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Biology and Biological Control of Common Gorse and Scotch Broom

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Bottom: Scotch broom (Eric Coombs, Oregon Department of Agriculture, bugwood.org).

Right of Scotch broom, top to bottom: *Bruchidius villosus* (Jennifer Andreas, Washington State University Extension); *Exapion fuscirostre* (Laura Parsons, University of Idaho, bugwood.org); *Leucoptera spartifoliella* (Eric Coombs, Oregon Department of Agriculture, bugwood.org).

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Biology and Biological Control of Common Gorse and Scotch Broom

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Contents

Contents (continued)

Contents (continued)

Contents (continued)

Contents (continued)

Chapter 1. Introduction

Overview

Common gorse (*Ulex europaeus* L., Figure 1-1a) and Scotch broom (*Cytisus scoparius* [L.] Link, Figure 1-1b) are related woody shrubs native to Europe. Both species were introduced to North America in the 1800s as ornamentals and later widely used in erosion control and as natural livestock fences. Both species escaped cultivation and are now invasive throughout western and eastern North America. Common gorse (hereafter referred to simply as gorse, its most common name) and Scotch broom continue to be available for purchase in the United States, though the sale of these two species is now illegal in states where they are classified as regulated plants or noxious weeds.

Although several exotic broom species have been intentionally or accidentally introduced to North America, Scotch broom is by far the most common and problematic for land managers. Gorse and Scotch broom have been the primary targets of biological control efforts in the United States, and are the focus of this manual. Additional information for understanding and differentiating other related broom species is given in Chapter 2.

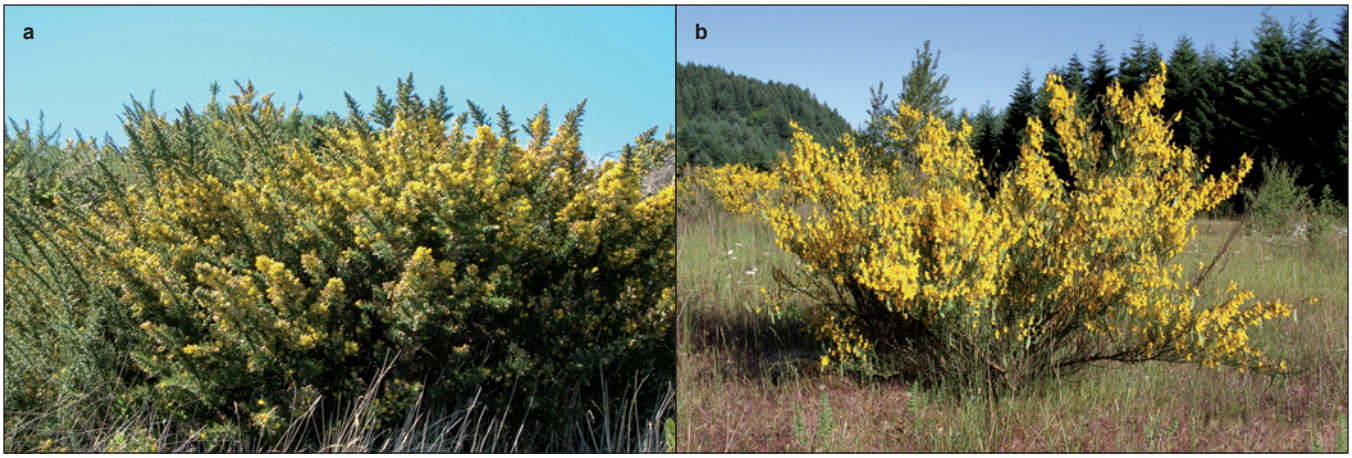


Figure 1-1. a. Gorse; b. Scotch broom. (a. Forest and Kim Starr, Starr Environmental, bugwood.org; b. Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Gorse is present in eight states in eastern North America as well as four states (including Hawaii) and one province in western North America (Figure 1-2a). Scotch broom is present in 19 states and two provinces in eastern North America and eight states (including Hawaii) and one province in western North America (Figure 1-2b). Though both gorse and Scotch broom are sparsely distributed on hillsides and along roadsides in the East, the worst infestations occur in western North America. Neither species is established in central states or provinces of North America.

Throughout their native and introduced ranges, gorse and Scotch broom are found at open sites, including hillsides, pastures, roadsides, river banks, dry river beds, chaparral, grasslands, degraded coastal dunes, forest edges and clear cuts, and fallow fields. They are most commonly found in cool, temperate regions in coarse, dry to semi-moist soils with low fertility. Severe winter temperatures, extensive summer drought, and heavy shading limit the distribution of both species.

Gorse and Scotch broom compete aggressively for light, water, and nutrients, and are a major concern for displacing native and/or more desirable species in natural areas, grasslands, and commercial forests. Because of their nitrogen-fixing ability, both species have an advantage over competing vegetation in poor soils. Cattle avoid grazing both species; older growth is unpalatable, and toxic compounds in seeds have resulted in livestock death. Wildlife, goats, and sheep will browse young growth and flowers of both gorse and Scotch broom; however, both gorse and broom frequently form dense, impenetrable thickets that block animal access to water and more desirable forage. Gorse and Scotch broom are extreme fire hazards due to the high oil content of foliage and seeds and the large amount of dead growth/litter in plant centers and beneath their canopies. Both species are long-lived (15-30 years) and their seeds can remain viable in the soil for 30 years or more, exacerbating their negative impacts.

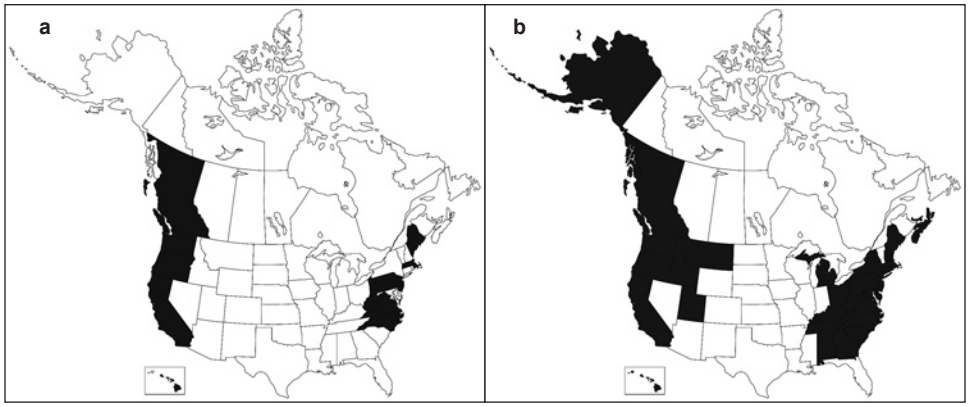


Figure 1-2. North American and Hawaiian distribution of: a. gorse; b. Scotch broom. Some states and provinces are more heavily infested than others. (USDA PLANTS Database, EDDMapS)

Responding to the Threat of Gorse and Scotch Broom

Gorse and Scotch broom are invasive species not native to North America whose introduction causes or is likely to cause economic or environmental harm. In Washington State, Scotch broom could cause an estimated $59 million in direct losses to range, timber, and hunting lands. If it were to spread into 35 percent of productive land, primarily in western Washington, it may cost $142.8 million in business activity, including the loss of 660 jobs and over $36 million in lost wages. In Oregon alone, Scotch broom currently causes a nearly $39 million loss in economic activity. This loss would increase to nearly $180 million if Scotch broom successfully invades all suitable/susceptible habitat in Oregon. Likewise, gorse currently causes $441,000 of damage in Oregon; however, it only infests a fraction of its suitable habitat. Should all susceptible acres be infested, the loss of economic activity from gorse in Oregon would exceed $205 million.

A general management response to the threat of invasive species is based on four key elements or intermediate outcomes: prevention and preparedness, eradication, containment, and asset-based protection. In order to ensure a timely and appropriate management response, land managers must continually monitor, evaluate, and report new gorse and Scotch broom infestations and evaluate how gorse and broom responded to each control effort. Research and development informed by the observations and needs of land managers will play a critical role in the eventual success or failure of gorse and broom prevention and management activities in their invaded range.

Prevention and Preparedness

Preventing high-risk invasive species from establishing is the most cost-effective approach to managing the threat they pose. Considerable resources and planning are required to maintain prevention of a large number of species. Preparedness encompasses all the activities and resources necessary to successfully manage new invasions.

Eradication

Eradication is generally only possible in the early stages of establishment when distribution and abundance of the invasive species are low. This approach can be almost as cost-effective as prevention.

Containment

Where an invasive species cannot be eradicated, there can be substantial net benefit gained from preventing its further spread. Containment involves measures to eradicate outlying (satellite) infestations and prevent spread beyond the boundaries of core infestations (those that are too large and well established to eradicate). Obtaining a high degree of community support is a prerequisite for any long-term containment program.

Asset-Based Protection

An asset-based approach to managing an invasive species is appropriate once it has become so widespread that it would be inefficient to control the species everywhere it occurs, and containment would provide a low return on investment.

The asset-based approach manages the invasive species only where reducing their adverse effects provides the greatest benefits by achieving protection and restoration outcomes for specific highly valued assets.

Monitoring, Evaluation, and Reporting

For science-based programs, such as invasive species management, monitoring, evaluation, and reporting are elements of adaptive management, whereby programs are continually reviewed and analyzed to ensure that their approaches are consistent with and supportive of any changes in environmental response, community expectation, or scientific knowledge.

Research and Development

The knowledge that comes from research and development is critical to implement evidence-based management approaches. In many cases, substantial advances in invasive species management will require development of new techniques and acquisition of greater and new knowledge. The investment in research needs to be sufficient to ensure future management is not seriously constrained by insufficient research and development support.

The Invasion Curve

The invasion curve (Figure 1-3) shows that eradication of an invasive species such as gorse or Scotch broom becomes less likely and control costs increase as an invasive species spreads over time. Prevention is the most cost-effective solution, followed by eradication. If a species is not detected and removed early, intense and long-term control efforts will be unavoidable.

While gorse and Scotch broom infest large acreages in some regions, there are entire states and provinces where both weeds are absent or are present at very low population levels. The diversity of gorse and broom populations, from absent to widespread and abundant, throughout their potential range requires land managers to coordinate their management response to gorse and broom across larger landscapes to prevent current infestations from spreading into uninfested areas.

Identifying where gorse and Scotch broom are on the invasion curve in a particular area is the first step to taking management action. Inventorying and mapping current gorse and broom populations, coupled with research efforts to predict where gorse and broom are most likely to inhabit (Figure 1-4a,b), enables land managers to concentrate resources in areas where gorse and broom are likely to invade, and then to treat individual plants and small populations before it is too late to remove them.

Biological control is one of many control methods available to land managers, but biological control is not appropriate for areas on the left side of the invasion curve (species absent [prevention] – small number of localized populations [eradication]). Biological control as a control method is best suited to gorse and broom populations in the later phases of the invasion curve (rapid increase in distribution and abundance [containment] – widespread and abundant throughout potential range [asset based protection]).

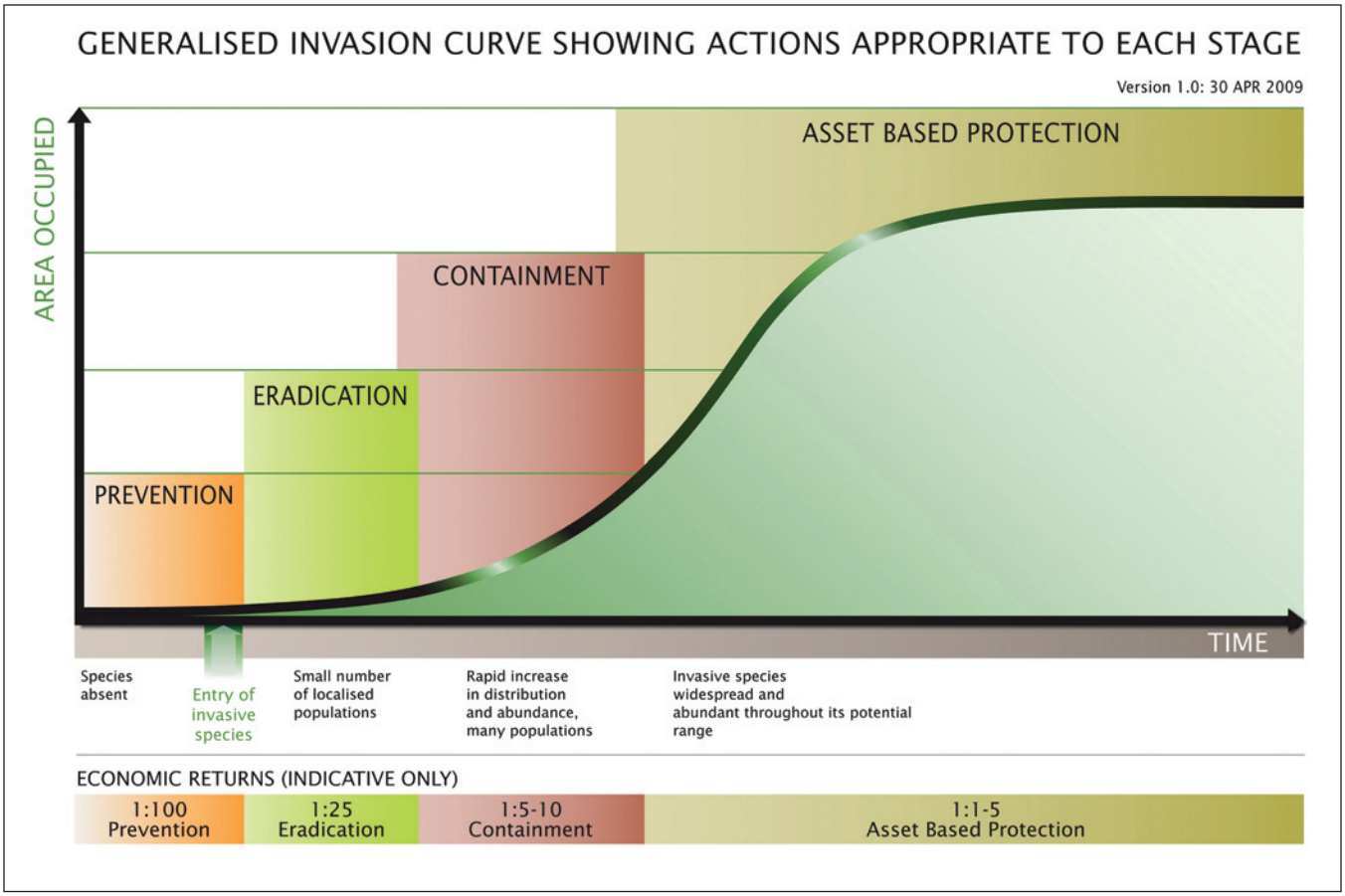


Figure 1-3. Generalized invasion curve showing actions appropriate to each stage. (© State of Victoria, Department of Economic Development, Jobs, Transport and Resources. Reproduced with permission.)

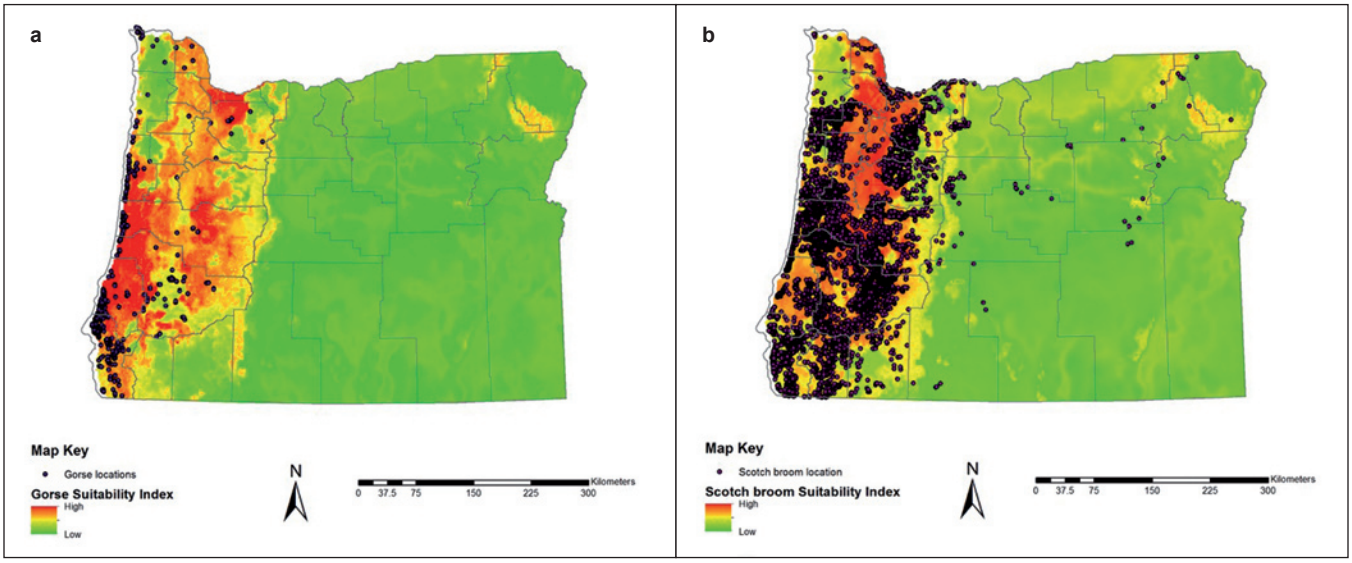


Figure 1-4. Current distribution (black dots) and habitat suitability index (red high, green low) for: a. gorse; b. Scotch broom. (The Research Group, LLC 2014)

Management of Gorse and Scotch Broom Infestations

Successful management of gorse and Scotch broom is an intensive process which requires land managers to continuously inventory, map, and assess the extent and severity of infestations. Land managers must also understand the benefits and shortcomings of each weed control method, alone and in combination, when applied to gorse and Scotch broom. Pulling or digging seedlings and young, individual gorse and broom plants is feasible; pulling large plants may exacerbate the problem as damaged roots and stems generate new shoots, and the disturbance of large pulling efforts provides a perfect environment for gorse and broom seedling recruitment. Mowing is similarly only feasible on young gorse and broom plants, and it may also exacerbate the problem by triggering re-growth and spreading seeds. Cutting large plants flush to the ground and chemically treating the stump has proven effective, though this method is time intensive and expensive for large infestations. Burning often facilitates gorse and broom re-sprouting and seedling establishment, and it can be dangerous due to the high flammable oil content of these species. Grazing gorse and broom can be effective on young growth, but larger plants are typically unpalatable or toxic, and grazing may have severe negative, long-term consequences for other components of the plant community. Chemical control (using herbicides) provides control of small infestations where monitoring and re-treatment can occur as necessary; however, it can be impractical, prohibitively expensive, and damaging to desired vegetation when treating very large infestations. Due to the inherent difficulties in managing gorse and broom throughout their invaded range, a biological control program was initiated in the 1920s. Many of the biological control agents that have since been approved for use against common gorse and Scotch broom in North America and/or Hawaii are already widespread. However, there are some infestations where biocontrol agents are not currently present or where the populations present might benefit from augmentative releases. This manual discusses the biological control of gorse and Scotch broom in North America and Hawaii, within the larger context of an integrated management strategy.

The most effective weed management strategies are based on regular inventory and monitoring of target weed populations, application of one or multiple weed control methods, evaluation of treatment efficacy, additional inventory and mapping, and adjustment of control methods as needed to meet management objectives in response to changing weed populations through time.

Integrated Pest Management (IPM) incorporates additional activities that enable land managers to address the threat of gorse and broom invasions in infested as well as uninfested areas across a landscape. Integrated pest management activities include education and outreach, inventory and mapping, prevention methods, and control methods (physical control [pulling or mowing], cultural control [revegetation, grazing, or fire], chemical control [herbicides], and biological control). IPM relies on the development of realistic pest management objectives, accurate pest identification and mapping, appropriate prevention and control methods, and post-treatment monitoring to ensure current pest-management activities are meeting gorse and broom management goals.

Land managers choose control methods, either alone or in combination, that enable them to achieve their gorse and broom management goals or objectives in the most cost-effective manner. No single control method will enable managers to meet their gorse and broom management goals in all environments or instances. Control method(s) employed will depend on the size and location of the infested area and specific management goals (e.g., eradication vs. weed density reduction). Small patches of gorse and broom may be eliminated through a persistent physical or chemical control program, but large infestations will often require the use of additional control methods. A combination of control methods consistently applied, evaluated, and adjusted through time is usually necessary to attain and maintain weed management goals for gorse and Scotch broom.

