weed. Despite multiple releases since 2004, the white lygodium moth, *Austromusotima camptozonale,* failed to establish. Additional species are being tested for potential future release into North America. The weed does not occur in Canada.

NOTES: Thick skirts of old rachises and fronds often encase trees and serve as ladders that carry fire into tree canopies, killing trees that are normally able to withstand ground fires.

Floracarus perrepae Knihinicki & Boczek

Lygodium mite

DESCRIPTION: All stages of this species are tiny and best viewed through a microscope. Eggs are spherical and white. Larvae and nymphs are transparent and resemble adults but are smaller in size. Adults have 4 legs and are cream-colored at first, darkening gradually to brown at maturity.



Floracarus perrepae a. magnified adults; b. leaf galling/rolling up close; c. leaf galling/rolling on frond (a-c Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory)

LIFE CYCLE: All stages of this species are active year-round, but activity is highest in south Florida during the dry season when temperatures are moderate and rainfall is lower. Adult females lay eggs (~37-58 per lifetime) between newly emerging leaflets of Old World climbing fern sporelings (newly germinated plants). Larvae, nymphs, and adults all feed by piercing and sucking cell contents. Feeding on leaflet edges causes leaflets to roll and gall. Though leaf roll galls frequently contain multiple mites, a single adult is capable of inducing a gall. Subsequent generations lay eggs and feed within the gall, which provides a humid and safe environment from predators. There are multiple generations per year. Mites move between plants and sites by walking or jumping; jumping allows mites to move great distances via wind dispersal.

DAMAGE: Larval, nymph, and adult feeding damage deforms frond/rachis growth tips and may kill sporelings. Feeding causes leaflets to form leaf roll galls that act as physiological sinks and reduce plant biomass; galled leaflets sometimes turn brown. Mites preferentially feed on young, sterile leaflets.

PREFERRED HABITAT: Mites do best under moderate to high humidity and moderate ambient temperatures (~70°F or 21°C) and favor new, soft green foliage for gall initiation.

RELEASE HISTORY: Mites sourced in Australia were released in Florida, US beginning in 2008.

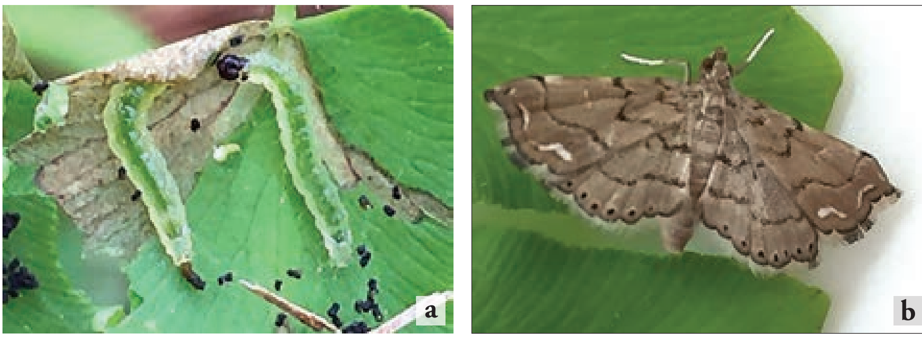
CURRENT STATUS: The mite only established and persisted at a limited number of the initial release sites. More recently it has been observed spreading to additional locations, including having been discovered over 75 miles south of the nearest rearing or release sites. Though it is too soon following its release and spread to evaluate its overall impact, the weed has responded variably to mite galling. Variations might be attributed to genetic differences in susceptibility to gall induction between different populations of Old World climbing fern.

REDISTRIBUTION: This species is currently being mass reared and released in Florida. It is most easily transferred via potted plants or by collecting fronds heavily infested with leaf roll galls and placing these against uninfested Old World climbing fern plants in new locations. This can be done throughout the year, though high humidity and moderate maximum temperatures may aid in successful establishment. Throughout the following seasons and subsequent years, establishment can be monitored by observing leaf roll galls on Old World climbing fern.

Neomusotima conspurcatalis (Warren)

Brown Lygodium defoliating moth

DESCRIPTION: Eggs are oval-shaped, pale yellow, and often deposited in overlapping clusters. Early instars are translucent yellow-green with black head capsules. Fourth and fifth instars are bright green with black head capsules. Larvae are up to 11 mm long at maturity. Pupae are cylindrical, dark brown, and 6-7 mm long. Adults are small (11 mm wingspan) and brown with a few fine, dark bands and a distinctive white boomerang-shaped marking at the tip of each forewing.