Classical Biological Control of Weeds

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

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

Biological control agents may attack a weed's flowers, seeds, roots, foliage, and/or stems. Effective biological control agents seldom kill weeds outright, but work with other stressors such as moisture or nutrient shortages to reduce vigor and reproductive capability, or facilitate secondary infection from pathogens—all of which compromise the weed's ability to compete with other plant species. Once established, root- and crown-feeding biocontrol agents are usually more effective against perennial plants that primarily spread by root buds. Flower- and seed-feeding biocontrol agents are typically more effective on annual or biennial plants that spread only by seed. Regardless of the plant part attacked by biocontrol agents, the aim is always to reduce populations and vigor of the target weed.

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. When classical

biological control alone does not result in an acceptable level of weed control, other weed control methods (e.g. physical, cultural, or chemical control) may be incorporated to achieve desired results. For a more in-depth description of weed control methods in the context of gorse and broom management, please refer to Chapter 5.

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

To be approved for release in North America, weed biocontrol agents must be host specific, meaning they must feed and develop only on the target weed, or in limited cases, on a few closely related plant species. They must never feed on any crop or protected plant species; attack on ornamental plants may be minimally tolerated and is evaluated on a case-by-case basis. Rigorous testing is required to confirm that biocontrol agents are host specific and effective. Potential biocontrol agents 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 United States Department of Agriculture's Animal and Plant Health Inspection Service – Plant Protection and Quarantine (USDA-APHIS-PPQ) is the federal regulatory agency responsible for providing testing guidelines and authorizing the importation of biocontrol agents into the USA. The Canadian Food Inspection Agency (CFIA) serves the same regulatory role in Canada. Federal laws and regulations are in place to identify and avoid potential risks to native and economically valuable plants and animals that could result from exotic organisms introduced to manage weeds. The Technical Advisory Group (TAG) for Biological Control Agents of Weeds is an expert committee with representatives from USA federal regulatory, resource management, and

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

Advantages	Disadvantages
Target specificity	Will not work on every weed in every setting
Continuous action	Permanent; cannot be undone
Long-term cost-effective; can provide sustained control at the landscape scale	Funding and testing candidate biocontrol agents is expensive; measurable impact may take years or even decades to materialize
Integrates well with other control methods	Approved biocontrol agents are not available for all exotic weeds
Generally environmentally benign	Like all weed control methods, nontarget effects are possible, but pre-release testing reduces the risks
Self-dispersing, even into rough or difficult to access terrain	Unpredictable level of control; does not eliminate weed

environmental protection agencies, and regulatory counterparts from Canada and Mexico. TAG members review all petitions to import new biocontrol agents into the USA, and make recommendations to USDA-APHIS-PPQ regarding the safety and potential impact of prospective biocontrol agents. Weed biocontrol researchers work closely with USDA-APHIS-PPQ and TAG to accurately assess the environmental safety of potential weed biocontrol agents. In addition, some states in the USA have their own approval process to permit field release of weed biocontrol agents. In Canada, the Biological Control Review Committee (BCRC) draws upon the expertise and perspectives of Canadian-based researchers (e.g., entomologists, botanists, ecologists, weed biological control scientists) from academic, government, and private sectors for scientific review of petitions submitted to the CFIA. The BCRC reviews submissions for compliance with the North American Plant Protection Organization's (NAPPO) Regional Standards for Phytosanitary Measures (RSMP) No. 7. The BCRC also reviews submissions to APHIS. The BCRC conclusions factor into the final TAG recommendation to APHIS on whether to support the release of the proposed biocontrol agent in the USA. When release of a biocontrol agent is proposed for both the USA and Canada, APHIS and the CFIA attempt to coordinate decisions based on the assessed safety of each country's plant resources.

Code of Best Practices for Classical Biological Control of Weeds

Biological control practitioners have adopted the International Code of Best Practices for Biological Control of Weeds. The Code was developed in 1999 by delegates and participants in the Tenth International Symposium for Biological Control of Weeds to both improve the efficacy of, and reduce potential negative impacts from, weed biological control. In following the Code, practitioners

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

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.

There are several resources that provide additional information about general weed biocontrol practices and specific weed-biocontrol systems, which can be found in the Chapter 3 references under Andreas et al. 2017, Coombs et al. 2004, and Winston et al. 2014b.

Biological Control of Gorse and Scotch Broom

Although many species "hitchhiked" on gorse and Scotch broom plants when they were introduced from Europe, four of these species are now credited with the earliest incidences of biological control of gorse and broom in North America. The gorse tip moth *Agonopterix nervosa*, the broom gall mite *Aceria genistae*, the broom psyllid *Arytainilla spartiophila*, and the broom seed beetle *Bruchidius villosus* were first recorded between 1915 and 2005 on gorse and/or Scotch broom growing in Canada and/or the USA. Following the initiation of the gorse and broom biocontrol program in the 1920s, 11 additional biocontrol agents were released in the USA after being officially screened for safety, suitability, host specificity, and efficacy. Six of these species were released only in Hawaii and only on gorse.

The first tested and approved biocontrol agent, the gorse seed weevil *Exapion ulicis* (Figure 1-5), was released in Hawaii in 1926 and in the continental United States in 1953. From 1960-1994 three additional biological control agents were approved for release in the continental USA, including the Scotch broom seed weevil *Exapion fuscirostre*, the broom twig miner *Leucoptera spartifoliella*, and the gorse spider mite *Tetranychus lintearius*. The Scotch broom seed beetle *B. villosus*, accidentally introduced into the eastern USA in 1918, was tested for host specificity and approved for redistribution in the continental USA in 1998. From 1958-2000, six additional species were tested, approved, and released only in Hawaii, including the gorse soft shoot moth *Agonopterix umbellana* (formerly

Figure 1-5. Adult *Exapion ulicis*, the gorse seed weevil. (Janet Graham)

A. ulicetella), the gorse weevil *Apion* sp., the gorse colonial hard shoot moth *Pempelia genistella*, the gorse thrips *Sericothrips staphylinus*, the gorse stem-galling weevil *Stenopterapion scutellare*, and the gorse rust *Uromyces pisi* f. sp. *europaei*.

The four Scotch broom and gorse biological control agents currently established in Canada arrived adventively from Europe or naturally spread from the continental USA.

Is Biological Control of Gorse and Scotch Broom Right for You?

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

As stated in Table 1-1, biological control is not effective in every weed system or at every infestation. Furthermore, many of the biocontrol agents currently approved for use against gorse and Scotch broom are already widespread. We recommend that you develop an integrated weed management program in which biological control is one of several control methods considered. Here are some questions you should ask before you begin a biological control program:

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

How soon do I need results: this season, one to two seasons, or within five to ten years?
Biological control requires time and patience to work. Generally, it can take one to three years after release to confirm that biological control agents are established at a site, and even longer for biocontrol agents to cause significant impacts to populations of the target weed. For some weed infestations, 5-30 years may be needed for biological control to reach its weed management potential.

What resources can I devote to my weed problem?
If you have only a small gorse and broom problem (< 1 acre or 0.4 ha), weed control methods such as pulling and/or herbicides, followed by regular monitoring for re-growth and re-treatment when necessary, may be most effective. These intensive control methods may allow you to achieve rapid control and prevent the weeds from spreading and infesting additional areas, especially when infestations occur in high-priority treatment areas such as travel corridors where the weeds are more likely to readily disperse. Where broom or gorse are well established over a large area (>1 acre or 0.4 ha), and resources are limited, biological control may be the most economical weed control option.

Is the weed the problem, or a symptom of the problem?
Invasive plant infestations often occur where desirable plant communities have been or continue to be disturbed. Without restoration of a desirable, resilient plant community, and especially if disturbance continues, biological control is unlikely to solve your weed problems.

The ideal biological control program:

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

About This Manual

This manual provides information on the biology and ecology of gorse and Scotch broom and each of their biological control agents, with emphasis on North America. It also presents guidelines to establish and manage approved biological control agents as part of an integrated gorse and broom management program.

Chapter 1: Introduction provides introductory information on gorse and Scotch broom (including their distribution, habitat, and economic impact) and classical biological control.

Chapter 2: Getting to Know Gorse and Scotch Broom provides detailed descriptions of the taxonomy, growth characteristics and features, invaded habitats, and occurrence of gorse and Scotch broom in North America. It also describes how to differentiate gorse and Scotch broom from related and look-alike species.

Chapter 3: Biology of Gorse and Scotch Broom Biological Control Agents describes biological control agents of gorse and Scotch broom, including details on each biocontrol agent's native range, original source of releases in North America, parts of gorse and broom plants attacked, life cycle, description, host specificity, known nontarget effects, habitat preferences, and availability. This chapter is particularly useful for identifying biological control agents in the field.

Chapter 4: Elements of a Gorse and Scotch Broom Biological Control Program includes detailed information and guidelines on how to plan, implement, monitor, and evaluate an effective gorse and Scotch broom biological control program. Included are guidelines and methods for:

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

Chapter 5: An Integrated Gorse and Scotch Broom Management Program discusses the role of biological control in the context of an integrated gorse and Scotch broom management program.

The **Glossary** defines technical terms frequently used by those involved in gorse and Scotch broom biological control and found throughout this manual.

References lists selected publications and resources utilized to compile this manual.

Appendices:

I. Troubleshooting Guide: When Things Go Wrong
II. Biological Control Agent Release Form
III. Gorse and Broom Biological Control Agent Monitoring Form
IV. Gorse and Scotch Broom Qualitative Monitoring Form
V. Scotch Broom Seedpod Quantitative Monitoring Form

Chapter 2: Getting to Know Gorse and Scotch Broom

Taxonomy and Related Species

Common gorse, hereafter referred to simply as gorse, and Scotch broom belong to the pea family (Fabaceae or Leguminosae). Members of the pea family produce unique five-petal flowers that resemble sailboats. A single large petal comprises the banner, two petals form the wings, and two fused petals form the keel (Figure 2-1).

Gorse is in the genus *Ulex*. There are approximately 20 species in this genus, all of which are thorny evergreen shrubs with green stems and yellow flowers in the form of a 2-lipped sailboat. No species of *Ulex* are native to North America, and other than common gorse, no other *Ulex* species occur in North America.

Scotch broom is in the genus *Cytisus*, which is represented by approximately 65 species worldwide. No species in this genus are native to North America, though four species and two cultivated hybrids are currently established in North America. Of these, only Scotch broom and Portuguese broom (*Cytisus striatus*) are considered invasive and problematic in the USA. Three closely related genera contain additional broom species considered invasive and problematic in the USA, including *Genista*, *Spartium*, and *Retama*. Scotch broom is by far the most problematic broom species present in North America and the primary target of broom biological control efforts and this manual. All of the invasive brooms are thornless shrubs with green stems and flowers in the form of a 2-lipped sailboat. The related invasive brooms are described in greater detail later in this chapter on page 31.

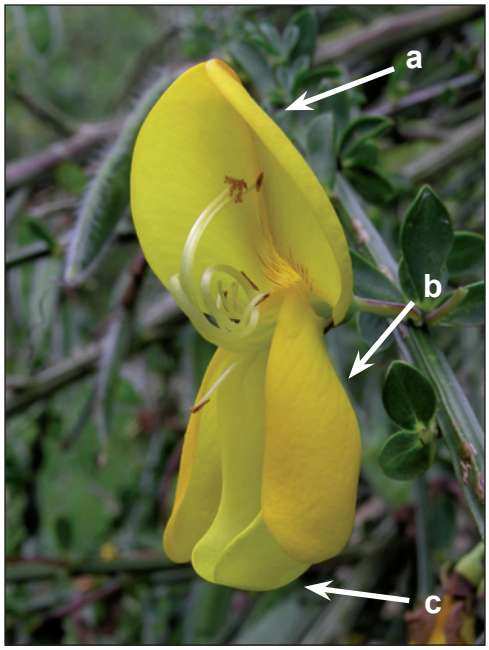


Figure 2-1. Pea flower diagram: a. single-petal banner; b. one of two single-petal wings; c. two-petal keel. (Tony Wills)

Gorse

Scientific Name

Ulex europaeus L.

Other Names

Common gorse, furze, whin, European gorse

Classification

KINGDOM	Plantae	Plants
SUBKINGDOM	Tracheobionta	Vascular plants
SUPERDIVISION	Spermatophyta	Seed plants
DIVISION	Magnoliophyta	Flowering plants
CLASS	Magnoliopsida	Dicotyledons
SUBCLASS	Rosidae	
ORDER	Fabales	
FAMILY	Fabaceae (Leguminosae)	Pea family
GENUS	*Ulex*	Gorse
SPECIES	*Ulex europaeus* L.	Gorse

History

Gorse, a native of Western Europe, was intentionally introduced to North America in the 1800s as an ornamental and as a hedge plant to contain livestock. It was recorded escaping cultivation by 1900. Gorse was introduced to Hawaii in the late 1800s as a hedge plant and was considered invasive there by 1925.

Description

At a Glance

Gorse (Figure 2-2) is an evergreen shrub typically growing 3-13 feet (1-4 m) tall from a woody, multi-branched root system. Stems are hairy when young and less so as the plant ages. Leaves are alternate and three-parted when the plant is young and are reduced to scales or thick spines as the plant ages. Flowers are

Figure 2-2. Gorse plant. (Wendy DesCamp, Washington State Noxious Weed Control Board)

yellow and occur either singly in leaf axils or in numerous clusters on the ends of older branches. Flowers are characteristic of the pea family with petals forming a banner and keel (similar to a boat). Seedpods are hairy, turning black with age. They grow to 0.8 inches (2 cm) long.

Roots

Gorse develops a large taproot up to 2 feet (60 cm) long (Figure 2-3a) with multiple branching lateral roots occurring in the top 4 inches (10 cm) of soil. Gorse stems growing low along the ground sprout adventitious aerial roots (Figure 2-3b). All roots have numerous nodules that contain nitrogen-fixing bacteria, allowing gorse to colonize nutrient poor soils and outcompete other plant species.

Stems

Plants may grow prostrate or erect. Prostrate plants typically occur in exposed, windy locations. Erect plants grow 3-13 feet (1-4 m) tall and are often as wide as they are tall. When growing in locations with dense vegetation, gorse produces a single main stem. At more open sites, gorse produces multiple densely branched stems. Stems of young plants are soft, gray-green, and hairy. As the plants age, stems remain green but become woody, angled, and terminate in a spine 1.5-2.5 inches (3.8-6.3 cm) long. Mature stems appear leafless and covered with spines (Figure 2-3c). Both stems and spines photosynthesize.

Leaves

Leaves are small, alternate, and three-parted when the plant is young, and are reduced to scales or stiff spines as the plant ages. Spines and leaves have a waxy coating. Mature plants are densely covered in sharp spines; spines are 1.8-2.6 inches (4.6-6.6 cm) long and end in a yellow point (Figure 2-3c,d). Plants are evergreen; the green scales and spines are present on stems year-round.

Flowers

Flowers occur either singly in leaf axils or in numerous clusters on the ends of older branches. Flowers are yellow, 0.5-1 inch (1.3-2.5 cm) long, and characteristic of the pea family with petals forming a banner and keel (similar to

Figure 2-3. Gorse: a. underground root system; b. adventitious aerial roots; c. stems; d. spines. (a.,c.,d. Nancy Ness, Grays Harbor Noxious Weed Control Board; b. ©Phil Bendle, Friends of Te Henui, T.E.R:R.A.I.N)

a boat, Figure 2-4a). Plants begin flowering from 18 months to 3 years of age. In North America, flowering occurs in early spring with a smaller secondary bloom in late fall at some locations.

Fruits and Seeds

Seedpods (legumes) are hairy and green, turning black with age (Figure 2-4b). They grow 0.5-0.8 inches (1.3-2 cm) long and contain 1-6 seeds. The oval seeds are 0.1-0.15 inches (3-4 mm) across, hard, shiny, and dark brown or black (Figure 2-4c). A mature plant can produce up to 18,000 seeds annually.

See Figure 2-5 on the next page for a line drawing of key gorse diagnostic traits.

Figure 2-4. Gorse: a. flowers; b. seedpods; c. seeds in pod. (a. Jennifer Andreas, Washington State University Extension; b. Forest and Kim Starr, Starr Environmental, bugwood.org; c. Steven Conaway, Penn State University, bugwood.org)

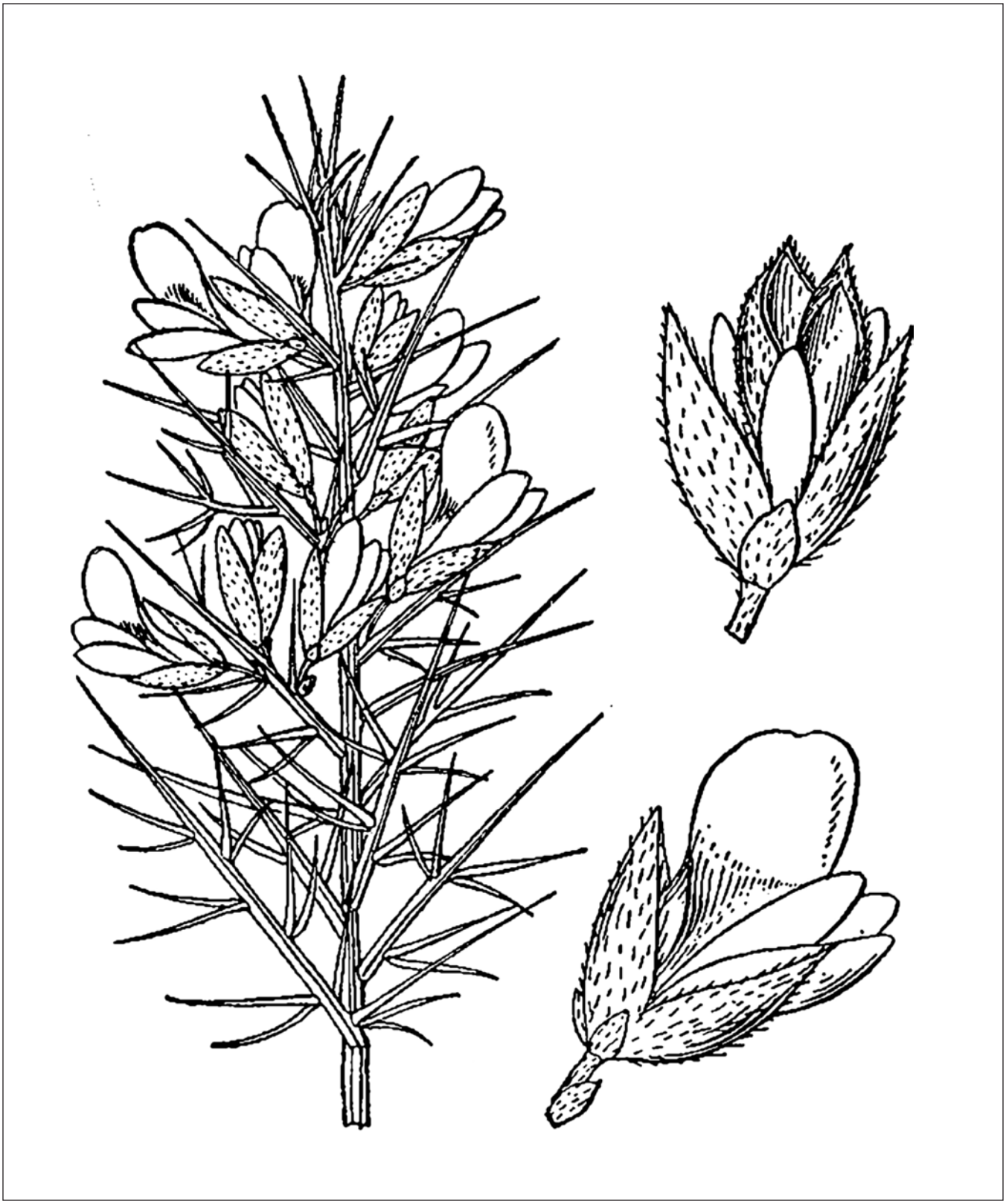


Figure 2-5. Illustration of gorse key traits. (Britton, N.L., and A. Brown. 1913. *An illustrated flora of the northern United States, Canada and the British Possessions*. 3 vols. Charles Scribner's Sons, New York. Vol. 2: 349., USDA PLANTS database)

Biology and Ecology

Gorse spreads by seed only, but it can also regenerate from the root crown after the stem is damaged (Figure 2-6). Mature seedpods split open rapidly in dry weather, ejecting seeds up to several feet (a few meters), though most fall within 3.2 feet (1 m) of the plant. Seeds are transported by insects, birds, humans, other animals, waterways, and vehicles/equipment. Due to their thick seed coats, seeds can remain viable in the soil for up to 30 years.