Neomusotima conspurcatalis a. larvae; b. adult (a,b Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory)

LIFE CYCLE: Adult females lay eggs (65-172 per lifetime) either singly or in small clusters on Old World climbing fern leaflets. Larvae typically develop through five instars, though some pupate after four instars. First to third instars skeletonize the climbing fern leaflets, leaving distinctive clear “windows” that eventually turn brown, and leaflets die. Later instars defoliate the plant by feeding along the margins of leaflets. Some late instars construct temporary refuges of silk and plant particles beneath which they continue to defoliate leaflets. Pupation occurs on a stem or in leaf debris, often in thin silken cocoons. There are multiple generations per year (potentially 10-12), and all stages may be active throughout the year, depending on site conditions.

DAMAGE: Heavy leaf defoliation by larvae causes “brown out” events and leads to frond and plant dieback.

PREFERRED HABITAT: This species does best where temperatures average 80°F (26.5°C). Higher and lower temperatures result in slowed development or death.

RELEASE HISTORY: Moths sourced in Australia were released in Florida, US beginning in 2008.

Neomusotima conspurcatalis c. early instars "window" feeding; d. late instar feeding along leaflet margins (Melissa C. Smith, USDA ARS Invasive Plant Research Laboratory); e. damage in the field (brown fronds and rachises)(c,e Ellen C. Lake, USDA ARS Invasive Plant Research Laboratory)

CURRENT STATUS: Though is still too soon following its release to evaluate its overall impact, this moth is well established across wide areas of southeastern Florida. Periodic outbreak populations of this biocontrol agent cause substantial damage to Old World climbing fern populations. Regrowth from rhizomes and dormant lateral buds occurs after defoliation events; however, regrowth is subjected to additional oviposition and subsequent rounds of larval defoliation. Low winter temperatures cause drastic population reductions of this moth and enable partial recovery of the weed. Attack by this moth, alone, is unlikely to provide adequate control, but could be beneficial in combination with other biological control agents and other control methods. Multiple species of native parasitoids attack this moth in Florida. Ongoing research is assessing parasitism and whether or not it is likely to substantially impact biocontrol agent populations.

REDISTRIBUTION: This moth is currently being mass reared and released in Florida. Foliage of Old World climbing fern heavily infested with *N. conspurcatalis* larvae can be cut and transferred to new sites and manually inserted in between the climbing leaves of uninfested *L. microphyllum* plants. Transfers of at least 4,000 larvae appear to establish better than transfers using fewer individuals. Establishment can be monitored by observing feeding larvae later in the same or subsequent years or by observing skeletonizing feeding damage on Old World climbing fern leaves.

NOTES: *Neomusotima conspurcatalis* is similar to the closely related biocontrol agent *Austromusotima camptozonale,* which failed to establish on Old World climbing fern in Florida. It is believed the higher reproductive output of *N. conspurcatalis* is a big contributor to its establishment.

Non-Established Biocontrol Agent

Austromusotima camptozonale (Hampson)

= *Cataclysta camptozonale* (Hampson)

(Lepidoptera: Crambidae)

Austromusotima camptozonale (Christine A. Bennett, USDA ARS, bugwood.org)

DESCRIPTION AND LIFE CYCLE: Adults are small (11 mm wingspan) and white with delicate tan bands. Adults are short-lived, mating and ovipositing shortly after emergence. Females lay an average of 60 eggs singly or in small clusters Old World climbing fern leaflets or stems. Eggs are small and opaque. Larvae develop through five instars. The first two instars are pale in color and feed on leaflet cells, creating clear "windows." Later instars are bright green, up to 11 mm long, and are leaf defoliators. Fifth instars spin cases made of silk and leaf particles in which to feed and then pupate; these are attached to concealed plant parts. There are potentially multiple generations per year, and all stages may be active throughout the year, depending on site conditions.

RELEASE HISTORY: Moths sourced from Australia was released in Florida, US from 2004-2007. Breeding was initially detected for a short time following release, but there was no evidence of persistence or establishment. A second attempt at field colonization began in 2010 using fresh collections of the biocontrol agent again sourced from Australia. All attempts failed. Establishment failure was possibly influenced by high ant predation and lower reproductive output than for the related species, *Neomusotima conspurcatalis.*