The highest rates of germination occur in moist soils and in open, disturbed soils with limited competing vegetation. Most seeds germinate in spring or early summer; germination rates are highest after seed scarification. Seedlings are sensitive to shading from other plants and survive better in areas with little competition for light. Juvenile plants have small, three-parted leaves. These are reduced to scales and spines as the plant ages. Mature plants photosynthesize with their spines and green stems. Plants begin flowering at 18 months to three years of age and continue to grow for 25-30 years. In North America, flowering occurs in early spring with a smaller secondary bloom in late fall at some locations. When seedpods mature, they dry out and burst open with an audible popping sound. This action, known as dehiscing, helps scatter seeds short distances.

Habitat

Soil disturbance is an important contributor to gorse seedling establishment. Gorse can often be found creating dense infestations on hillsides, pastures,

Figure 2-6. Gorse sprouting from cut stem. (Jennifer Andreas, Washington State University Extension)

roadsides, river banks, dry river beds, chaparral, grasslands, degraded coastal dunes, forest edges, and fallow fields (Figure 2-7a-f). A variety of habitat types and plant communities can be invaded by gorse following heavy grazing, cultivation, logging, and burning. Gorse does best in cool, temperate regions. Severe winter temperatures, extensive summer drought, and heavy shading limit its distribution. Gorse performs best in coarse, well-drained, dry to semi-moist soils with low fertility and in areas without significant competing vegetation.

Distribution

As of 2017, gorse has been declared noxious in four states and one Canadian province (Figure 2-8a). Though gorse is considered established in 12 states (including Hawaii) and one Canadian province (Figure 2-8b,c), it is most abundant and problematic in western North America and Hawaii (Figure 2-8c).

Comments

Mature gorse plants contain approximately 2 to 4 percent flammable oils. This, in combination with the large amount of dry branches and spines throughout the plant centers and beneath their canopies, can create an extreme fire hazard year round. Once ignited, gorse can burn rapidly and with high intensity. In 1936, a wildfire fueled primarily by gorse swept through the coastal community of Bandon, Oregon, killing thirteen people and destroying much of the town. Established gorse plants are rarely killed by fire, so post-fire gorse populations can regenerate rapidly by both seed recruitment and by re-sprouting from basal stems.

Figure 2-7. Gorse infestations: a. along a river and encroaching forested mountainsides; b. on an urban sidewalk; c. in a golf course; d. in pastures, roadsides and cleared areas in a rural town; e. in coastal scrubland; f. in an abandoned field. (a., c.-f. Wyatt Williams, Oregon Department of Forestry; b. King County Noxious Weed Control Board)

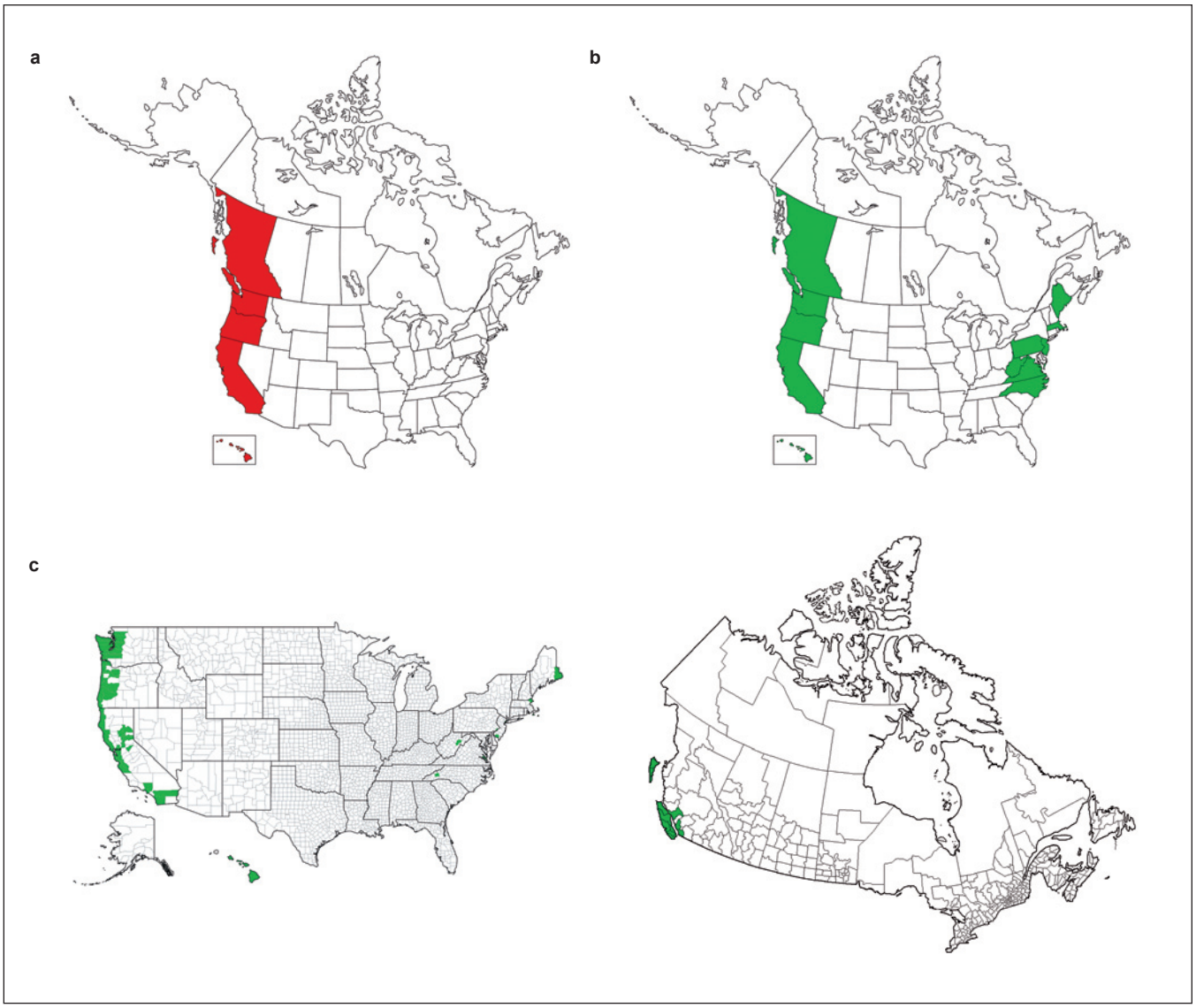


Figure 2-8. Gorse: a. noxious weed and/or regulated species listings; b. establishment by states and provinces; c. establishment by counties and districts. (EDDMapS, USDA PLANTS Database, Washington State Noxious Weed Control Board, The Research Group LLC 2014, British Columbia IAPP [accessed 30 November 2016], Clements et al. 2001)

Gorse is still available for purchase in the USA, though the sale of this species is now illegal in states where it is classified as a regulated plant or noxious weed (Figure 2-8a).

Commonly Confused Species

Numerous species present in North America have yellow, pea-like flowers similar to gorse; however, most potential look-alikes are not shrubs and do not have sharp spines in places of leaves. Camelthorn (*Alhagi maurorum*) is a spiny shrub with pea-like flowers similar to gorse (Figure 2-9a,b). Camelthorn can be differentiated by its pink or maroon flowers, by growing only 2-3 feet (0.6-0.9 m) tall from a rhizomatous root system, and by its elliptic leaves that remain persistent on mature stems. Brooms are the species most closely resembling gorse. Brooms can be readily differentiated by their lack of spines and by having a less dense, open appearance. Species of broom resembling gorse are listed in Table 2-1 on page 31, along with key characteristics in Table 2-2 (page 32) that can be used for accurate identification.

Figure 2-9. Camelthorn (*Alhagi maurorum*), a potential look-alike for gorse; a. plant; b. close-up of features. (a.,b. Franklin County Noxious Weed Control Board)

Scotch Broom

Scientific Name

Cytisus scoparius (L.) Link

Other Names

Broom, broomtops, common broom, English broom, European broom, Irish broom, Scot's broom, *Cytisus scoparius* (L.) Link subsp. *scoparius*, *Cytisus scoparius* subsp. *andreanus* (Puiss.) Dippel, *Sarothamnus scoparius* (L.) Wimm. ex W.D.J. Koch

Classification

KINGDOM	Plantae	Plants
SUBKINGDOM	Tracheobionta	Vascular plants
SUPERDIVISION	Spermatophyta	Seed plants
DIVISION	Magnoliophyta	Flowering plants
CLASS	Magnoliopsida	Dicotyledons
SUBCLASS	Rosidae	
ORDER	Fabales	
FAMILY	Fabaceae (Leguminosae)	Pea family
GENUS	*Cytisus*	Broom
SPECIES	*Cytisus scoparius* (L.) Link	Scotch broom

History

Scotch broom is considered native throughout Europe and also the Canary Islands. It was intentionally introduced to North America in the 1800s as an ornamental, fodder for domestic sheep, and erosion control. It was reported invasive by 1860. Scotch broom was introduced to Hawaii as an ornamental, possibly as early as the 1800s, though it was reportedly first collected growing on Hawaii Island in 1909.

Description

At a Glance

Scotch broom (Figure 2-10) is a shrub typically growing 3-10 feet (1-3 m) tall from a forked taproot. Stems are hairy when young and less so as the plant ages. Stems are 5-angled or star-shaped in cross section. Leaves are alternate and three-parted, and are deciduous early in the season and in times of stress. Flowers are yellow, appear singly or in clusters of two, and are characteristic of the pea family with petals forming a banner and keel (similar to a boat). Seedpods can grow up to 3 inches (7.5 cm) long; they are flattened and have hair on the margins, turning brown at maturity.

Figure 2-10. Scotch broom plants in flower. (Jennifer Andreas, Washington State University Extension)

Roots

Scotch broom develops a large, forked taproot over 2 feet (60 cm) long (Figure 2-11a) with multiple branching lateral roots growing shallowly just beneath the soil surface. All roots have numerous nodules that contain nitrogen-fixing bacteria, allowing broom to colonize nutrient poor soils and outcompete other plant species.

Stems

Scotch broom plants may grow prostrate or erect. Prostrate plants typically occur in exposed, windy locations. Erect plants grow 3-10 feet (1-3 m) tall and are often as wide as they are tall. When growing in locations with dense vegetation or shade, Scotch broom produces a single main stem. At more open sites, Scotch broom produces multiple densely branched stems. Stems of young plants are hairy. As the plants age, stems become woody, hairless, and 5-angled or star-shaped in cross section (Figure 2-11b). All stems are green and used in photosynthesis. Leaves are deciduous early in the season, leaving stems bare and green (Figure 2-11c).

Leaves

Leaves are small, alternate, three-parted (separated into three leaflets), and appear in early spring. Each leaflet is elliptical, 0.3-0.7 inches (5-20 mm) long, and 0.06-0.3 inches (1.5-8 mm) wide (Figure 2-11d). The bottom sides of leaflets are often fuzzy with short hairs. Leaves are deciduous early in the growing season and in times of stress. When leaves fall from the plant, the remaining bare green plant stems are the primary source of photosynthesis.

Flowers

Flowers occur either singly or in clusters of two in leaf axils or in numerous clusters on the ends of older branches. Flowers are 0.6-1 inch (1.5-2.5 cm) long, and characteristic of the pea family with petals forming a banner and keel (similar to a boat, Figure 2-12a and 2-14). Most flowers are yellow, though they can vary from off-white and creamy yellow to orange, red, and a combination of these colors (Figure 2-12a-f). Plants begin flowering from 18 months to 3 years of age. Flowering usually occurs in early spring, though sporadic flowering can occur throughout the year.

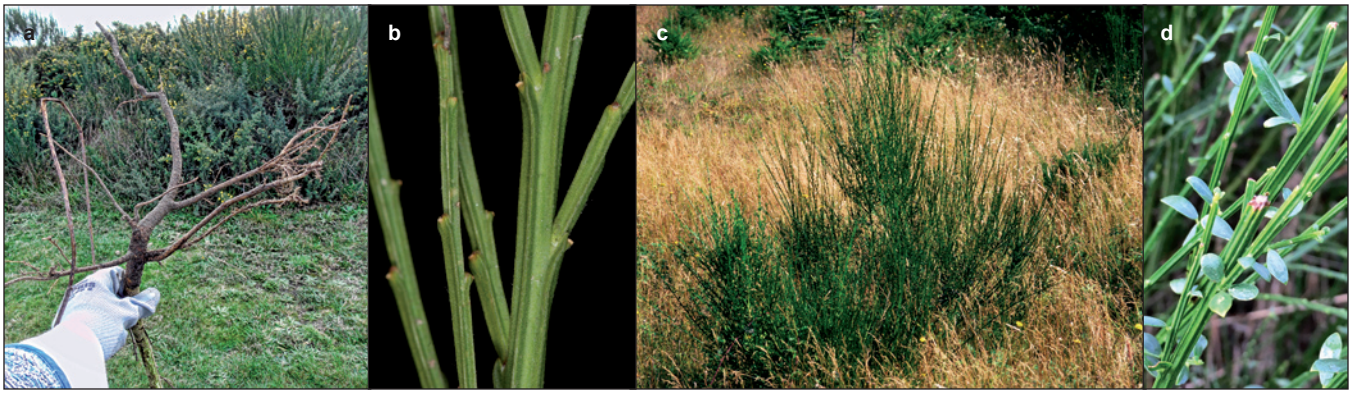


Figure 2-11. Scotch broom: a. root; b. stems; c. upper stems becoming bare as leaves fall; d. leaves. (a. Nancy Ness, Grays Harbor Noxious Weed Control Board; b. Robert Vidéki, Doronicum Kft., bugwood.org; c. Steve Dewey, Utah State University, bugwood.org; d. Jennifer Andreas, Washington State University Extension)

Figure 2-12. Scotch broom flower color variation: a. yellow (most typical); b. cream and orange; c. yellow and red; d. red with pink; e., f. landscape images with variable flower colors. (a.-c. Jennifer Andreas, Washington State University Extension; d.-f. Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Fruits and Seeds

Seedpods (legumes) are green, turning dark brown with age (Figure 2-13a). They are flattened with hairs along the margins (Figure 2-13b). Seedpods grow 1-2.8 inches (2.5-7 cm) long and 0.3-0.5 inches (8-13 mm) wide and contain 3-12 seeds each. The oval seeds are 0.1-0.15 inches (3-4 mm) long, hard, smooth, and brown (Figure 2-13c). A mature plant can produce up to 15,000 seeds annually.

See Figure 2-14 for a line drawing of key Scotch broom diagnostic traits.

Figure 2-13. Scotch broom: a. green and brown seedpods (immature and mature); b. immature seedpod with hairs along the margins; c. seeds in a mature pod. (a.-c. Jennifer Andreas, Washington State University Extension)

Figure 2-14. Illustration of Scotch broom key traits. (Encyclopædia Britannica Eleventh Edition, Vol. 4: 650)

Biology and Ecology

Similar to gorse, Scotch broom spreads by seed only, but it can also regenerate from the root crown if the stem is damaged. Mature seeds pods split open rapidly in dry weather, ejecting seeds up to several feet (a few meters), though most fall within 3.2 feet (1 m) of the plant. Seeds are transported by insects, birds, humans, other animals, waterways, and vehicles/equipment. Due to their thick seed coats, seeds can remain viable in the soil for 30 years; some sources claim seeds remain viable for up to 80 years under proper storage conditions.

The highest rates of germination occur in moist soils and in open, disturbed soils with limited competing vegetation. Most seeds germinate in spring or early summer; germination rates are highest after seed scarification. Seedlings are sensitive to shading from other plants and survive better in areas with little competition for light. Scotch broom leaves are deciduous early in the growing season and after stress, leaving the bare green plant stems as the sole source for photosynthesis. Plants begin flowering at 18 months to three years of age and continue to grow for up to 30 years, though most plants only live for 15 years. Flowering usually occurs in early spring though an occasional plant may bloom throughout the year. When seedpods mature, they dry out and burst open with an audible popping sound. This action, known as dehiscing, helps scatter seeds short distances.

Habitat

Scotch broom seedling establishment is facilitated by soil disturbance. The weed can often be found creating dense infestations on timber clear cuts, hillsides, pastures, roadsides, river banks, dry river beds, chaparral, grasslands, degraded coastal dunes, forest edges, and fallow fields (Figure 2-15a-f). A variety of habitat types and plant communities can be invaded by Scotch broom, especially following logging, flooding, and burning. The weed does best in cool, temperate regions, but is able to survive Mediterranean climates if summer droughts are not extensive. Severe winter temperatures, extensive summer drought, and heavy shading limit its distribution. Scotch broom performs best in sandy, well-drained, dry to semi-moist soils with low fertility and in areas without significant competing vegetation.

Distribution

Scotch broom has been declared noxious and/or regulated in nine states (including one state where it has not yet been recorded, Figure 2-16a). As of 2017, it is considered established in 27 states (including Hawaii) and three Canadian provinces (Figure 2-16b,c).

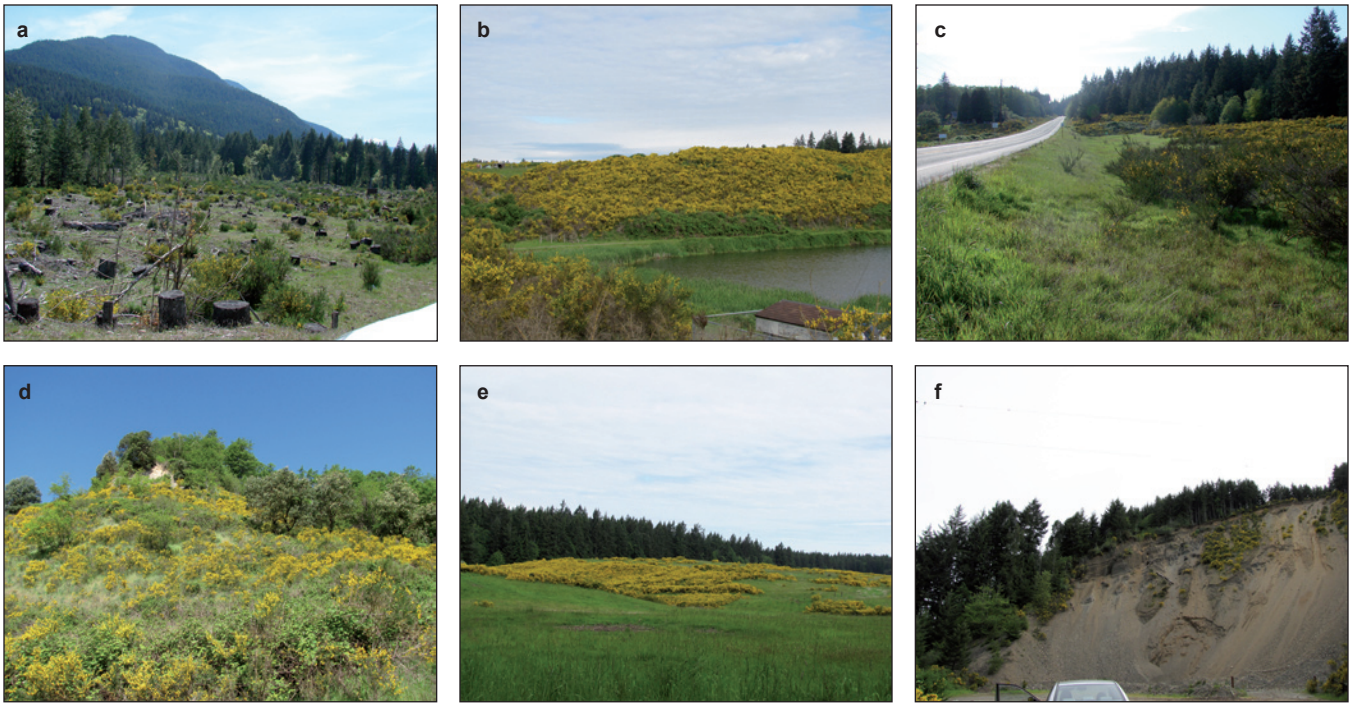


Figure 2-15. Scotch broom infestations: a. in a logging clear cut; b. surrounding a reservoir; c. on a roadside; d. on an open, disturbed hillside; e. in a pasture; f. on an eroded slope. (a.-f. Jennifer Andreas, Washington State University Extension)

Figure 2-16. Scotch broom: a. noxious and/or regulated species listings; b. establishment by states and provinces; c. establishment by counties and districts. (EDDMapS, USDA PLANTS Database, Washington State Noxious Weed Control Board, The Research Group LLC 2014, British Columbia IAPP [accessed 30 November 2016], Peterson and Prasad 1998)

Comments

While mature Scotch broom plants have a lower oil content than gorse, they are still flammable and considered a fire hazard. As plants age, the ratio of dry wood to moist green material increases. Consequently, dense and mature stands of Scotch broom could be highly flammable. Furthermore, Scotch broom's fire hazard potential is increased by its frequent occurrence on steep slopes. Scotch broom seed germination is stimulated by fire, which may lead to rapid post-fire recolonization.

Although still sold and planted for its beauty as an ornamental, Scotch broom's negative environmental impact has caused its sale to become restricted or, in some places, illegal. Where distribution of the species is restricted, many sterile or less aggressive varieties are still sold, including Burkwood's broom and moonlight broom (Figure 2-17). It is important to note these are the same species as Scotch broom (*Cytisus scoparius*); extreme caution should be applied when considering these varieties in an ornamental setting.

Commonly Confused Species

Numerous species present in North America have yellow, pea-like flowers similar to Scotch broom, including the native goldenbanners (*Thermopsis* spp., Figure 2-18a) and exotic birdsfoot trefoil (*Lotus corniculatus*, Figure 2-18b), which all may be mistaken for young Scotch broom. Goldenbanners, birdsfoot trefoil, and most other potential look-alikes are not shrubs so can be easily differentiated. Gorse resembles Scotch broom with its similar shrub habit, yellow, pea-like flowers, legume fruit, and green stems. Gorse differs in that mature plants are covered with sharp spines rather than leaves. Other exotic broom species most closely resemble Scotch broom. Table 2-1 contains photographs and Table 2-2 lists key characteristics useful for differentiating these species from Scotch broom and from each other.

Figure 2-17. Moonlight broom, a commercially available ornamental variety of *Cytisus scoparius*. (Jennifer Andreas, Washington State University Extension)

Figure 2-18. Potential look-alike species for young Scotch broom: a. mountain goldenbanner (*Thermopsis montana*); b. birdsfoot trefoil (*Lotus corniculatus*). (a. Peganum; b. Ohio State University Weed Lab, bugwood.org)

Table 2-1. Other exotic broom species present in North America similar in appearance to Scotch broom and gorse

	a. Plant	b. Flowers	c. Pods
Bridal veil broom *Retama monosperma*			
French broom *Genista monspessulana*			
Portuguese broom *Cytisus striatus*			
Spanish broom *Spartium junceum*			
Gorse *Ulex europaeus*			
Scotch broom *Cytisus scoparius*			

Bridal veil broom: a. Jean-Paul Peltier, b. Javier Martin, c. Fouad Msanda; French broom: a. Philipp Weigell, b. Calibas, c. Xemenendura; Portuguese broom: a., b. ©2011 Vernon Smith, c. ©2011 Zoya Akulova; Spanish broom: a., b. Jennifer Andreas, Washington State University Extension, c. Eugene Zelenko; Scotch broom: a.-c. Jennifer Andreas, Washington State University Extension.

Table 2-2. Key characteristics for differentiation of other exotic broom species present in North America similar to Scotch broom and gorse

	Plant Trait					
Species	**Preferred Habitat**	**Height**	**Leaves**	**Stems**	**Flowers**	**Pods**
Bridal veil broom *Retama monosperma*	Disturbed, open areas; rocky, infertile soil; dry conditions	3-10 ft (1-3 m)	Single; <⅓ in (¾ cm); linear; hairy above and below; sparse; quickly deciduous	All: slender, green, drooping	White; ½ in (1¼ cm); clusters 2-20 along stems; early summer	Circular; ⅓-½ in diameter (1 cm); inflated; smooth
French broom *Genista monspessulana*	Disturbed, open; high pH soil; mesic habitat	3-10 ft (1-3 m)	3-parted; leaflets ⅓-½ in (1-1¼ cm); hairy; numerous; on plant year-round	Young: slender, green, ridged; Mature: brown, round	Yellow; ≤½ in (1¼ cm); clusters 4-10 at branch ends; spring/summer	Linear; ½-1 in (1¼-2½ cm); dense hair
Portuguese broom *Cytisus striatus*	Disturbed, open; mesic habitat	3-10 ft (1-3 m)	Single to 3-parted; leaflets ⅓-½ in (1-1¼ cm); smooth above, hairy below; sparse; deciduous early	Young: slender, green; Mature: brown, woody	Pale yellow; ≤1 in (2½ cm); clusters 1-2 in leaf axils; spring/summer	Linear; ½-1½ in (1¼-4 cm); inflated; dense hair
Spanish broom *Spartium junceum*	Disturbed, open areas; dry conditions	5-15 ft (1½-4½ m)	Single; ½-1 in (1¼-2½ cm); oval, smooth-margined; deciduous early	Young: slender, green, round, rush-like; Mature: woody, round	Yellow; ≤1 in (2½ cm); clusters of several at current-year branch ends; summer into fall	Linear; 2-4 in (5-10 cm); slightly flattened; dense hair
Gorse *Ulex europaeus*	Disturbed, open; well-drained soil; mesic habitat	3-13 ft (1-4 m)	Young: 3-parted, small; Mature: leaves reduced to spines 1¾-2½ in (4½-6½ cm), ending in yellow point, on plant year-round	Young: soft, green, hairy; Mature: woody, green, hairless, terminate in spine ≤1 in (2½ cm)	Yellow; ½-1 in (1¼-2½ cm); singly in leaf axils or large clusters at stem ends of mature plants; early spring	Linear; ½-¾ in (1¼-2 cm); inflated; dense hair
Scotch broom *Cytisus scoparius*	Disturbed, open; well-drained soil; mesic habitat	3-10 ft (1-3 m)	3-parted; ⅓-¾ in (≤⅓ cm); smooth above, hairy below; deciduous early	Young: slender, green, hairy; Mature: woody, hairless, 5-angled cross-section	Yellow; ½-1 in (1¼-2½ cm); clusters 1-2 in leaf axils or large clusters at stem ends of mature plants; early spring	Linear; 1-2¾ in (2½-7 cm); flattened; hair only along margins

Chapter 3: Biology of Gorse and Scotch Broom Biological Control Agents

Classical biocontrol agents may be found in a number of taxonomic groups. The majority of approved biocontrol agents are invertebrates in the kingdom Animalia and 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 mites (arthropods in the class Arachnida), nematodes (kingdom Animalia and phylum Nematoda), and fungi (kingdom Fungi) biocontrol agents. The gorse and Scotch broom biocontrol agents currently approved for use in North America include four species of insects (three beetles and a moth) and one mite species. Six additional biocontrol agents that were approved for use in Hawaii include five insects (two beetles, two moths, and a thrips) and one species of rust fungus. Three accidentally introduced species currently not approved for redistribution but commonly found on gorse or Scotch broom in the continental USA include two insects (a moth and a psyllid) and a mite. The taxonomic groups of all approved and unapproved gorse and broom biocontrol agents are described in greater detail in the following sections.

Insects

Insects are the largest and most diverse class of animals. Basic knowledge of insect anatomy and life cycle will help in understanding insects, and recognizing them in the field.

Most insects used in weed biocontrol have complete metamorphosis, which means they exhibit a life cycle with four distinct stages: egg, larva, pupa, and adult (Figure 3-1). All insects have an exoskeleton (a hard external skeleton) and a segmented body divided into three regions (head, thorax, and abdomen, Figure 3-2a,b). Adult insects have three pairs of segmented legs attached to the thorax, and a head with one pair each of compound eyes and antennae.

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

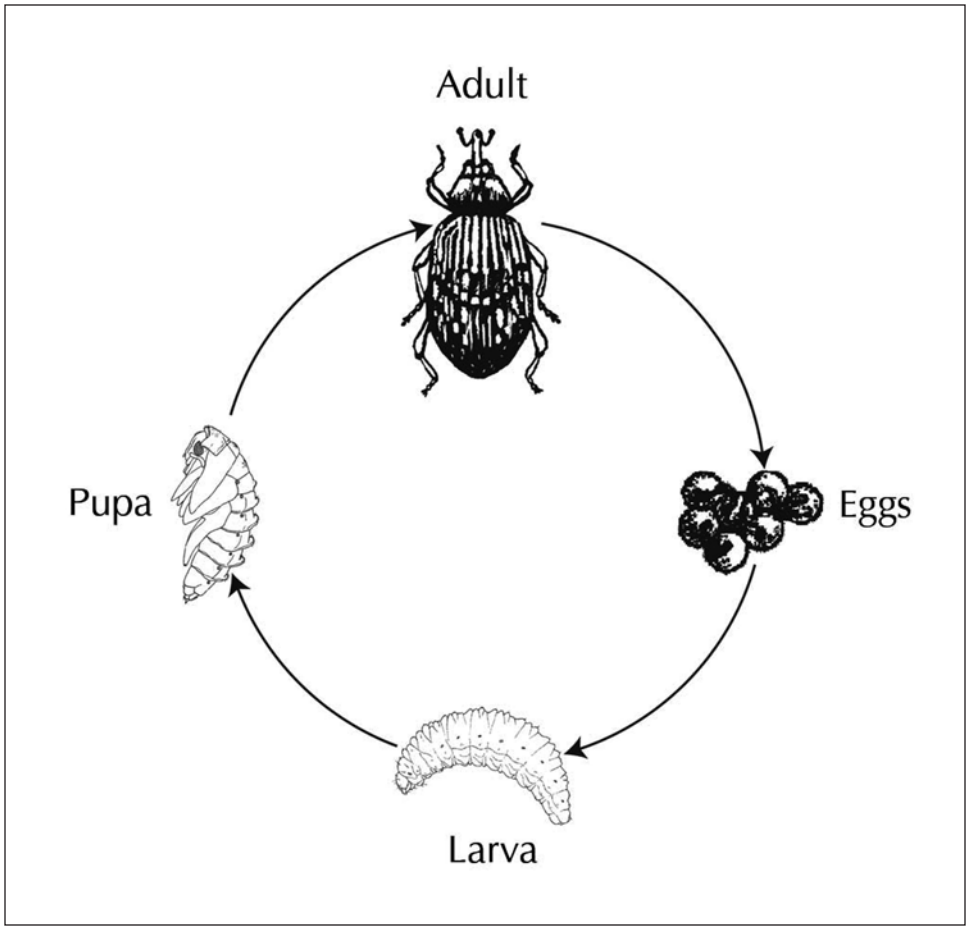


Figure 3-1. Line drawings of a beetle life cycle showing complete metamorphosis. (University of Idaho)

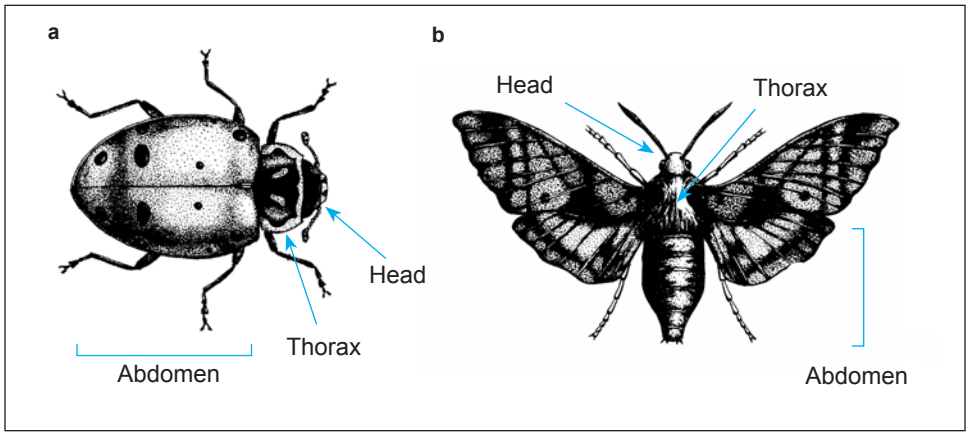


Figure 3-2. Line drawings of insect anatomy: a. beetle; b. moth. (a., b. adapted from Biological Control of Weeds in the West, Rees et al. 1996)

Beetles (Order Coleoptera)

Adult beetles are hard-bodied insects with tough exoskeletons. Adult beetles possess two pairs of wings. The two front wings, called elytra, are thickened and meet in a straight line down the abdomen, forming a hard, shell-like, protective covering (Figure 3-2a). The two hind wings are membranous and used for flight; these are larger and are folded under the elytra when not in use. Beetle larvae are grub- or worm-like with three small pairs of legs, allowing some to be quite mobile. Many are pale white with a brown or black head capsule, though some may be quite colorful and change markedly in appearance as they grow. Beetles, like those used for gorse and broom biocontrol, have chewing mouthparts.

Butterflies and Moths (Order Lepidoptera)

Adult Lepidoptera have two pairs of membranous wings that are covered with powder-like scales. Adult butterflies/moths have prominent antennae and coiled mouthparts that are adapted to siphoning sap and nectar from plant flowers. They can be bright- or dull-colored, and males and females of the same species do not always have the same coloration. Many adult butterflies/moths feed very little, if at all. Lepidoptera larvae (known as caterpillars) have a toughened head capsule, chewing mouthparts, and a soft body; they are mobile and active feeders. The pupal stage can be naked or enclosed in a cocoon, depending on the species.

Thrips (Order Thysanoptera)

Thysanoptera undergo incomplete metamorphosis with only three distinct stages: egg, nymph, and adult. There is no true pupal stage for this order of insects. Adult thrips can be wingless or have two pairs of stalk-like wings with long hair fringing the margins. There are two actively feeding nymphal instars for all thrips and 2-3 inactive (non-feeding) instars. Nymphs somewhat resemble adults, but they lack wings and functional reproductive organs. Adult and active nymphal stages of thrips feed by piercing the plant with their straw-like mouthparts and sucking out the cell contents.

True Bugs, Including Psyllids (Hemiptera)

True “bugs” are in the order Hemiptera and undergo incomplete metamorphosis with only three distinct life stages: egg, nymph, and adult. There is no true pupal stage for this order of insects. Adult Hemiptera possess two pairs of wings. The hind wings are membranous; the front wings are generally hardened at their base and membranous at their tips, but the broom psyllid has entirely membranous front wings. Psyllid nymphs molt multiple times, and each subsequent instar more closely resembles adults. Psyllid nymphs and adults feed by piercing the plant with their straw-like mouthparts and sucking out the cell contents.

Mites

Like insects, mites are in the phylum Arthropoda and have an exoskeleton; however, they belong to a different class, Arachnida, whose adult members are typically characterized by having 8 legs (compared to the 6 legs of adult 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 nymph and has 8 legs. Nymphs are usually very similar in appearance to adults (Figure 3-3). Some mite species do not have a larval stage, and some mite families have only 4 legs. Larvae, nymphs, and adults all feed by piercing and sucking cell contents.

Fungi

Fungi belong to their own kingdom (Fungi). The fungus described in this manual is a rust, which is in the phylum Basidiomycota. Rust fungi are obligate parasites; they require a living host to complete their life cycle. Rusts typically attack leaves and stems of the host plant. Rust infections usually appear as numerous rusty, orange, yellow, or even white colored spots (pustules) that rupture the leaf surface and release spores that resemble colored powder (typically yellow, orange, or brown). Most rust infections are local spots but some may spread internally through the plant. Rusts spread from plant to plant mostly by windblown spores, although insects, rain, and animals may aid in the rust transmission and infection process.

The life cycle of rust fungi can be very complicated. Rust fungi can produce up to five distinctive spore types which have different functions from infesting a new host plant, re-infecting the same host plant, and producing pustules on infected plant leaves and stems.

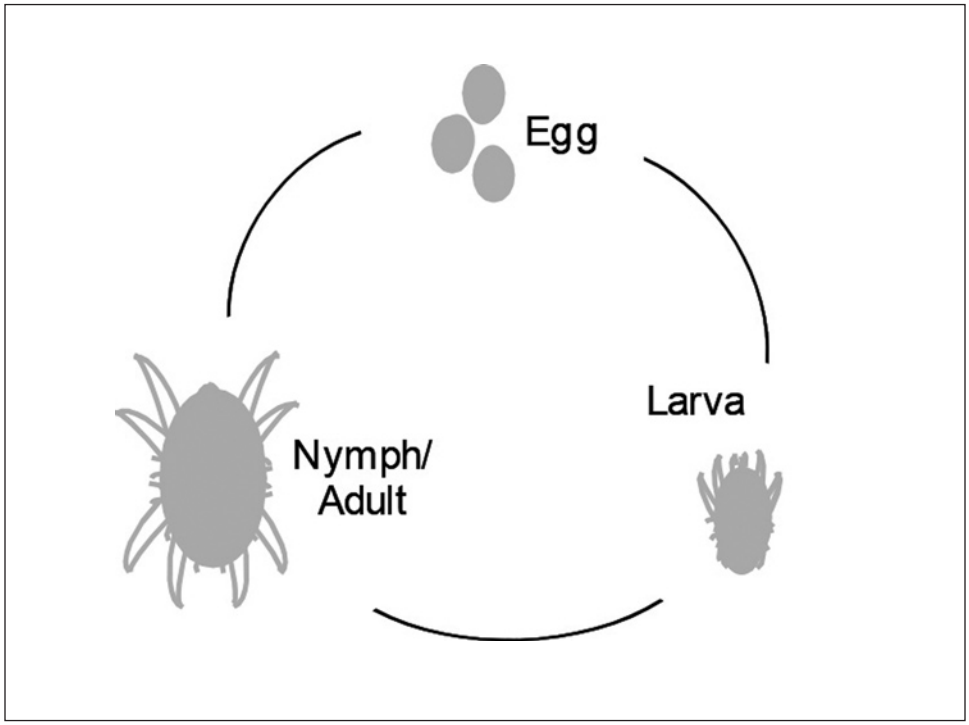


Figure 3-3. Mite life cycle. (Rachel Winston, MIA Consulting)

Gorse and Scotch Broom Biological Control Agents

Biocontrol agents used on North American gorse and broom attack the stems, seeds, and foliage. Each biocontrol agent is described in detail in the following sections, separated by approved species attacking gorse in North America and Hawaii, approved species attacking Scotch broom in North America, and species accidentally introduced to North America but not currently approved for redistribution. All gorse and broom biocontrol agents already established in North America and/or Hawaii are summarized and compared in Tables 3-1 through 3-5 near the end of this chapter.

Gorse Biological Control Agents (North America and Hawaii)

Exapion ulicis (Forster)

Gorse seed weevil

Synonym: *Apion ulicis* (Forster)

Order		Coleoptera
Family		Brentidae
Native Distribution		Western Europe
Target Weed		Gorse
North America	Original Source	USA: England
	First Release	USA: 1953 (CA)
	Nontarget Effects	None reported
Hawaii	Original Source	England, France
	First Release	1926
	Nontarget Effects	None reported

Description

Eggs are round, small, and translucent yellow. Larvae are cream colored with brown head capsules, C-shaped, and can reach 3 mm in length (Figure 3-4a). Pupae are typically 3 mm long and cream colored, becoming dark gray with age. Adults are gray with very long, slightly curved snouts and brownish gray legs (Figure 3-4b). Faint stripes are sometimes apparent on their elytra, and they are typically 2-3 mm long.

Life Cycle

In North America, overwintering adults emerge during late winter-early spring depending on location. Adults feed on gorse flowers and foliage (Figure 3-4c), and deposit eggs into young seedpods. Larvae begin hatching in early to late spring and feed on developing seeds. Larvae develop through three instars. Pupation occurs in seedpods, and new adults emerge in late summer. Adults do not chew their way out of the seedpod, instead relying on the plant's dehiscing mechanism to escape. Seedpods dehisce, or dry out, and burst open at maturity in order to spread their seeds. Adults feed on spines and stems of gorse and then overwinter among gorse foliage. There is one generation per year (Figure 3-5).