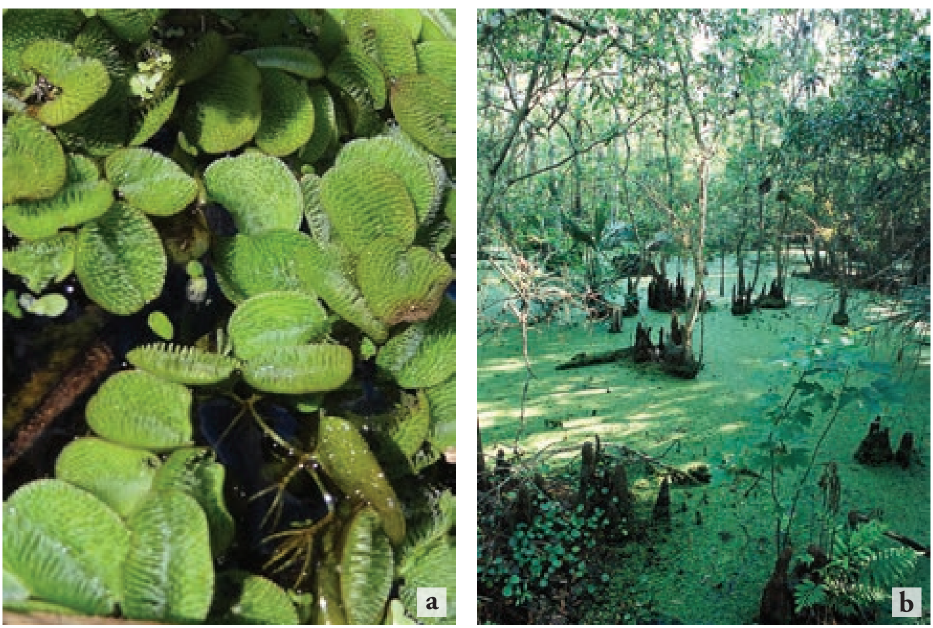
Common salvinia

Salvinia minima Baker

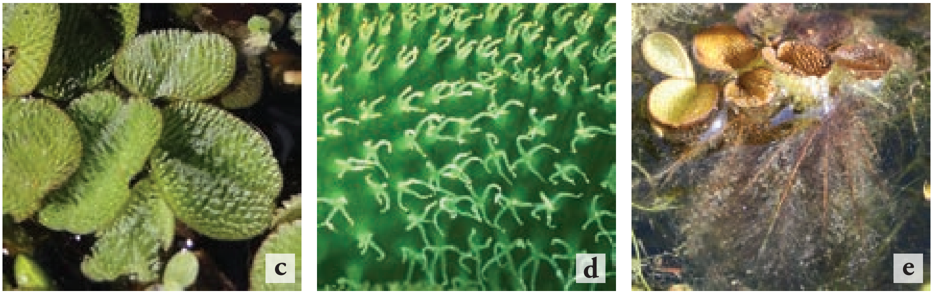
SYNONYMS: water fern, salvinia, water spangles. The names *Salvinia auriculata* Aublet and *S. rotundifolia* Willd. are occasionally listed as synonyms, though this is incorrect as both names refer to a different, distinct species.

ORIGIN: Native to Mexico, Central America, and South America. It was introduced to the US by the 1920s, likely via the aquarium trade.

DESCRIPTION: Aquatic, free-floating fern growing as an annual or short-lived perennial. The plant has no true roots. Horizontal branching rhizomes float just below the surface and bear three leaves (fronds) at each node. Two leaves are floating and one is submersed and divided into several filaments that resemble (but do not function as) roots. Floating leaves are up to 0.8 in long (2 cm), have smooth margins, have distinct midribs, and are oval-shaped overall but heart-shaped at their base. Water repellent, white hairs on the upper surface of floating leaves have 4 branches while hairs on the undersides of leaves and filaments are unbranched and chestnut-colored. Floating leaves growing in shade remain green, small, and flat on the water while those growing in sun may become rusty brown, elongate, and fold upright on the midrib. Spore-producing structures



Common salvinia a. plants (Joseph LaForest, University of Georgia); b. infestation growing in shade (Barry Rice, sarracenia.com)(a,b bugwood.org)



Common salvinia c. floating leaves (Joseph LaForest, University of Georgia); d. branching hairs on upper surface of floating leaf (Mic Julien, CSIRO); e. senescing plant with rusty floating leaves and filaments (Supermartl)(c,d bugwood.org)

(sporocarps) shaped like small lemons (~1 mm wide) are spirally arranged on the main axis of submersed filaments.

HABITAT: Common salvinia grows best in still, shallow water with high organic content, and is most frequently found in ponds, lakes, bayous, swamps, slow streams, canals, and ditches. It can tolerate salinity levels as high as 4-7 ppt.

ECOLOGY: Though sporocarps can be found on submersed filaments, this species is not known to produce fertile spores in the US, and all reproduction occurs vegetatively. Rhizomes containing numerous lateral buds are easily and regularly fragmented. Fragments are readily carried by water currents, animals, boats, etc., and give rise to new plants under favorable conditions. Buds remain dormant during dry and cold periods, allowing this species to survive in cold climates as well as long transports on boats/trailers. The numerous leaf hairs prevent drying, further enabling leafy plants to survive long distance transport.

BIOLOGICAL CONTROL: The FL ecotype of *Cyrtobagous salviniae* is abundant and helps suppress this weed in FL and LA, US. The weed does not occur in Canada.

NOTES: Common salvinia is smaller than giant salvinia, and its upper leaf hairs are free near the tips while the upper leaf hairs of giant salvinia come together at the tips.

Giant salvinia

Salvinia molesta D.S. Mitch.