Figure 3-4. *Exapion ulicis*: a. larvae and damage within a gorse seedpod; b. adult; c. adults on gorse flower.
(a. George Markin, USDA Forest Service, bugwood.org; b. Janet Graham; c. Eric Coombs, Oregon Department of Agriculture, bugwood.org)

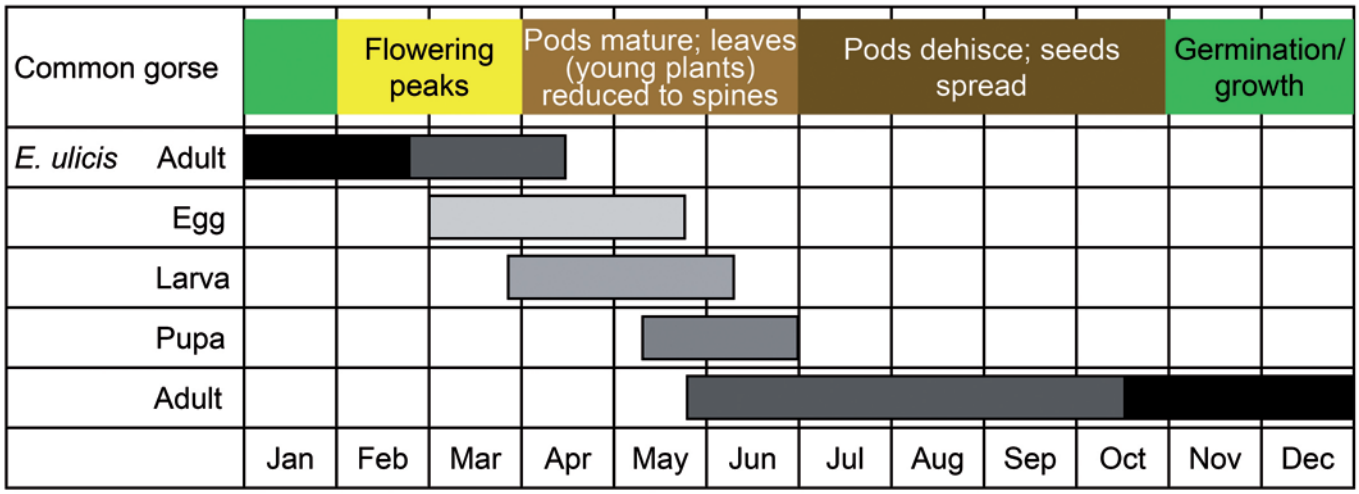


Figure 3-5. Schematic life cycles of *Exapion ulicis* and gorse in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. The life cycle of *E. ulicis* differs in Hawaii where both the biocontrol agent and gorse are subjected to different climatic conditions. Black bars represent the beetle's inactive overwintering period.

Habitat Preference

Similar to its host plant, the gorse seed weevil does best in open, sunny sites and at locations with dense gorse infestations. Its distribution is limited in regions with cold winters, shade, only scattered host plants, and in salt spray zones along coastlines.

Damage

Adult feeding leads to the destruction of stem tissue but without significantly harming the attacked plant. Larval seed feeding (Figure 3-4a) may reduce seed output. While this does not kill existing gorse plants, it can help reduce the rate of spread of gorse populations.

Current Status and Availability

This beetle is widespread and abundant on gorse in the western USA (Figure 3-6), though its overall impact is limited. From 30 to 95 percent of seedpods are attacked, but this does not reduce established stand density. At best, it may slow the rate of spread of gorse; however, it is ineffective on seed maturing in autumn/winter. **This species is currently not known to be present in Canada.**

In Hawaii, *E. ulicis* is established on Maui and Hawaii Island. Aggressive chemical/burning control programs have destroyed gorse at some locations, bringing about a collapse of the weevil populations, followed by a slow biocontrol agent recovery. Attack rates have varied by year on both islands. Annual attack rates of up to 95 percent of seedpods have had only limited impact on the invasiveness of gorse, likely due to the long-lived seed bank and subsequent plant recruitment.

Comments

In Hawaii, feeding damage by *E. ulicis* may increase the susceptibility of gorse plants to the pathogenic fungus *Colletotrichum* sp.

Figure 3-6. Current establishment of *Exapion ulicis* on gorse in North America and Hawaii. (Winston et al. 2014a)

Tetranychus lintearius Dufour

Gorse spider mite

Order		Acari
Family		Tetranychidae
Native Distribution		Europe
Target Weed		Gorse
North America	Original Source	USA: England, Portugal, Spain via New Zealand
	First Release	USA: 1994 (CA, OR)
	Nontarget Effects	None reported
Hawaii	Original Source	England, Portugal, Spain via New Zealand via USA (OR)
	First Release	1995
	Nontarget Effects	None reported

Description

Eggs are tiny, round, and largely transparent. First instar (larval) mites are light in color and have six legs. Second to fourth instar (nymphal) mites have eight legs, are brown, and resemble small adults. Adults also have eight legs, are brick red in color, and are up to 0.5 mm long (Figure 3-7).

Life Cycle

Adults form a colony with large amounts of webbing on the terminal branches of gorse. Females lay eggs year-round on infested shoots. Hatching mites complete four immature stages, with larvae and nymphs feeding on plant tissue. Adults feed on stems and spines and live up to four weeks. There are up to six generations per year, with all stages capable of overwintering (Figure 3-8).

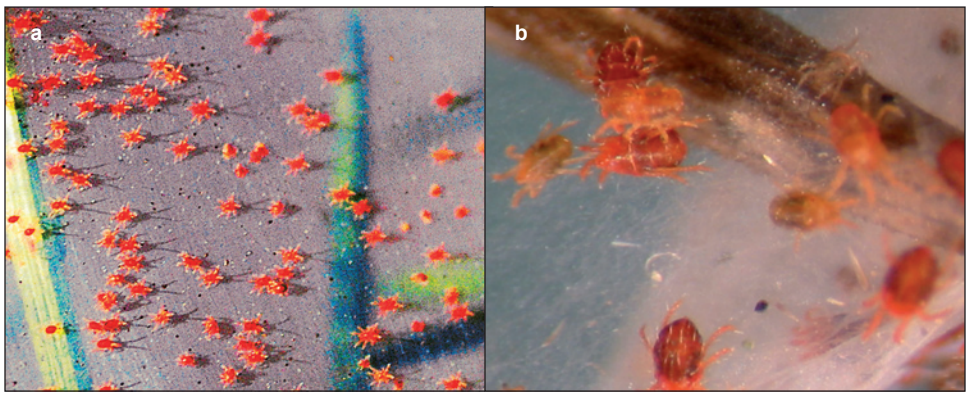


Figure 3-7. *Tetranychus lintearius* adults. (a. Rich Lee, San Juan County Noxious Weed Control Board; b. Eric Coombs, Oregon Department of Agriculture)

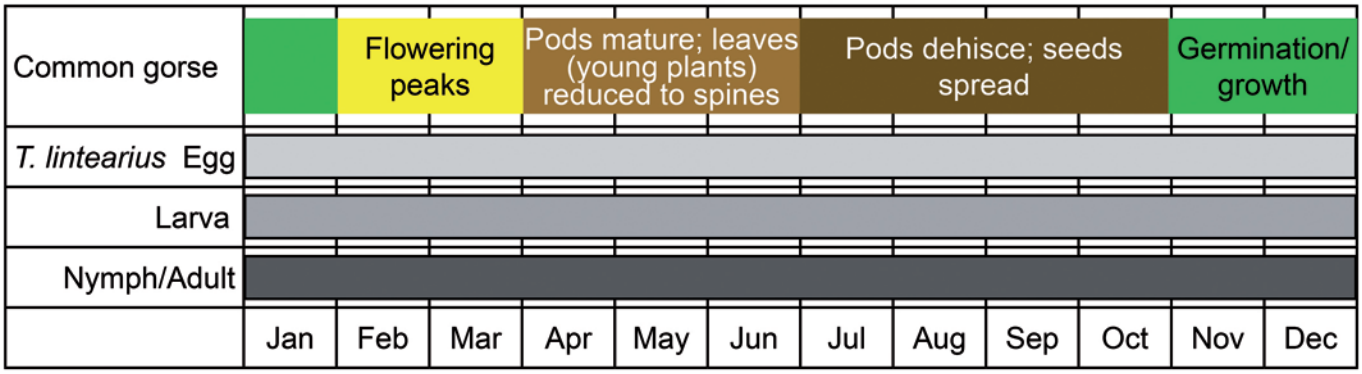


Figure 3-8. Schematic life cycles of gorse and *Tetranychus lintearius*. There are multiple generations of *T. lintearius* annually (up to 6); all stages are capable of actively overwintering. The life cycle of gorse differs in Hawaii where it is subjected to different climatic conditions.

Habitat Preference

The mite does best in warm, open gorse patches and away from the ocean. Damp, ocean-side infestations or heavily shaded forest patches are seldom attacked. *Tetranychus lintearius* can be somewhat cold hardy, but severe winter temperatures limit populations.

Damage

Large populations of this mite produce extensive amounts of webbing over mite colonies on gorse terminal branches (Figure 3-9a,b). Larval, nymphal, and adult feeding stunts branch growth and reduces flowering (Figure 3-9c), thus contributing to a reduction in the spread of gorse. Heavily infested plants are killed by the extensive feeding.

Current Status and Availability

This biocontrol agent was initially widely distributed on gorse throughout the western USA, even leading to an 80 percent reduction in gorse flowering in Oregon. It was most effective in open patches in inland areas. Populations have since decreased significantly due to heavy predation by beetles and predatory

Figure 3-9. *Tetranychus lintearius* webbing: a. with mass of adults; b. over large infested gorse patch; c. covering gorse stems with *T. lintearius* feeding damage. (a. Rich Lee, San Juan County Noxious Weed Control Board; b. Eric Coombs, Oregon Department of Agriculture; c. Steven Conaway, Penn State University, bugwood.org)

mites. Weak webbing indicates predators are likely present. *Tetranychus lintearius* is now considered an ineffective biocontrol agent in the continental USA. **This species is currently not known to be present in Canada.**

In Hawaii, *Tetranychus lintearius* is established on Maui and Hawaii Island. It initially provided partial to substantial control of gorse until the year 2000, when predacious mites may have first appeared. Populations of *T. lintearius* are now limited on both islands where it is established (Figure 3-10).

Figure 3-10. Current establishment of *Tetranychus lintearius* on gorse in North America and Hawaii (Winston et al. 2014a)

Gorse Biological Control Agents (Hawaii Only)

Six gorse biological control agents were approved and released only in Hawaii. Each of these is described in the following section. Because these species are not currently approved for release in the continental USA or Canada, less detail is given for their descriptions, life cycles, and current status.

Agonopterix umbellana (Fabricius)

Gorse soft shoot moth

Order: Lepidoptera
Family: Oecophoridae

Synonym: *Agonopterix ulicetella* (Stainton)

Description and Life Cycle

Adults are light brown with dark brown or black longitudinal lines on the front wings that fade as the adult ages. Adults are typically 12 mm long with a wingspan of 21 mm, and they have long, dark antennae (Figure 3-11a). Overwintering adults emerge during late winter/early spring and lay eggs in gorse leaf and spine axils. Eggs are bright yellow, barrel-shaped, and 1 mm long.

Figure 3-11. *Agonopterix umbellana*: a. adult (body length top line, wingspan length bottom line); b. silken feeding tubes and damage to gorse; c. larva. (a.,b. Fritzi Grevstad, Oregon State University; c. Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Larvae hatch in late spring and spin silken tubes on gorse buds, feeding on new shoots and spines. Attack by multiple larvae can defoliate an entire shoot and kill the developing tip (Figure 3-11b). There are five larval instars. First to fourth instars are dark brown with dark spots on their sides. Fifth instars are olive green with dark side spots, and can be up to 20 mm long (Figure 3-11c). Pupation occurs in the silken feeding tubes. Adults emerge in late summer and overwinter in gorse foliage. There is one generation per year.

History and Current Status

Agonopterix umbellana was collected from England and released in Hawaii from 1988. A second population of warmer-adapted individuals collected from Portugal was released from 1991, in an attempt to increase establishment at lower elevation sites in Hawaii. Both releases resulted in successful establishment, and subsequent records do not differentiate between the two populations.

This species is currently established on two islands (Figure 3-12). It was initially widespread on Hawaii Island, but an aggressive chemical/burning control program in 2001/2002 destroyed the gorse, resulting in a collapse of the *A. umbellana* population. *Agonopterix umbellana* recovered and was again abundant by 2010. On Maui, this biocontrol agent is well established only at high elevations (> 3,280 feet or 1,000 m), where gorse is also most problematic. Overall in Hawaii, while larval feeding can destroy a high percentage of gorse shoot tips and sometimes leads to dieback, plants frequently compensate by initiating growth of new shoots later in the season when *A. umbellana* is no longer active. Impact is therefore limited. Parasitism may also contribute to low impact at some sites.

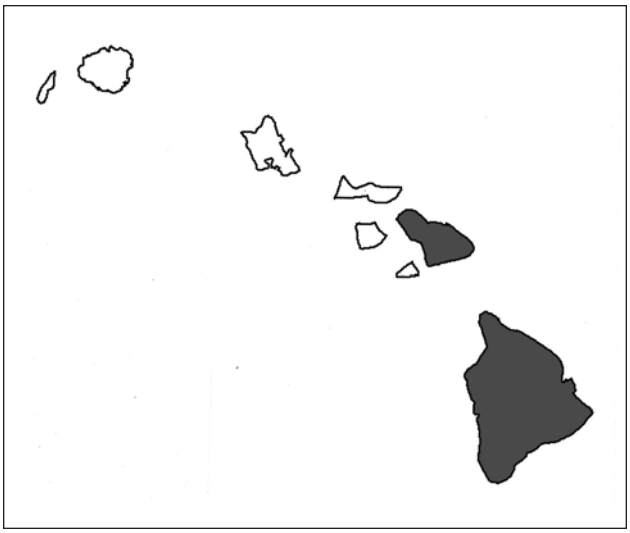


Figure 3-12. Current establishment of *Agonopterix umbellana* on gorse in Hawaii (Winston et al. 2014a)

Apion sp.

Gorse seed weevil

Order: Coleoptera
Family: Brentidae

The exact identification of this species is unknown, but it is possibly *Apion uliciperda* Pandelle.

Description and Life Cycle

Not much is known about this species beyond it being closely related and morphologically similar to *Exapion ulicis* (already described in the previous section). The description and life cycle of *E. ulicis* are, therefore, repeated here. Adults of the unknown *Apion* sp. have been described as being slightly larger and a deeper gray compared to *E. ulicis*.

Adult *E. ulicis* are gray with very long, slightly curved snouts and brownish gray legs. Faint stripes are sometimes apparent on their elytra, and they are typically 2-3 mm long. In the continental United States, overwintering adult *E. ulicis* emerge during early spring, feed on gorse flowers and foliage, and deposit eggs into young gorse seedpods. Eggs are round, small, and translucent yellow. Larvae hatch in late spring and early summer and feed on developing seeds. Larvae are cream colored, C-shaped, can reach 3 mm in length, and develop through three instars. Pupae are typically 3 mm long and become dark gray with age. Pupation occurs in seedpods, with adults emerging in late summer. Adults feed on spines and stems of gorse and then overwinter among gorse foliage. There is one generation per year.

History and Current Status

After several of the first releases of *E. ulicis* failed to result in establishment in Hawaii, a species closely related to *E. ulicis* encountered in Spain and Portugal was released on Maui in 1958. **This release did not result in successful establishment**, and future efforts with this species were abandoned once it was determined that *E. ulicis* had finally successfully established.

Pempelia genistella (Duponchel)

Gorse colonial hard shoot moth

Order: Lepidoptera
Family: Pyralidae

Description and Life Cycle

Larvae overwinter within a silken feeding web. They become active in spring and feed on gorse spines, leaves, buds, shoots, and flowers beneath their silk web. This feeding causes damaged foliage and stems to turn brown and die. Larvae have green and brown stripes and can be up to 25 mm long. Pupae are dark reddish-brown. Pupation occurs within the silk web in early summer. Adults emerge in summer and lay eggs at the base of mature spines on growing gorse shoots. Adults are light brown with black, brown, and white markings on their wings; males have a small tuft at the base of antennae. Adults are 10-15 mm long with a wingspan of 26-29 mm. Larvae emerge in late summer to early fall and congregate to spin a coarse creamy-gray silken web with many tunnels, often at the base of current gorse growth. There are typically 2-9 larvae per web, and overwintering occurs within webs. There is one generation per year.

History and Current Status

Individuals collected from Portugal were released on Hawaii Island in 1996. This moth initially established and was recovered in small amounts. Gorse at the release sites was subsequently exterminated by fire and herbicides, and *P. genistella* populations do not appear to have survived.

Sericothrips staphylinus Haliday

Gorse thrips

Order: Thysanoptera
Family: Thripidae

Description and Life Cycle

Adults are tiny (~1 mm long), black, and have white wing pads (Figure 3-13a,b). They are typically wingless, though some winged individuals do occur. Winged forms are more abundant when population densities are high. Adults lay eggs in slits within young stems of gorse. Eggs are pale yellow, cylindrical, and ~0.3 mm long. There are two actively feeding nymphal instars and two inactive (non-feeding) instars. Nymphs are creamy-yellow and look increasingly similar

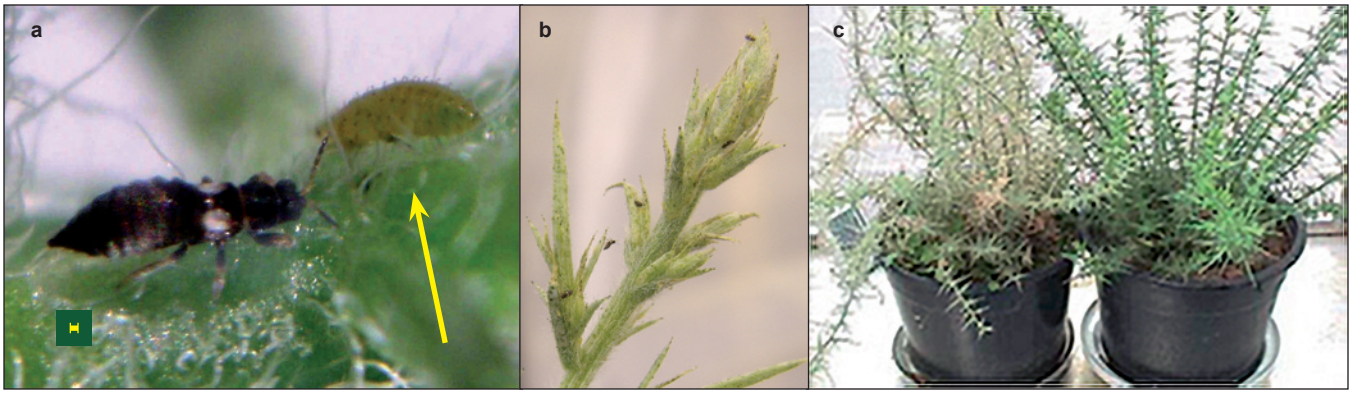


Figure 3-13. *Sericothrips staphylinus*: a. adult (foreground) and nymph (background, see arrow); b. adults on gorse foliage; c. feeding damage to gorse tissue in left pot. (a.-c. Fritzi Grevstad, Oregon State University)

to adults as they molt between instars (Figure 3-13a). The gorse thrips completes multiple generations during the warmer months of the year. At cold, high-elevation sites, adults overwinter among gorse foliage. Elsewhere in Hawaii, adults are active throughout winter. The entire life cycle of a single generation is approximately 6-8 weeks. Adults and feeding nymphs pierce gorse stems and suck out the contents of mesophyll cells (Figure 3-13b). This results in a mottled, blotchy appearance of attacked tissue (Figure 3-13c). At high numbers, the gorse thrips can reduce gorse growth and flowering, and kill seedlings.

History and Current Status

Sericothrips staphylinus was collected from England and Portugal and released in Hawaii in 1991. A second release was made with individuals from France in 1992. Both release events resulted in successful establishment, and subsequent records do not differentiate between the different source populations.

This species is currently established only on Hawaii Island (Figure 3-14). After becoming widespread, populations decreased, possibly due to predation. Even at the highest observed densities, feeding discoloration was only occasionally found on mature gorse plants, but plant death was not observed. Impact is therefore limited.

This species is currently under review for possible release in the continental USA. Additional host range testing was completed on 63 species, and a petition for field release was submitted in 2012 to the TAG and has since been recommended for release. USDA-APHIS-PPQ approval is currently pending.

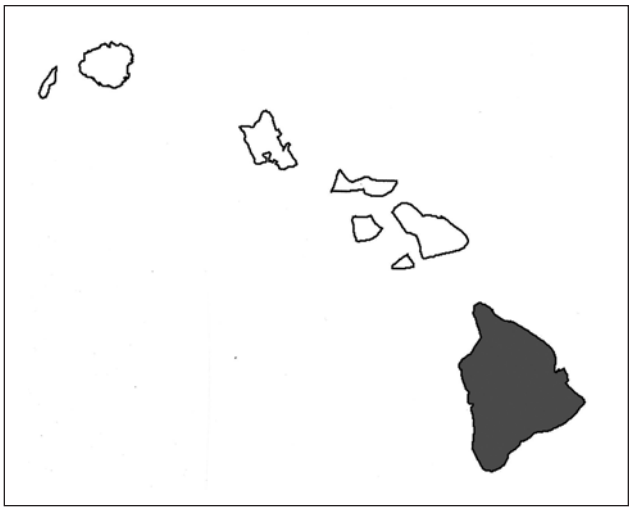


Figure 3-14. Current establishment of *Sericothrips staphylinus* on gorse in Hawaii. (Winston et al. 2014a)

Stenopterapion scutellare (Kirby)

Gorse stem-mining weevil

Order: Coleoptera
Family: Brentidae

Synonym: *Apion scutellare* Kirby, *Perapion scutellare* (Kirby)

Description and Life Cycle

Adults are dark gray with very long, slightly curved snouts and grayish-black legs. Faint stripes are sometimes apparent on their elytra, and they are typically 4-5 mm long. Adults emerge in spring and deposit eggs into growing shoot tips of gorse. Eggs are round, small, and translucent yellow. The shoot continues to grow, but within a month of the oviposition, a 1 cm gall forms in which the larva develops by feeding on galled tissue. Galling does not kill attacked shoots, but it halts or significantly reduces their growth. Larvae are cream colored, C-shaped, can reach 5 mm in length, and develop through three instars. Pupae are typically 4 mm long and become dark gray with age. Larvae overwinter in galls. Pupation occurs in galls by late winter/early spring, and new adults emerge in spring. There is one generation per year.

History and Current Status

Several releases of *S. scutellare* were made in Hawaii from 1961 to 1991 utilizing individuals collected from Portugal, Spain, and France. **All attempts failed for unknown reasons, and this biocontrol agent is not believed to have established.**

Uromyces pisi f. sp. *europaei* M. Wilson & D.M. Hend.

Gorse rust

Class: Pucciniomycetes
Order: Pucciniales

Description and Life Cycle

Rust fungi produce up to five spore stages throughout the growing season. In the spring, overwintering spores germinate and infest the stem and spine surfaces of gorse, forming masses of reddish-brown and powdery pustules. Pustules spread rapidly from plant to plant; they are easily dispersed by both wind and rain. Multiple cycles may be produced throughout the year. Infected plants can experience stunted growth and reduced seed production.

History and Current Status

Uromyces pisi f. sp. *europaei* collected from England was released on Hawaii Island in 2000. A single pustule was observed at the release site two years following release; however, all subsequent surveys have failed to yield this biocontrol agent. **It is believed *U. pisi* f. sp. *europaei* did not establish.**

Scotch Broom Biological Control Agents

Bruchidius villosus (Fabricius)

Broom seed beetle

Order		Coleoptera
Family		Chrysomelidae
Native Distribution		Europe
Target Weed		Scotch broom, French broom
North America	Original Source	USA: Accidental introduction CAN: Accidental introduction
	First Documentation	USA: 1918 (MA) CAN: 2001 (BC)
	First Redistribution	USA: 1998 (OR) CAN: 2006 (BC)
	Nontarget Effects	None reported

Description

Eggs are tiny, white, and oval-shaped (Figure 3-15a,b). Larvae are an off-white color with brown head capsules and can reach up to 2 mm in length. Pupae are gray or brown and up to 2 mm long. Adults can also be up to 2 mm long. They have gray-black bodies, antennae, and legs. Both their elytra and snouts are short (Figure 3-15d).

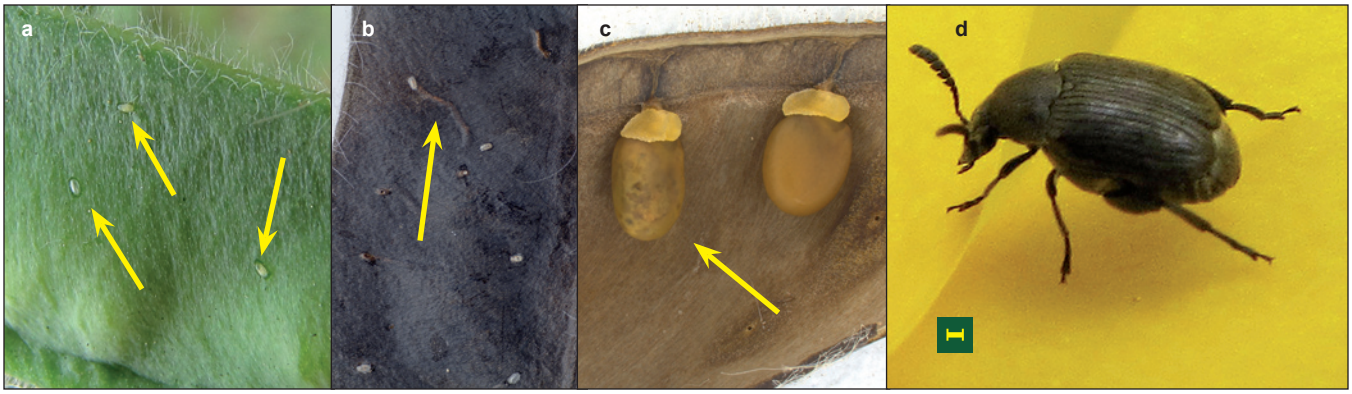


Figure 3-15. *Bruchidius villosus*: a. three eggs on a Scotch broom seedpod; b. larval tunnel extending from an egg; c. larva feeding completely within the left seed; d. adult. (a.-d. Jennifer Andreas, Washington State University Extension)

Life Cycle

Overwintering adults emerge in spring when broom begins to flower. They congregate on flowers to feed on pollen, which helps stimulate ovary maturation. Eggs are laid on the seedpod. Hatching larvae burrow into the seedpod wall, sometimes forming visible tunnels (Figure 3-15b), before entering into and feeding on developing seeds. Larvae develop through four instars completely within seeds (Figure 3-15c, left seed); generally there is one larva per seed. Pupation occurs within the seed coat. New adults emerge in late summer, leaving behind round emergence holes in seeds (Figure 3-16). Adults do not chew their way out of the seedpod, instead relying on the plant's dehiscing mechanism to escape. Seedpods dehisce, or dry out, and burst open at maturity in order to spread their seeds. Adults overwinter away from the host plant. There is one generation per year (Figure 3-17).

Figure 3-16. *Bruchidius villosus* adult and feeding damage to a Scotch broom seed. (Jennifer Andreas, Washington State University Extension)

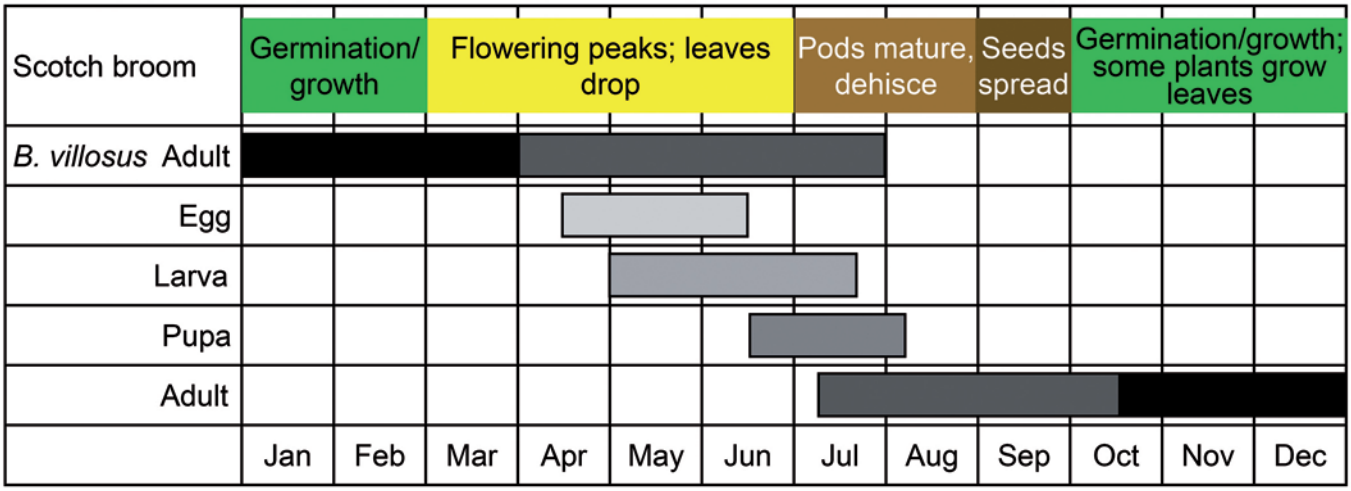


Figure 3-17. Schematic life cycle of *Bruchidius villosus* and Scotch broom in North America. Bars indicate the approximate length of activity for each of the beetle's life stages; dates will vary depending on local conditions. Black bars represent the inactive overwintering period.

Habitat Preference

The broom seed beetle does best in meadows or on hillsides with southern exposure. It may perform poorly in heavily shaded, cold, high elevation, and/or damp sites.

Damage

Larval feeding on developing seeds (Figures 3-15c, 3-16) reduces viable seed production. One beetle typically kills one seed. While this does not kill existing broom plants, it can help reduce the rate of spread of broom populations and may have long-term impacts by reducing seed recruitment as established plants senesce.

Current Status and Availability

Bruchidius villosus was unintentionally introduced to North America. First reported on Scotch broom in Massachusetts in 1918, it later spread naturally along the east coast of the USA. Individuals from these unintentionally introduced populations were tested for host specificity following USDA-APHIS TAG protocols and approved for redistribution in the USA. Beginning in 1998, the broom seed beetle was deliberately transferred from North Carolina to Scotch broom growing in Oregon and Washington. By 2001, the beetle spread naturally to French broom (*Genista monspessulana*) growing in Oregon and to Scotch broom growing in British Columbia, Canada. From 2006-2008 it was redistributed within British Columbia on Scotch broom. In 2003, the beetle was recorded as present on Scotch Broom in Nova Scotia.

This beetle is now widespread on Scotch Broom in the northwestern USA (Figure 3-18a) where its abundance is variable but increasing. In 2014, a study evaluating the attack rate of *B. villosus* and *Exapion fuscirostre* on Scotch broom seeds was conducted in California, Oregon, Washington, and British Columbia. Across 30 sites in Washington, the average *B. villosus* attack rate was 44.2% but

ranged from 0 to 87.4%. At 32 sites in Oregon, an average of 40.8% seeds were destroyed with a range of 1.8 to 83.5%. At three sites in California, the average *B. villosus* attack rate was 0.6% with a range of 0 to 1%. Subsequent surveys in California in 2015 and 2016 found the abundance of *B. villosus* to have steadily increased; in 2016, at 16 sites where it was recovered, an average of 13% of seeds were destroyed (range 1-32%). Studies are continuing as it is still unclear if densities and attack rates are sufficiently high to decrease plant recruitment.

Parasitism is typically low but may limit biocontrol agent populations in some regions, and *B. villosus* seems to be less affected than *E. fuscirostre*. This species appears to outcompete *E. fuscirostre* at sites where they both occur. In 2014, *B. villosus* was the dominant species at 27/28 Washington sites and 22/32 Oregon sites. It was not intentionally released in California but has self-dispersed at least 100 miles south from the Oregon border. It appears to be a recent invasion, and populations of *B. villosus* are likely to continue increasing and spreading further south. *Bruchidius villosus* is also widespread on French broom in southwestern Oregon (Figure 3-18b), though its impact on this weed has not been formally evaluated.

In Canada, *B. villosus* has established at sites in both the coastal/lower mainland and southeastern interior areas of British Columbia, although its abundance and impact on Scotch broom are still unknown. In 2014, an average of 59% of seeds were destroyed across 10 sites with a range from 0.7 to 98%. This species is more active than the other adventive Scotch broom beetle, *E. fuscirostre*. In 2014, *B. villosus* was the dominant species at 90% of the study sites; *E. fuscirostre* was entirely absent from 60% of the sites.

Figure 3-18. Current North American establishment of *Bruchidius villosus*: a. on Scotch broom; b. on French broom. (Winston et al. 2014a)

The previously mentioned 2014 study evaluated the combined impact of *B. villosus* and *E. fuscirostre* on Scotch broom seed development. Although *B. villosus* is more abundant than *E. fuscirostre* at many sites, the additive affect between the two species increases the amount of overall seed destruction. The average attack rate on Scotch broom seeds across 10 sites in British Columbia was 69.1 percent but ranged at individual sites from 0.7 to 98 percent seed destruction. The highest attack rates were at sites in the southwestern mainland; the lowest seed destruction occurred at sites on Vancouver Island and in the interior (Figure 3-19a). At 30 sites in Washington, an average of 56.4 percent of seeds were destroyed with a range of 0 to 92.5 percent. The highest level of attack was in the Puget lowlands, and the lowest rate of attack was on the Olympic Peninsula (Figure 3-19a). Across 32 sites in Oregon, the average attack rate was 67.3 percent and ranged from 6.1 to 91.4 percent. The highest attack rates were found in the Willamette Valley with slightly lower rates at higher elevations; the lowest seed destruction occurred along the Oregon coast (Figure 3-19b). At the three sites in California, the average attack rate was 37.4 percent and ranged from 33.4 to 41.9 percent. Seed destruction was fairly consistent across the sampled regions; however, with so few sites it is unclear whether there is greater variation in biocontrol agent populations at other Scotch broom infestations (Figure 3-19c). Further monitoring of seed destruction is necessary to evaluate fluctuations in insect populations and associated attack rates over time.

Comments

Though *B. villosus* was first an accidental introduction in the USA, it is approved for redistribution within the USA and was intentionally redistributed in British Columbia, Canada from 2006-2008.

The weevil *Exapion fuscirostre* also attacks seedpods of Scotch broom (see next section). Late instar larvae of *B. villosus* can be differentiated from *E. fuscirostre* in that *B. villosus* larvae feed completely within broom seeds (Figure 3-20a), to the extent their presence can be difficult to detect unless seeds are dissected. *Exapion fuscirostre* larvae cause external feeding damage to seeds which is obvious when the pod is first opened (Figure 3-20a). Adult *B. villosus* are black and have much shorter snouts and elytra than adult *E. fuscirostre* (Figure 3-20b).

While there are no reports of nontarget effects in the United States, *B. villosus* was found to attack *Lupinus arboreus* in a common garden experiment in France. This is currently being assessed in California and Washington.

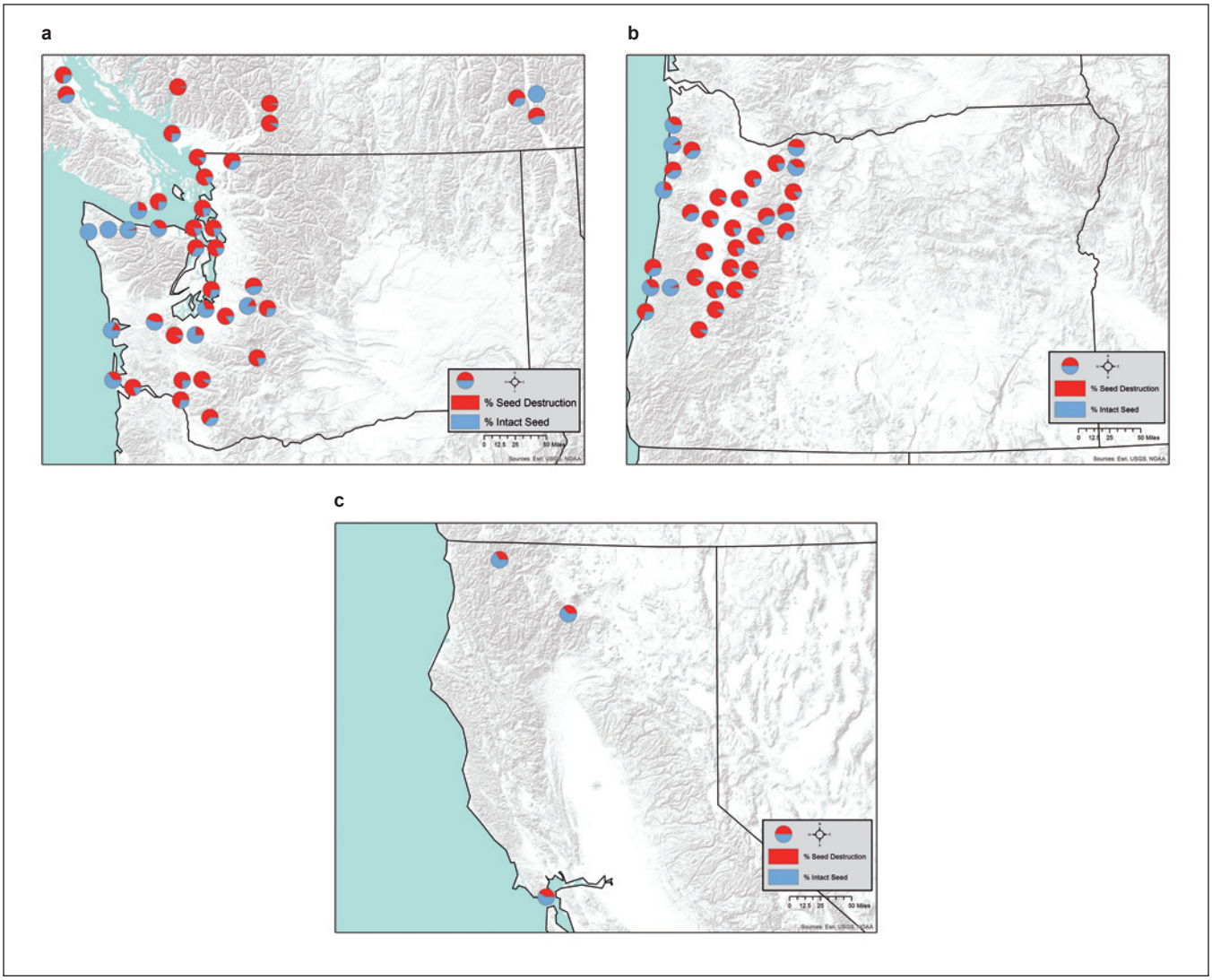


Figure 3-19. Attack rates of Scotch broom seeds by *Bruchidius villosus* and *Exapion fuscirostre* in 2014 at sites in: a. British Columbia and Washington; b. Oregon; c. California. At each site, red represents the proportion of seeds damaged by the biocontrol agents and blue represents the proportion of intact, undamaged seeds. (Maps prepared by Perry Beale, Washington State Department of Agriculture)

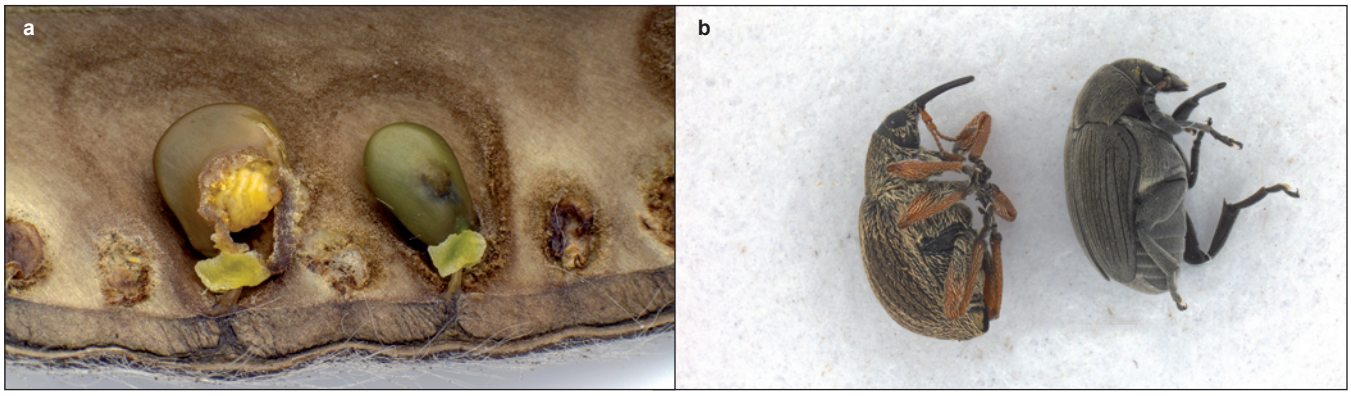


Figure 3-20. Comparison of *Bruchidius villosus* (right) and *Exapion fuscirostre* (left): a. larvae attacking Scotch broom seeds; b. adults. (a. Thomas Shahan, Oregon Department of Agriculture; b. Jennifer Andreas, Washington State University Extension)

Exapion fuscirostre (Fabricius)

Scotch broom seed weevil

Synonym: *Apion fuscirostre* Fabricius

Order		Coleoptera
Family		Brentidae
Native Distribution		Europe
Target Weed		Scotch broom
North America	Original Source	USA: Italy CAN: Accidental introduction via USA
	First Release	USA: 1964 (CA)
	First Documentation	CAN: 2006 (BC)
	First Redistribution	CAN: 2007 (BC)
	Nontarget Effects	None reported

Description

Eggs are small, white to yellowish, and round. Larvae are an off-white color with brown head capsules (Figure 3-21a). They can be up to 2.5 mm in length while adults can be up to 3 mm. Pupae are cream colored and up to 3 mm long. Adults have brown bodies with two long, silver or tan bands that run down either side of their bodies (one on each side). Their snouts are long and curved, and they have light brown legs (Figure 3-21b).