SYNONYMS: water fern, salvinia, kariba-weed, African pyle

ORIGIN: Native to Brazil, it was introduced to North America via the aquatic plant trade. It was first reported growing in the wild in the US in 1995.

DESCRIPTION: Aquatic, free-floating fern growing as an annual or short-lived perennial. The plant has no true roots. Horizontal branching rhizomes float just below the surface and bear three leaves (fronds) at each node. Two leaves are floating and one is submersed and divided into several filaments that resemble (but do not function as) roots. Floating leaves are oval-shaped and up to 1.6 in long (4 cm) and have smooth margins and distinct midribs. Water repellent, white hairs on the upper surface of floating leaves have 4 branches that join back together at the tip, giving them an "egg beater" appearance. Hairs on the undersides of leaves and filaments are unbranched and chestnut-colored. Depending on nutrient and space availability, plants may be slender with small leaves or dense mats with large crowded, folded leaves. Spore-producing structures (sporocarps) shaped like small eggs are arranged in chains on submersed filaments.

Giant salvinia a. plant with crowded leaves (Leslie J. Mehrhoff, University of Connecticut); b. infestation (Kenneth Calcote, Mississippi Department of Agriculture and Commerce)(a,b bugwood.org)

Giant salvinia c. floating leaves on a non-crowded plant; d. “egg beater” hairs on upper surface of floating leaf (Mic Julien, CSIRO); e. senescing plant with rusty floating leaves and filaments with sporocarps (c,e Leslie J. Mehrhoff, University of Connecticut)(c-e bugwood.org)

HABITAT: Giant salvinia grows best in still, shallow water with high organic content, and is most frequently found in ponds, lakes, bayous, swamps, slow streams, canals, and ditches. It does not tolerate saline environments.

ECOLOGY: Though sporocarps can be found on submersed filaments, this species is not known to produce fertile spores in the US, and all reproduction occurs vegetatively. Rhizomes containing numerous lateral buds are easily and regularly fragmented. Fragments are readily carried by water currents, animals, boats, etc., and give rise to new plants under favorable conditions. Buds remain dormant during dry and cold periods, allowing this species to survive in cold climates as well as long transports on boats/trailers. The numerous leaf hairs also prevent drying, enabling leafy plants to survive long distance transport as well.

BIOLOGICAL CONTROL: The FL ecotype of *Cyrtobagous salviniae* suppresses the few populations of this weed present in FL, US. The Brazilian ecotype helps control giant salvinia at coastal infestations in LA and TX, but is less effective at inland sites where it is hindered by cold temperatures. The weed does not occur in Canada.

NOTES: Giant salvinia is larger than common salvinia, and its upper leaf hairs come together at the tips while common salvinia upper leaf hairs are free near the tips.

Cyrtobagous salviniae Calder & Sands
Salvinia weevil

DESCRIPTION: Eggs are white, elliptical, and tiny (0.5 mm long). Larvae are white, C-shaped, and have brown head capsules. They are up to 4 mm long. Adults are up to 2.5 mm long and have a long snout. Females are usually slightly larger than males. Newly emerged adults are brown, but they change to shiny black within a few days. There are two ecotypes of this species present in the US: the Florida ecotype is significantly smaller than the Brazilian ecotype.

Cyrtobagous salviniae a. larva; b. adult (Scott Bauer, USDA ARS); c. larval damage to giant salvinia leaves (browning)(a,c Peggy Greb, USDA ARS)(a-c bugwood.org)

LIFE CYCLE: Females lay up to 300 eggs singly in cavities they chew in salvinia rhizomes, leaves, and filaments. Larvae feed externally on buds and leaves before burrowing to feed within rhizomes. There are three larval instars. Pupation occurs underwater in cocoons attached to filaments or leaf bases. Emerging adults feed on buds, leaves, and filaments leaving a distinctive “shot-hole” feeding pattern. When adults are underwater, a film of air trapped beneath their body allows them to breathe. Adults may live 20-38 weeks, depending on site conditions. This species is restricted to warm regions where its salvinia hosts actively grow year-round. Consequently overwintering information is unknown. In North America, the number of generations per year is also unknown, but is believed to be one.

DAMAGE: While adult feeding helps suppress plant growth, larval feeding is most damaging to salvinia. Larval mining disconnects the flow of nutrients from submersed fronds to emergent leaves and buds. Plants attacked by salvinia weevil larvae turn brown, disintegrate, and eventually sink.

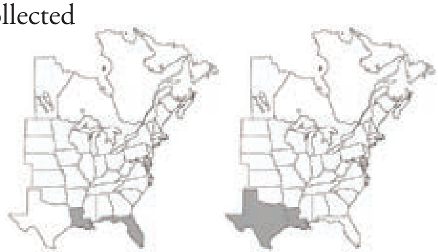
PREFERRED HABITAT: This weevil is restricted to warm regions and does best between 55 and 91°F (13-33°C). It appears to prefer larger plants and performs best on plants with higher nitrogen content.