Life Cycle

Overwintering adults emerge in early spring when Scotch broom begins to flower and feed on stems and flowers. Females must feed on Scotch broom flowers in order to produce eggs. Eggs are laid inside the seedpod, with hatching larvae feeding on developing seeds. Larvae feed half in and half out of attacked seeds, developing through three instars and pupating within the seedpod. New adults emerge in late summer. Adults do not chew their way out of the seedpod, instead

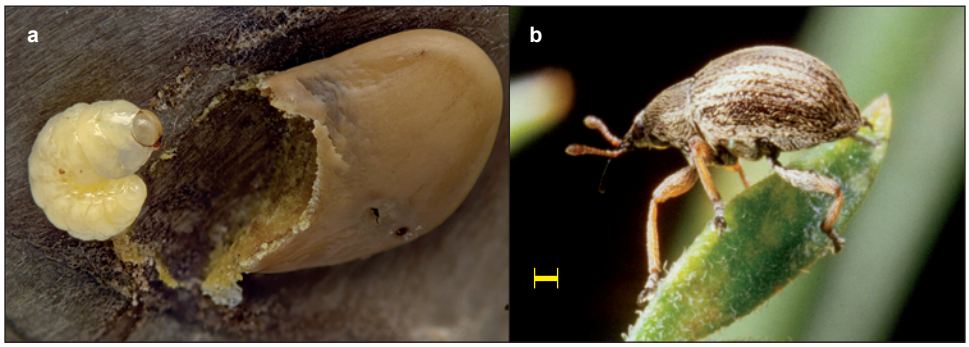


Figure 3-21. *Exapion fuscirostre*: a. larva and damage to a seed; b. adult. (a. Thomas Shahan, Oregon Department of Agriculture; b. Laura Parsons, University of Idaho, bugwood.org)

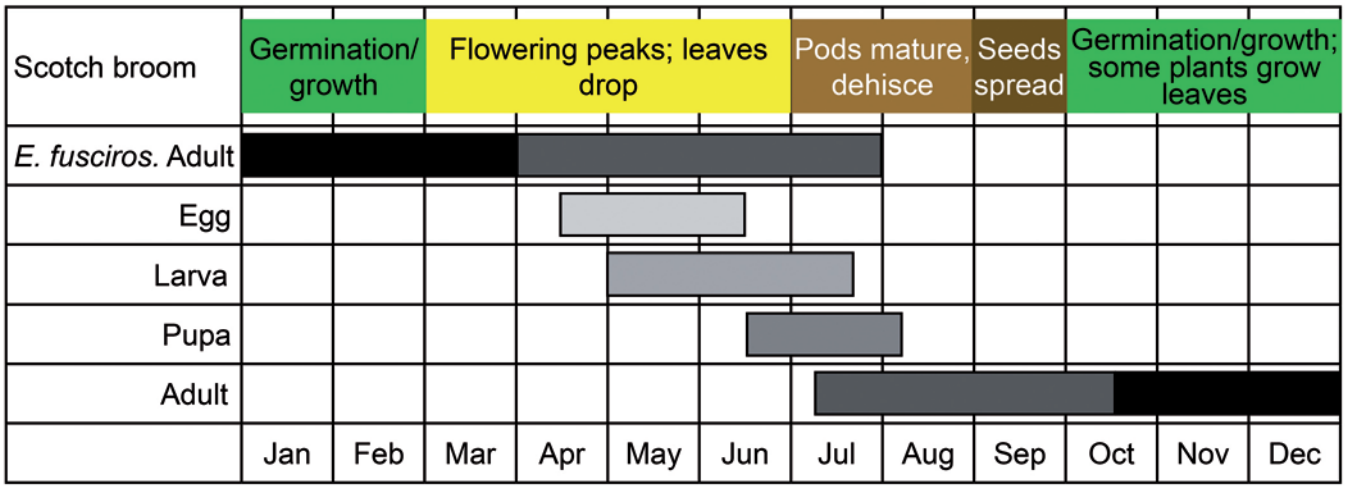


Figure 3-22. Schematic life cycle of *Exapion fuscirostre* and Scotch broom in North America. Bars indicate the approximate length of activity for each of the beetle's life stages; dates will vary depending on local conditions. Black bars represent the inactive overwintering period.

relying on the plant's dehiscing mechanism to escape. Seedpods dehisce, or dry out, and burst open at maturity in order to spread their seeds. Adults overwinter in soil litter. There is one generation per year, though generations sometimes overlap as adults are frequently active year-round (Figure 3-22).

Habitat Preference

The Scotch broom seed weevil does best in meadows or on hillsides with southern exposure. It performs poorly in heavily shaded, cold, high elevation, and/or damp sites (e.g. in direct contact with ocean spray).

Damage

Adult feeding (Figure 3-23a) causes terminal shoot dieback, but does not kill the plant. Larval feeding on developing seeds (Figures 3-21a, 3-23b) reduces viable seed production. While this does not kill existing broom plants, it may help reduce the rate of spread of Scotch broom populations; however, the overall efficacy of this biocontrol agent is questionable due to high seed production and the longevity of viable seeds in the seed bank.

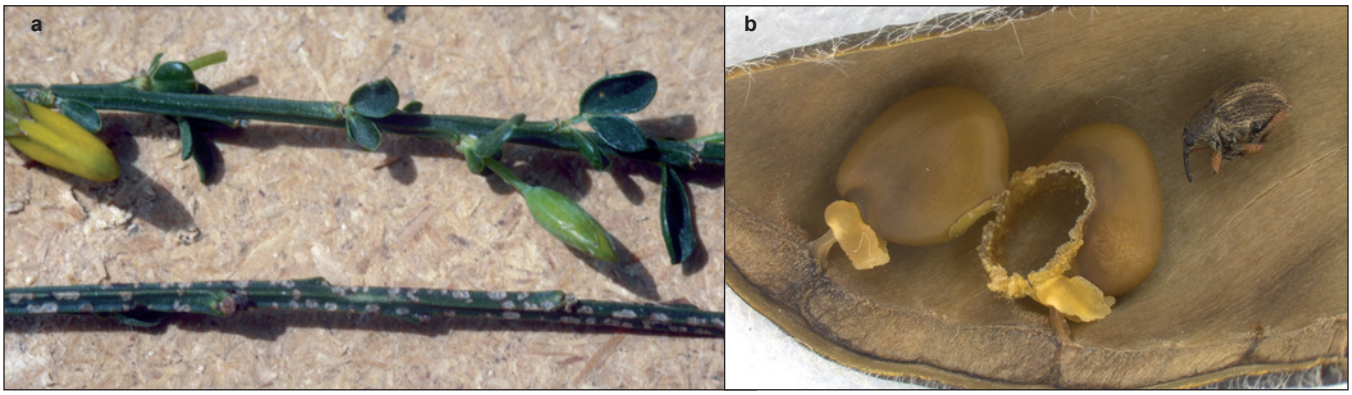


Figure 3-23. *Exapion fuscirostre*: a. adult feeding damage, bottom stem; b. emerged adult and larval feeding damage. (a. Eric Coombs, Oregon Department of Agriculture, bugwood.org; b. Jennifer Andreas, Washington State University Extension)

Current Status and Availability

Though *E. fuscirostre* is moderately abundant on Scotch broom in the western USA (Figure 3-24), its impact is generally low. At most sites its observed seed reduction rates are likely insufficient to impart significant control of Scotch broom populations alone, but it may contribute to a slowed rate of spread. In 2014, a study evaluating the attack rate of *E. fuscirostre* and *Bruchidius villosus* on Scotch broom seeds was conducted in California, Oregon, Washington and British Columbia. Across 30 sites in Washington, the average *E. fuscirostre* attack rate was 12.2 percent but ranged from 0 to 50.1 percent at individual sites. At 32 sites in Oregon, an average of 26.5 percent seeds were destroyed with a range of 0 to 83.5 percent, and at three sites in California, the average *E. fuscirostre* attack rate was 36.8 percent with a range of 32.4 to 41.9 percent.

Parasitism is typically low but may limit populations in some regions. *Exapion fuscirostre* seems to be more affected by parasitism than *B. villosus*, which may contribute to *B. villosus*'s ability to outcompete *E. fuscirostre* at sites where they both occur. In 2014, *E. fuscirostre* was the secondary species at most sites in Washington and Oregon. It was the dominant species at only 1/28 sites in Washington and 10/32 sites in Oregon but was the dominant species at all three California sites.

Exapion fuscirostre spread naturally from the USA to British Columbia, Canada by 2006. It was intentionally redistributed within British Columbia from 2007-2008. As of 2014, its abundance and impact in Canada appear to be less than the other adventive Scotch broom beetle, *B. villosus*. Across 10 sites in southern British Columbia, the average attack rate was 10.2 percent with a range from 0 to 51.9 percent. It was the dominant species at only one of the 10 sites, contributed to up to 26 percent of seed destruction at three sites, and was absent from the six remaining sites.

Figure 3-24. Current establishment of *Exapion fuscirostre* on Scotch broom in North America. (Winston et al. 2014a)

The previously mentioned 2014 study evaluated the combined impact of *B. villosus* and *E. fuscirostre* on Scotch broom seed development. Although *B. villosus* is more abundant than *E. fuscirostre* at many sites, the additive affect between the two species increases the amount of overall seed destruction. The average attack rate on Scotch broom seeds across 10 sites in British Columbia was 69 percent but ranged at individual sites from 0.7 to 98 percent seed destruction. The highest attack rates were at sites in the southwestern mainland; less seed destruction occurred at sites on Vancouver Island and in the interior (Figure 3-19a). At 30 sites in Washington, an average of 56.4 percent of seeds were destroyed with a range of 0 to 92.5 percent. The highest level of attack was in the Puget lowlands and the lowest rate of attack was on the Olympic Peninsula (Figure 3-19a). In Oregon, across 32 sites, the average attack rate was 67.3 percent and ranged from 6.1 to 91.4 percent. The highest attack rates were found in the Willamette Valley with slightly lower rates at higher elevations; the lowest seed destruction along the Oregon coast (Figure 3-19b). At the three sites in California, the average attack rate was 37.4 percent and ranged from 33.4 to 41.9 percent. Seed destruction was fairly consistent across the sampled regions; however, with so few sites it is unclear whether there is greater variation in biocontrol agent populations at other Scotch broom infestations (Figure 3-19c). Further monitoring of seed destruction is necessary to evaluate fluctuations in insect populations and associated attack rates over time.

Comments

The beetle *B. villosus* also attacks seedpods of Scotch broom (see previous section). Late instar larvae of *E. fuscirostre* can be differentiated from *B. villosus* once seedpods are opened in that *E. fuscirostre* larvae feed half in and half out of attacked seeds (Figure 3-20a). *Bruchidius villosus* larvae feed completely enclosed within seeds (Figure 3-20a), so individual seeds must be dissected to confirm the species is present. Adult *E. fuscirostre* have much longer snouts and elytra than adult *B. villosus* (Figure 3-20b).

Leucoptera spartifoliella (Hübner)

Scotch broom twig miner

Order		Lepidoptera
Family		Lyonetiidae
Native Distribution		Europe
Target Weed		Scotch broom
North America	Original Source	USA: France, but also found already present in USA
	First Release	USA: 1960 (CA)
	Nontarget Effects	None reported

Description

Eggs are tiny, oval, and white. Larvae are green-brown, translucent, appear somewhat flattened, and can reach 3-4 mm in length. Pupae are contained within white, silky cocoons 4-5 mm long (Figure 3-25a). Adults are small (3-5 mm long) and are seldom seen. They are white with white antennae, feathered wing tips, and have pale gold markings (Figure 3-25b).

Life Cycle

Adults lay eggs in late summer on young Scotch broom stems when broom has finished flowering. Larvae hatch in late summer and early autumn and tunnel into young shoots to feed (Figure 3-25c). Larvae develop through six instars over several months and overwinter in the stems of Scotch broom. Larvae emerge in early spring and spin cocoons on broom stems (Figure 3-25a) or the undersides of broom leaves, where they pupate. New adults emerge in late spring and early summer when broom flowers. There is one generation per year (Figure 3-26).

Figure 3-25. *Leucoptera spartifoliella*: a. pupa in a cocoon; b. adult; c. damage to a Scotch broom stem. (a.,b. Eric Coombs, Oregon Department of Agriculture, bugwood.org; c. © Charlie Streets)

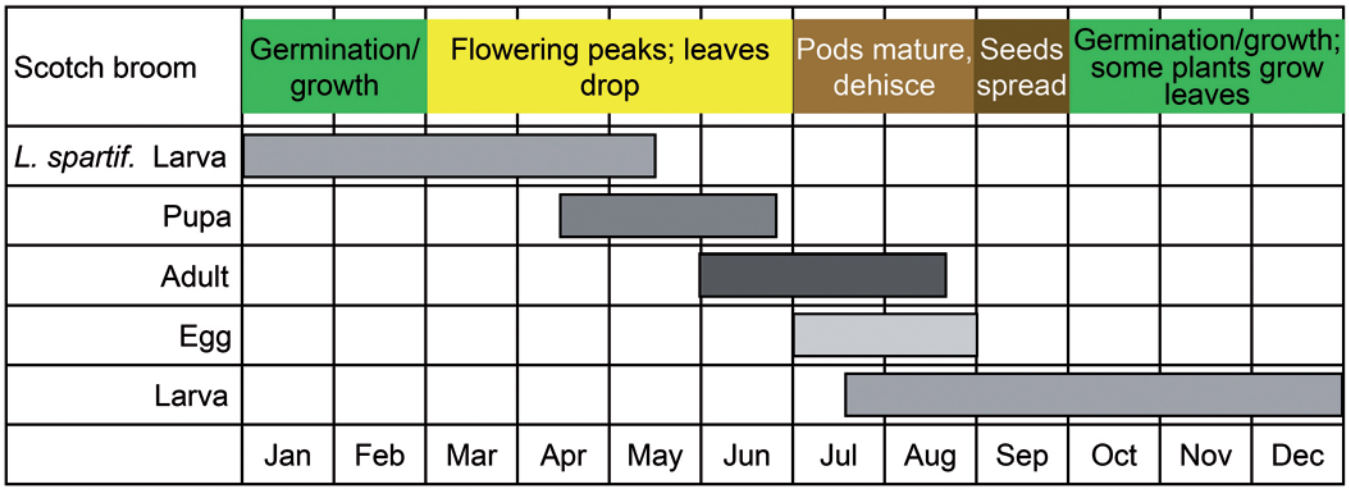


Figure 3-26. Schematic life cycle of *Leucoptera spartifoliella* and Scotch broom in North America. Bars indicate the approximate length of activity for each of the moth's life stages; dates will vary depending on local conditions.

Habitat Preference

The Scotch broom twig miner moth does best at low-elevation infestations with moderate temperature and ample moisture.

Damage

Larval mining causes dieback of Scotch broom stems; however, plants often re-sprout new stems below the sites of damage.

Current Status and Availability

Though this biocontrol agent was intentionally introduced to the USA in 1960, it was found to have already been present in California, Oregon, and Washington. It was likely imported on ornamental plants prior to 1940. Both the intentional and adventive populations have since intermixed and are no longer differentiated.

Leucoptera spartifoliella is now widespread on Scotch broom in California and Oregon, but is present at only limited sites in Washington (Figure 3-27). High moth numbers can deform Scotch broom plants and cause stem dieback, but plant density is not affected. Because attacked plants often re-grow below the sites of damage, the overall impact of this biocontrol agent is negligible. Populations are also heavily parasitized and do not fare well in hot, dry sites. **This species is currently not known to be present in Canada.**

Figure 3-27. Current establishment of *Leucoptera spartifoliella* on Scotch broom in North America. (Winston et al. 2014a)

Unapproved Natural Enemies of Gorse and Scotch Broom

Three accidentally introduced species that are established on broom in North America are covered in this manual; one of these is also established on common gorse. Several other unapproved natural enemies are established on common gorse and Scotch broom in North America, including *Aceria davidmansoni*, *Dictyonota fuligosa*, *Gargara genistae*, *Melanotrichus concolor*, *M. virescens*, and *Selenophoma juncea*. These species are not included herein because they play a more minor role in regulating gorse and/or broom populations or they have also been found attacking additional desirable species. **It is illegal to intentionally move any unapproved natural enemies to new areas in the USA.** Care should be taken when transferring approved biocontrol agents to ensure unapproved species are not also included in transferred material.

Aceria genistae (Nalepa)

Order: Acari
Family: Eriophyidae

Host: Scotch broom

Description and Life Cycle

All stages are tiny and best viewed with a microscope. Larvae and nymphs are white to orange and 0.10-0.12 mm long (Figure 3-28a). Adults are white to orange (typically orange) and have a worm-like appearance (Figure 3-28b). They have two pairs of developed legs near their heads and can be 0.16-0.225 mm long. All stages feed on stem bud tissue by extracting sap from plant cells. This induces the development of galls 5-30 mm in diameter, which serve as protective housing to hundreds of mites. Galls are the best indication of mite presence (Figure 3-28c,d). As galls grow, they become increasingly hairy until they senesce, at which time mites migrate to new buds to form new galls. Galls may develop faster and have greater impact at hot, dry sites. There can be several generations per year. Mite numbers appear to be greatly reduced during overwintering. All stages are capable of overwintering within new buds.

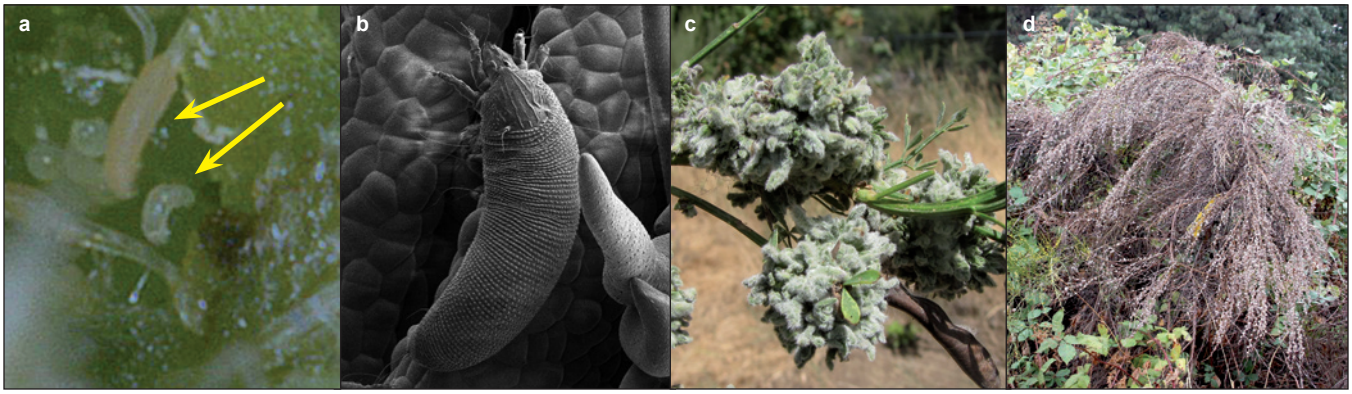


Figure 3-28. *Aceria genistae*: a. larva/nymph (see arrows) between gall hairs; b. magnified adult; c. galls; d. extensive damage to a Scotch broom plant. (a.,d. Eric Coombs, Oregon Department of Agriculture, bugwood.org; b. Paul Pratt, USDA ARS WRRC; c. Jennifer Andreas, Washington State University Extension)

History and Current Status

Aceria genistae was first recorded in the USA by 2005 as an accidental introduction on Scotch broom in Oregon and Washington (Figure 3-29). The mite is currently abundant in Washington where its overall impact is moderate, as it reduces Scotch broom flowering and plant biomass and, in some cases, may cause stem and plant mortality (Figure 3-28d). In Oregon, the mite is widespread but only abundant locally with a slight overall impact. In British Columbia, Canada, sightings of *Aceria genistae* were first reported in 2007, and identification was later confirmed in 2010; it has had only minor impact to date. The mite was first recorded in California in 2014. Though its distribution in California is still limited, the mite has significant impact at well-established sites, reducing plant growth and reproduction and sometimes causing plant death.