RELEASE HISTORY: Two ecotypes of this species are known in the US. The smaller Florida ecotype was likely introduced accidentally to FL along with common salvinia prior to 1960, and it spread naturally to giant salvinia in FL. This ecotype was subsequently intentionally redistributed to common salvinia in LA beginning in 2002 and to giant salvinia in LA and TX in 1999. The larger Brazilian ecotype was intentionally released in Australia and from there redistributed to giant salvinia in LA and TX from 2001.

CURRENT STATUS: Attacks both common and giant salvina in North Amrica. The Florida ecotype failed to establish on giant salvinia in LA. In FL, it is abundant on the few giant salvinia infestations present as well as on common salvinia populations throughout the state. The Florida ecotype helps control both species in FL where both the weeds and the weevils go through numerous boom and bust cycles. The Florida ecotype is abundant on common salvinia in LA, but at some sites predation by red imported fire ants may decrease weevil populations below the threshold needed to provide control. The Brazilian ecotype successfully suppresses most giant salvinia infestations along the Gulf Coast. Further inland in LA and TX, control is reduced because colder temperatures slow weevil growth and hinder overwintering. Research is underway to find more cold tolerant populations of the weevil in South America.

REDISTRIBUTION: Plants infested with weevil larvae can be transferred to new sites and placed against uninfested salvinia plants. This should only be done at sites with large salvinia populations to ensure the plant transfer does not increase the weed problem. Alternatively adults can be collected with a Berlese funnel or by submerging infested plant material and hand-collecting adults as they rise to the surface. This can be done year-round. Adults can be transferred to new sites in groups of 200-500. Establishment can be monitored the following year by observing adults or their shot-hole feeding on foliage. Rhizomes can also be dissected for evidence of larval feeding.

NOTES: When this weevil was first collected in both Florida and southeastern Brazil, it was thought to be *Cyrtobagous singularis* or a biotype of this species. Detailed comparative studies following releases in Australia helped researchers determine it was a new, undescribed species, later to be named *Cyrtobagous salviniae*.



common giant

Current Studies in Weed Biocontrol

Earlier portions of this guide focus on biocontrol agents that have been intentionally released and/or are already established in eastern North America. Multiple studies are currently underway to obtain approval for additional biocontrol agents for use against some of the weed systems already described as well as some entirely new weeds. The current status of these studies is summarized in the following tables. Biocontrol agents that have already been approved by the Technical Advisory Group (TAG) and are closest to release in eastern North America are described below. As of 2016, these are still within the regularoty process and are not yet fully approved for field release. Potential biocontrol agents that are further behind in the approval process are listed briefly on the following pages. It is important to note that some of the species described on the following pages have already been rejected, and many of the species still showing promise may not receive final approval.

Potential Biocontrol Agents Approved by the Technical Advisory Group (TAG)

Host	Biocontrol Agent	Impact
Brazilian peppertree *Schinus terebinthifolius*	*Pseudophilothrips ichini* (Thysanoptera: Phlaeothripidae)	Pierces/sucks leaf cell contents. This often kills leaves, reduces photosynthetic capacity, and stunts plant growth
Brazilian peppertree *Schinus terebinthifolius*	*Calophya latiforceps* (Hemiptera: Calophyidae)	Pierces/sucks plant cell contents, killing shoot tips, reducing the growth of young plants, and inhibiting seed production
Chinese tallow *Triadica sebifera*	*Bikasha collaris* (Coleoptera: Chrysomelidae)	Larval root-feeding and adult leaf-feeding reduce stem height, total biomass, number of leaves and stem diameter
Garlic mustard *Alliaria petiolata*	*Ceutorhynchus scrobicollis* (Coleoptera: Curculionidae)	Larval feeding on the root crown reduces plant stature and may kill plants outright
Russian thistle *Salsola tragus*	*Uromyces salsolae* (Pucciniomycetes: Pucciniales)	Infection can stunt plant growth and reduce seed production

Potential Biocontrol Agents Further Behind in the Approval Process

Host	2016 Status
Air potato *Dioscorea bulbifera*	The beetle *Lilioceris egena* is under investigation.
Australian pine *Casuarina* spp.	Foreign exploration is currently underway in the weed's native range, and preliminary testing has started on the most promising candidates.
Brazilian peppertree *Schinus terebinthifolius*	Three species that have been petitioned were denied approval. One of these (the sawfly *Heteroperreyia hubrichi*) is still of interest. Two additional psyllids are under investigation.
Canada thistle *Cirsium arvense*	The pathogen *Pustula spinulosa* was a species of interest, but was recently abandoned after it was found infecting nontarget species in field experiments.
Chinese privet *Ligustrum sinense*	One potential biocontrol agent has been denied approval. The beetle *Argopistes tsekooni* is under investigation.
Chinese tallow *Triadica sebifera*	One potential biocontrol agent has been denied approval. The moth *Gadirtha fusca* is under investigation.
Cogongrass *Imperata cylindrica*	Foreign exploration is currently underway, and preliminary testing has started on the most promising candidates.
Earleaf acacia *Acacia auriculiformis*	Under investigation to determine the feasibility of biological control.
Eurasian watermilfoil *Myriophyllum spicatum*	The fungus *Mycoleptodiscus terrestris* was originally studied for its use as a bioherbicide against *Hydrilla verticillata* but was found to be ineffective. It is currently being studied for its efficacy against Eurasian watermilfoil in field trials in Michigan.
Fig buttercup *Ficaria verna*	Under investigation to determine the feasibility of biological control.
Flowering rush *Butomus umbellatus*	Two weevils (*Bagous nodulosus* and *B. validus*) and the fly *Phytoliriomyza ornata* are under investigation.

Current Studies in Weed Biocontrol

Potential Biocontrol Agents Further Behind in the Approval Process

Host	2016 Status
Garlic mustard *Alliaria petiolata*	In addition to *Ceutorhynchus scrobicollis,* which has been approved by TAG, three other *Ceutorhynchus* species are under investigation.
Himalayan balsam *Impatiens glandulifera*	The rust fungus *Puccinia komarovii* var. *glanduliferae* is under investigation.
Hydrilla *Hydrilla verticillata*	The fungus *Mycoleptodiscus terrestris* was studied for its use as a bioherbicide but was found to be ineffective in several trials. Foreign exploration for additional biocontrol candidates is still underway.
Invasive common reed *Phragmites australis* ssp. *australis*	Petitions are currently being prepared for the release of two moths, *Archanara geminipuncta* and *A. neurica*.
Japanese stiltgrass *Microstegium vimineum*	Two *Bipolaris* pathogens already present in eastern North America are currently being studied for specificity and efficacy as potential biocontrol agents. Differential response in susceptibility to *Bipolaris microstegii* has been discovered; much of the population is not susceptible, but the remaining portion is severely damaged. An aphid is also being studied in China.
Kudzu *Pueraria lobata*	Two Chinese insects tested thus far have failed host specificity tests. Foreign exploration is still underway to identify additional potential agents.
Melaleuca *Melaleuca quinquenervia*	The sawfly *Lophyrotoma zonalis* was rejected following concerns it would be toxic to native fauna if ingested. The midge *Lophodiplosis indentata* is under investigation.
Mile-a-minute weed *Persicaria perfoliata*	The fungal pathogen *Colletotrichum gloeosporioides* is under investigation.
Old World climbing fern *Lygodium microphyllum*	The sawfly *Neostromboceros albicomus* and the moth *Lygomusotima stria* are well along in the host range testing process. Also under evaluation, but in the very preliminary stages, are two stem borers: *Siamusotima disrupta* and another unidentified crambid species, as well as a *Callopistria* sp.
Oxeye daisy *Leucanthemum vulgare*	Four species are currently being studied as potential biocontrol agents.

POTENTIAL BIOCONTROL AGENTS FURTHER BEHIND IN THE APPROVAL PROCESS

Host	2016 Status
Parrotfeather *Myriophyllum aquaticum*	Foreign exploration is currently underway in the weed's native range. Insects native to North America are also being studied as potential biocontrol agents.
Perennial pepperweed *Lepidium latifolium*	The weevil *Ceutorhynchus marginellus* and the mite *Metaculus lepidifolii* are under investigation.
Rose myrtle *Rhodomyrtus tomentosa*	Numerous species have been tested and found to lack specificity. The moths *Mesophleps albinella* and *Casmara* spp. are still undergoing testing.
Russian olive *Elaeagnus angustifolia*	The mites *Aceria angustifoliae* and *A. eleagnicola* are under investigation.
Skunk vine *Paederia foetida*	Numerous species have been tested and found to lack specificity. Foreign exploration is still underway to identify additional potential agents.
Swallow-worts *Vincetoxicum* spp.	The leaf beetle *Chrysochus* (*Eumolpus*) *asclepiadeus* and the fly *Euphranta connexa* are under investigation.
Toadflaxes *Linaria* spp.	Additional species of *Rhinusa* and also *Mecinus* weevils are currently under investigation.
Tropical soda apple *Solanum viarum*	Two leaf beetles (*Gratiana graminea* and *Metriona elatior*) and the flower bud weevil *Anthonomus tenebrosus* were petitioned for release, but all three were denied approval.
Tree-of-heaven *Ailanthus altissima*	The weevil *Eucryptorrhynchus brandti* was initially denied approval. Additional host testing was conducted, and the petition has since been revised for resubmission.
Water chestnut *Trapa natans*	The leaf beetle *Galerucella birmanica* is under investigation.
Waterhyacinth *Eichhornia crassipes*	The planthopper *Taosa longula* and the fly *Thrypticus truncatus* are under investigation.

GLOSSARY

Term	Definition
abdomen	The last of the three insect body regions; usually containing the digestive and reproductive organs
achene	A small, one-seeded fruit that does not split at maturity
adventive	Species that arrived in the geographical area from elsewhere by any means
aestivation	A period of dormancy to survive predictable, unfavorable environmental conditions, such as temperature extremes, drought, or reduced food availability
alternate	Where leaves appear singly at stem nodes, on alternate sides of the stem
antenna (pl. antennae)	In arthropods, one of a pair of appendages on the head, normally many jointed and of sensory function
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 then dies in its second year
biological control	Reducing a pest's abundance 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
bulbil	Bulbs or tubers that form at leaf axils or in place of flowers on certain plants. Bulbils give rise to new plants.

Term	Definition
capitulum (pl. capitula)	Seed head of a plant in the sunflower family
complete metamorphosis	An insect life cycle with four distinct stages (egg, larva, pupa, adult)
compound eyes	Paired eyes consisting of many facets, or ommatidia, in most adult Arthropoda
compound leaf	A leaf consisting of two or more leaflets borne on the same leaf stalk
coordinates	A set of numbers used to specify a location
crown	Location of where a plant's stems meets its roots
diapause	A suspension of development in response to regularly and recurring periods of adverse environmental conditions, such as extreme temperatures, drought, or reduced food availability
deciduous	Sheds its leaves annually
density	Number of individuals per unit area (e.g. plants, stems, or leaves)
dissemination	Dispersal. Can be applied to seeds or insects
elytron (pl. elytra)	Hardened front wing of a beetle
emergence	Act of adult insect leaving the pupal exoskeleton, or leaving winter or summer dormancy
erect	Grows upright and vertical as opposed to prostrate (spreading on the ground)
exoskeleton	Hard, external skeleton of the body of arthropods, including insects and mites
exotic	Not native
floret	One of the small, closely clustered flowers forming the head of a composite flower in the sunflower family

Term	Definition
flower head	A special type of inflorescence consisting of numerous florets that actually look like one flower
forb	Herbaceous plant (does not have solid woody stems)
frass	The fecal matter of 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
head	Insect body region 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 organism and its host (i.e. weed). A highly host-specific insect feeds only on its host and on no other species
incomplete metamorphosis	An insect life cycle with three distinct stages (egg, nymph, adult)
inflorescence	The flowering part of a plant
instar	The phase of an arthropod's nymphal or larval development between molts
involucre	A circle of bracts under an inflorescence
larva (pl. larvae)	Immature stage of some animals, including insects and mites. In insects with complete metamorphosis, it is the stage between the egg and pupa (examples include grubs, caterpillars and maggots)
leaflet	A leaf-like part of a compound leaf. Though it resembles an entire leaf, a leaflet is not attached to the main plant stem or branch as a leaf is, but rather on the leaf stalk
lobed	A leaf with shallow or deep, rounded segments, as in a thistle rosette leaf

Term	Definition
membranous	Thin and transparent
molting	Process of arthropod development that involves shedding its exoskeleton and producing another as the arthropod grows
NAD 83	North American Datum, the official datum used for the UTM geographic coordinate system in North America
node	Part of the stem of a plant from which a leaf, branch, or root grows
nontarget effect	When control efforts affect a species other than the species they were enacted to control (can be positive or negative)
nymph	Immature form of invertebrates, including mites and insects that undergo incomplete metamorphosis. Resembles adults
ocrea	Plant structure formed of stipules fused into a sheath surrounding the stem
opposite	Where leaves appear in twos at stem nodes, on opposite sides of the stem
oviposit	To lay or deposit eggs
pappus	A tuft of hairs, scales, or bristles at the base of an achene in flowers of the sunflower family
parasitoid	An insect (e.g., a wasp) whose larvae live as parasites, eventually killing their hosts (typically other insects)
perennial	A plant that lives for more than two years
petiole	Leaf stalk that attaches it to a plant stem
proleg	A fleshy, unsegmented, abdominal walking appendage of some insect larvae, common among caterpillars
prostrate	Grows flat along the ground as opposed to growing erect (upright)
pupa (pl. pupae) (v. pupate)	Non-feeding, inactive stage between larva and adult for an insect with complete metamphorsis
qualitative	Measurement of descriptive elements (e.g., age class, distribution)

Term	Definition
quantitative	Measurement of quantity; the number or amount (e.g., seeds per capitula)
rachis	Main stem of a compound plant structure. In ferns, the rachis is the midrib of the frond
receptacle	Part of the stem to which the flower is attached
rhizome	A modified stem of a plant that grows horizontally underground, often sending out roots and shoots from its nodes
rosette	A compact, circular, and normally basal cluster of leaves
seed head	Synonym for capitulum of a plant in the sunflower family. Consists of a receptacle and florets
senescence	Transition from living cells to dead ones as a function of age; the final stage in a life cycle
sepal	Part of a flowering plant occurring beneath flower petals, sepals function as protection for the flower in bud and petals when in bloom. Sepals are typically green, but some may resemble petals.
spadix	Inflorescence with several tiny flowers clustered on a narrow, fleshy stem
spathe	Leaf-like curved bract surrounding a spadix
species	A fundamental category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding
spillover feeding	When a biocontrol agent population reaches outbreak densities, some feeding may occur on adjacent nontarget plant species. Spillover feeding is temporary and is unlikely to have negative consequences at the population level of nontarget species
sporocarp	Specialized structure found on ferns; their primary function is the production and release of spores.
spore	Unit of asexual reproduction that is part of the life cycle of many plants (e.g. ferns), algae, fungi and protozoa. Similar to a seed produced by flowering plants

Term	Definition
sporeling	A young plant or fungus produced by a germinated spore, similar to a seedling derived from a germinated seed
stolon	Stem which grows at the soil (or water) surface or just below ground that forms adventitious roots at nodes and new plants from buds (also called runner)
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 (margin)	Saw-like leaf margin with somewhat regular teeth on the edge that may be different in size. Also called serrated
transect	A straight line of varying length along which items (e.g. plants) are periodically sampled individually or in quadrants
turion	Swollen leaf bud that gives rise to a new plant after it breaks free from the parent plant and sprouts
umbel	An inflorescence which consists of a number of short flower stalks which spread from a common point, somewhat like umbrella ribs. They can be simple or compound (the single flowers are replaced by many smaller umbels called umbellets).
UTM	Universal Transverse Mercator, a grid-based geographic coordinate system
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
winged	A membranous expansion of tissue extending beyond the normal outline of a structure

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I. Biocontrol Agent Monitoring Form

SITE: ______________________________ STATE: _________ DATE: ________ _________ _______

year month day

NAME: ____

GPS: Lat N _____°___________’ Long W_____°___________’ Elevation: ___________________ ft m

UTM: Datum Zone:________ Year: _______ Easting:_______________ Northing: _________________

TIME: ___________ TEMPERATURE: ____________ WEATHER: ___________________________

Species Type	Counting Method
Hard-bodied adults present on foliage during growing season (e.g. beetles)	Perform a series of 10 sweeps, counting the adults of all monitored species separately. Following each count, move to a new part of the infestation and repeat for a total of 10 counts. Record your counts in the table below, and then sum your measurements.
Larvae feeding within plant parts during growing season (e.g. seed heads, stems, galls, roots)	Randomly select 10 plants throughout the infestation. Dissect the tissue attacked by the target biocontrol agent (e.g. seed heads, stems, galls, roots) and in the table below, record the number of larvae found.
Species cryptic or too small to see/collect; feeding damage is best indicator of presence/abundance (e.g. fungi, mites, thrips)	Walk throughout the infestation and look closely at target weeds to identify biocontrol agent damage. Estimate the overall damage infection level in the “Total” column of the table below by using the letter for the most appropriate choice: A: No feeding or infection; B: Occasional, scattered feeding or infection; C: Conspicuous, widespread feeding or infection.

Count

Species	1	2	3	4	5	6	7	8	9	10	Total

Notes ____

____

____

II. Vegetation Monitoring Form

APPENDIX

SITE: ______________________________ STATE: _________ DATE: ________ _________ ________
year month day

NAME: ____

GPS: Lat N _____°___________' Long W_____°___________' Elevation: ___________________ ft m

UTM: Datum Zone:________ Year: _______ Easting:________________ Northing: _________________

TIME: ___________ TEMPERATURE: ____________ WEATHER: ___________________________

A transect is made in year 1, with 10 permanent markers inserted along the transect (1 marker per quadrat). All 10 quadrats are re-measured in subsequent site visits (preferably once/year). Position the quadrat frame along the transect, as close to the ground as possible. Gently arrange vegetation so that plant parts are either within or outside (rather than underneath) the frame. The quadrat should be in the same location as the previous year's quadrat. Standing over the frame, estimate how much of each quadrat is covered by the target weed and the other cover categories listed in the table, in increments of 5%. All cover readings should add up to 100% for each quadrat. Count the number of target weed species stems/plants in each quadrat and measure the height of the tallest (cm). List other major species present at the site and check if they are present in each quadrat.

	Quadrat									
% of Quadrat (to the nearest 5%)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Soil, litter										
Rock										
Water										
Target weed										
Other forbs, vines										
Other grasses, sedges										
Other woody plants										
TARGET WEED	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
# plants/stems										
Height tallest stem (cm)										
OTHER SPECIES (write name, ✓ if present)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

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