Aceria genistae underwent host specificity testing in Washington. It fed heavily on *Lupinus densiflorus*, an endangered species in Canada, during no-choice greenhouse tests but has not been found on naturally-occurring *L. densiflorus* populations. **This species is currently not approved for redistribution in the United States.**

A mite originally identified as *A. genistae* was recorded on French broom and gorse in California in the 1990s. This mite has since been identified as a different species, *Aceria davidmansoni*.

Figure 3-29. Current establishment of *Aceria genistae* on Scotch broom in North America. (Winston et al. 2014a)

Agonopterix nervosa (Haworth)

Order: Lepidoptera
Family: Oecophoridae

Synonyms: *Depressaria nervosa* Haw., *Depressaria costosa* Haw.

Hosts: Gorse, Scotch broom, Portuguese broom

Description and Life Cycle

Adults are 10-15 mm long with variable coloring. Typical adults have white or yellowish wings with small gray to brown mottling, sometimes appearing as stripes on wing veins (Figure 3-30a). Their wingspan is 16-22 mm. Overwintering adults emerge during early spring to lay eggs on stems and leaf axils of gorse, Scotch broom, and Portuguese broom. Eggs are yellowish, cylindrical, and 1 mm long. Larvae hatch in late spring and spin tubes of plant material on shoot tips of their host plant. Larvae feed on young leaves, shoot tips, and flower buds, which stunts stem growth and reduces seed production. Larvae vary in color from yellowish-gray to brown and can be up to 15 mm long (Figure 3-30b). There are five larval instars. The brown pupae (Figure 3-30c) are 10-15 mm long. Pupation occurs within the feeding tubes. New adults emerge in late summer and overwinter in their host plant foliage. There is one generation per year.

History and Current Status

This species was accidentally introduced to Canada. It was recorded on gorse in British Columbia by 1915 and has since been recorded on Scotch broom in British Columbia as well. Its overall abundance and impact on gorse and Scotch broom in Canada are unknown.

Agonopterix nervosa likely spread from Canada to the USA in the 1920s. It attacks both Scotch broom and gorse in California, Oregon, and Washington (Figure 3-31a), though it is more effective on gorse. It may stunt shoots (Figure 3-31b) and reduce seed production (Figure 3-31c), but overall its impact on both

Figure 3-30. *Agonopterix nervosa*: a. adult (body length top line, wingspan length bottom line) b. larva and Scotch broom stems; c. pupa. (a.,b. Eric Coombs, Oregon Department of Agriculture; c. Jennifer Andreas, Washington State University Extension)

weed species is limited. Populations are heavily parasitized in the USA. This moth also attacks Portuguese broom (*Cytisus striatus*) in Oregon. **This species is not approved for redistribution in the United States.**

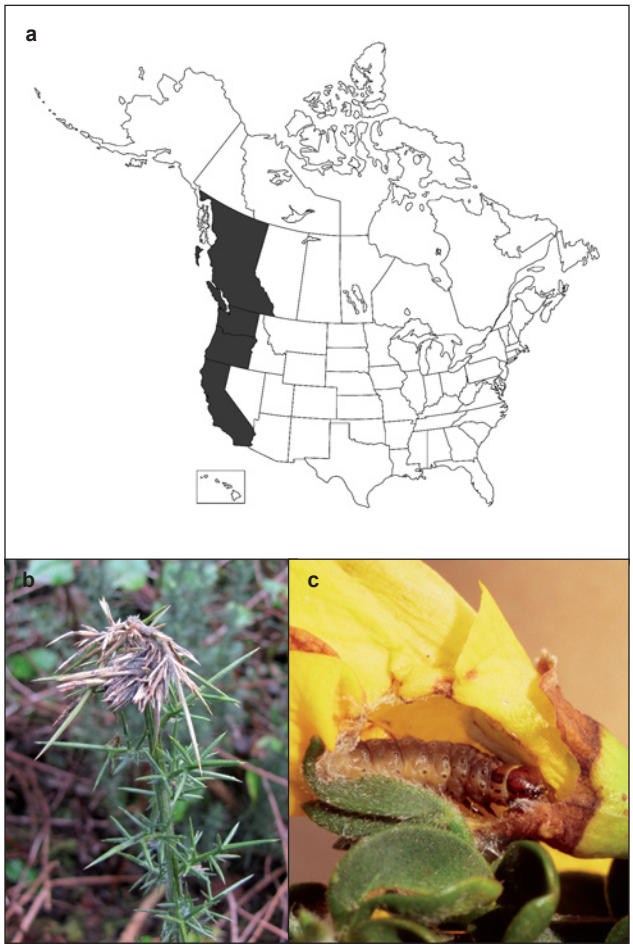


Figure 3-31. *Agonopterix nervosa*: a. distribution on gorse and Scotch broom in North America; b. damage to a gorse shoot tip and spines; c. damage to a Scotch broom flower. (a. Winston et al. 2014a; b. Jennifer Andreas, Washington State University Extension; c. Eric Coombs, Oregon Department of Agriculture)

Arytainilla spartiophila (Förster)

Order: Hemiptera
Family: Psyllidae

Host: Scotch broom

Description and Life Cycle

Overwintering eggs are embedded in Scotch broom stems beneath a waxy cap. Tiny, orangey-brown nymphs (<2 mm long) hatch in early spring and gather near new leaf buds to feed. Nymphs feed primarily along the stem, rarely on the leaves themselves. Nymphs grow through five instars before developing into pale brown aphid-like adults (2-3 mm long) with clear wings (Figure 3-32). Adults feed on new growth of Scotch broom, lay eggs, and die by early summer. There is one generation per year.

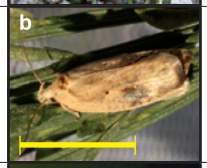
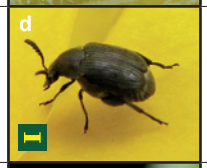
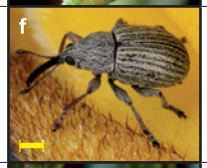
Figure 3-32. *Arytainilla spartiophila* adult. (Landcare Research Ltd., New Zealand)

History and Current Status

This accidentally introduced species was first recorded on Scotch broom in Washington, USA in 1935. It is now widespread in California, Oregon, and Washington (Figure 3-33) where it is the most common and abundant of Scotch broom natural enemies. It has also been reported on Scotch broom in Virginia, though its abundance and impact there are unknown. High densities can reduce Scotch broom growth and may weaken plants stressed from competition, making them vulnerable to pathogens; however, the overall impact of this psyllid is likely limited. In New Zealand, *Candidatus* Liberibacter europaeus, a new and possibly pathogenic bacteria thought to have been introduced along with *Arytainilla spartiophila*, appears to be damaging Scotch broom plants. It has not been found in the USA; consequently, the psyllid does not have the same impact in North America. **This species is not approved for redistribution in the USA; it is currently not known to be present in Canada.** Note: The honeydew produced by this species interferes with late-season collections of approved Scotch broom biocontrol agents.

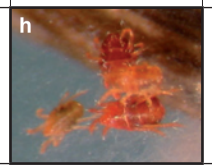
Figure 3-33. Current establishment of *Arytainilla spartiophila* on Scotch broom in North America (Winston et al 2014a)

Table 3-1. Traits of biological control agents established on gorse and Scotch broom in the continental USA and Canada. Red bolded species are not approved for redistribution in the USA.

Biological Control Agent	Species Attacked	Generations/ Year	Overwintering Stage, Location	Adult	Egg	Larva	Pupa
Aceria genistae **Unapproved**	Scotch broom	Multiple	All stages in communal galls on host plant		Microscopic	Nymphs: all stages white to orange and microscopic (0.10-0.12 mm long). Early stages with 6 legs; later stages with 8 legs.	
Agonopterix nervosa **Unapproved**	Gorse, Scotch broom, Portuguese broom	One	Adults among foliage of host plant		Cylindrical; yellowish; 1 mm long; laid on stems, leaf axils of host	Vary from yellow-gray to brown; 15 mm long; 5 instars	Within cocoons of plant material spun by larva
Arytainilla spartiophila **Unapproved**	Scotch broom	One	Eggs embedded in Scotch broom stems		Tiny; Not visible as embedded in broom stem beneath a waxy cap	Nymphs: all stages tiny; orangey-brown; <2mm long; 5 stages	
Bruchidius villosus Broom seed beetle	Scotch broom, French broom	One	Adults in soil litter away from the host plant		Tiny; oval-shaped; white; laid on the broom seedpod	Cream colored with brown head capsule; 2 mm long; 4 instars; inside broom seeds within pods	Gray or brown; 2 mm long; inside broom seeds within pods
Exapion fuscirostre Scotch broom seed weevil	Scotch broom	One	Adults in soil litter		Small; round; white to yellowish; laid in Scotch broom seedpods	Cream colored with brown head capsules; 3 mm long; 3 instars; exposed in broom seedpods	Cream colored; 3 mm long; exposed in broom seedpods
Exapion ulicis Gorse seed weevil	Gorse	One	Adults among gorse foliage		Small; round; translucent yellow; laid in gorse seedpods	Cream colored with brown head capsules; 3 mm long; 3 instars; exposed in gorse seedpods	Cream becoming dark gray with age; 3 mm long; exposed in gorse seedpods
Leucoptera spartifoliella Scotch broom twig miner	Scotch broom	One	Larvae in broom stems		Tiny; oval-shaped; white; laid on young broom stems after flowering ceases	Green-brown, translucent; a bit flattened; 3-4 mm long	Within white, silky cocoons spun by larva; 4-5 mm long

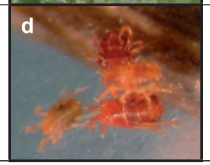
(continued on next page)

Table 3-1 (continued). Traits of biological control agents established on gorse and Scotch broom in the continental USA and Canada. Red bolded species are not approved for redistribution in the USA.

Biological Control Agent	Species Attacked	Generations/ Year	Overwintering Stage, Location	Adult	Egg	Larva	Pupa
Tetranychus lintearius Gorse spider mite	Gorse	Up to 6	All stages inside communal webbing		Tiny; round; largely transparent	Nymphs: first stage light in color with 6 legs; second to fourth stage brown with 8 legs	

a. *Aceria genistae*, numerous galls housing hundreds of mites each; b. *Agonopterix nervosa*; c. *Arytainilla spartiophila*; d. *Bruchidius villosus*; e. *Exapion fuscirostre*; f. *Exapion ulicis*; g. *Leucoptera spartifoliella*; h. *Tetranychus lintearius.* (a.,b.,g.,h. Eric Coombs, Oregon Department of Agriculture, bugwood.org; c. Landcare Research Ltd., New Zealand; d. Jennifer Andreas, Washington State University Extension; e. Laura Parsons, University of Idaho, bugwood.org; f. Janet Graham)

Table 3-2. Traits of biological control agents established on gorse in Hawaii

Biological Control Agent	Species Attacked	Generations/ Year	Overwintering Stage, Location	Adult	Egg	Larva	Pupa
Agonopterix umbellana Gorse soft shoot moth	Gorse	One	Adults among gorse foliage		Barrel-shaped; bright yellow; 1 mm long; laid in axils of gorse leaves and spines	Dark brown to olive green with dark side spots; 20 mm long; 5 instars	Within silken cocoons spun by larva
Exapion ulicis Gorse seed weevil	Gorse	One	Adults among gorse foliage; some adults actively feed through winter		Small; round; translucent yellow; laid in gorse seedpods	Cream colored with brown head capsules; 3 mm long; 3 instars; exposed in gorse seedpods	Cream becoming dark gray with age; 3 mm long; exposed in gorse seedpods
Sericothrips staphylinus Gorse thrips	Gorse	Multiple	At cold sites, adults among gorse foliage; at warmer sites adults/ nymphs active through winter		0.3mm long; cylindrical; pale yellow; laid in slits in gorse stems	Nymphs: all stages creamy-yellow; look increasingly similar to adults as they molt between stages; 4 stages	
Tetranychus lintearius Gorse spider mite	Gorse	Up to 6	All stages inside communal webbing		Tiny; round; largely transparent	Nymphs: first stage light in color with 6 legs; second to fourth stage brown with 8 legs	

a. *Agonopterix umbellana*; b. *Exapion ulicis*; c. *Sericothrips staphylinus*; d. *Tetranychus lintearius*. (a.,b. Janet Graham; c. Fritzi Grevstad, Oregon State University; d. Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Table 3-3. Comparison of North American-established biocontrol agent activity, according to gorse growth stages. Plant and biocontrol agent stages will vary by climate and location. The red bolded species is not approved for redistribution in the USA; it is included in this table to aid in proper identification to ensure it is not inadvertently collected and redistributed along with approved biocontrol agents.

<table>
<tr><th>Month</th><th>Gorse Life Stage</th><th>Exapion ulicis</th><th>Tetranychus lintearius</th><th>Agonopterix nervosa
Unapproved</th></tr>
<tr><td>January</td><td>Seeds germinate; older plants continue to grow overwinter</td><td rowspan="2">Adults overwinter in soil litter</td><td rowspan="2">All stages overwinter; mites continue life cycle and feeding</td><td rowspan="2">Adults overwinter in foliage of host plant</td></tr>
<tr><td>February</td><td rowspan="2">Flowering peaks for individuals ≥18 months old; seedpods begin to develop; previous-year seeds germinate</td></tr>
<tr><td>March</td><td>Adults emerge and feed on gorse flowers and foliage; eggs are laid in young gorse seedpods; hatching larvae feed on developing seeds</td></tr>
<tr><td>April</td><td rowspan="2">Seedpods begin to mature; some split at maturity; seed dispersal commences; juvenile plants have small, 3-parted leaves; leaves reduced to spines as plants age</td><td>Egg-laying continues; hatching larvae feed on developing seeds</td><td rowspan="5">Larvae, nymphs, and adults feed on stems and spines of gorse within webbing covering large colonies; life cycle repeated for up to six generations per year</td><td>Overwintered adults become active; eggs are laid on stems and leaf axils of hosts</td></tr>
<tr><td>May</td><td>Larvae continue feeding; pupation begins in seedpods; new adults emerge in seedpods</td><td rowspan="2">Hatching larvae spin feeding tubes, feed on young leaves, shoot tips, flower buds</td></tr>
<tr><td>June</td><td rowspan="3">Seed dispersal continues as seedpods split with maturity</td><td>Pupation continues; new adults continue emerging in seedpods</td></tr>
<tr><td>July</td><td rowspan="2">New adults escape pods when pods split naturally</td><td>Pupation occurs in feeding tubes</td></tr>
<tr><td>August</td><td>New adults emerge</td></tr>
<tr><td>September</td><td rowspan="2">Smaller secondary bloom at some locations; seed dispersal continues</td><td rowspan="4">Adults overwinter in soil litter</td><td rowspan="3">All stages overwinter; mites continue life cycle and feeding</td><td rowspan="3">Adults overwinter in foliage of host plant</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td><td rowspan="2">Seeds germinate; older plants continue to photosynthesize overwinter with spines/green stems</td></tr>
<tr><td>December</td><td></td></tr>
</table>

Table 3-4. Comparison of North American-established biocontrol agent activity, according to Scotch broom growth stages. Plant and biocontrol agent stages will vary by climate and location. Red bolded species are not approved for redistribution in the USA; they are included in this table to aid in proper identification to ensure they are not inadvertently collected and redistributed along with approved biocontrol agents.

<table>
<tr><th>Month</th><th>Scotch Broom Life Stage</th><th>Bruchidius villosus</th><th>Exapion fuscirostre</th><th>Leucoptera spartifoliella</th><th>Aceria genistae
Unapproved</th><th>Agonopterix nervosa
Unapproved</th><th>Arytainilla spartiophila
Unapproved</th></tr>
<tr><td>January</td><td rowspan="2">Seeds germinate; older plants grow leaves</td><td rowspan="2">Adults overwinter in soil litter away from host plant</td><td rowspan="2">Adults overwinter in soil litter</td><td rowspan="3">Overwintering larvae feed in stems of Scotch broom</td><td rowspan="5">All stages overwinter; mites continue life cycle and feeding, though populations and activity are reduced during colder months; found primarily in buds</td><td rowspan="3">Adults overwinter in foliage of host plant</td><td rowspan="2">Eggs overwinter embedded in Scotch broom stems beneath a waxy cap</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td><td>Seeds germinate; older plants begin losing leaves; flowering begins</td><td>Adults continue to overwinter; few adults begin emerging</td><td>Adults continue to overwinter; few adults begin emerging</td><td rowspan="4">Nymphs hatch, feed on Scotch broom stems through five stages</td></tr>
<tr><td>April</td><td rowspan="3">Seeds continue to germinate; older plants photosynthesize with green stems; flowering peaks for individuals ≥18 months old; seedpods begin to develop</td><td>Adults continue emerging, feed on pollen, begin mating; eggs are laid on developing seedpods</td><td>Adults continue emerging, feeding on Scotch broom terminal stems and flowers; mating begins; eggs are laid in seedpods</td><td rowspan="2">Larval feeding continues; pupation begins in cocoons on broom stems</td><td rowspan="2">Overwintered adults become active; eggs are laid on stems and leaf axils of hosts</td></tr>
<tr><td>May</td><td>Larvae begin hatching and feed within seeds</td><td>Adults continue laying eggs; larvae hatch and feed within seeds</td><td rowspan="2">Hatching larvae spin feeding tubes, feed on shoot tips and within flowers</td></tr>
<tr><td>June</td><td>Larval feeding continues; pupation begins</td><td>Larval feeding continues; pupation begins</td><td>Pupation continues; adults emerge</td><td>Adults feed on Scotch broom stems, lay eggs in Scotch broom stems, die</td></tr>
<tr><td>July</td><td rowspan="2">Seedpods begin to split at maturity; seed dispersal commences</td><td>Pupation continues; new adults begin emerging, remain in seedpods until pod splits naturally</td><td>Pupation continues; new adults begin emerging, remain in seedpods until pod splits naturally</td><td>Eggs are laid on Scotch broom stems; hatching larvae tunnel into young shoots</td><td>Pupation occurs in feeding tubes</td><td rowspan="5">Eggs overwinter embedded in Scotch broom stems beneath a waxy cap</td></tr>
<tr><td>August</td><td>New adults emerge</td></tr>
<tr><td>September</td><td>Seed dispersal continues</td><td rowspan="4">Adults overwinter in soil litter away from host plant</td><td rowspan="4">Adults overwinter in soil litter</td><td rowspan="4">Larvae feed in stems of Scotch broom during fall and winter</td><td rowspan="3">Adults overwinter in foliage of host plant</td></tr>
<tr><td>October</td><td rowspan="3">Seeds germinate; older plants continue to photosynthesize overwinter with green stems; some plants grow leaves</td><td rowspan="3">All stages overwinter; mites continue life cycle and feeding, though populations and activity are reduced during colder months</td></tr>
<tr><td>November</td></tr>
<tr><td>December</td></tr>
</table>

Table 3-5. Comparison of Hawaii-established biocontrol agent activity, according to gorse growth stages. Plant and biocontrol agent stages will vary by climate, elevation, and location.

<table>
<tr><th>Month</th><th>Gorse Life Stage</th><th>Agonopterix umbellana</th><th>Exapion ulicis</th><th>Sericothrips staphylinus</th><th>Tetranychus lintearius</th></tr>
<tr><td>January</td><td rowspan="3">Flowering peaks for individuals ≥18 months old; seedpods begin to develop at high-elevation sites; previous-year seeds germinate</td><td rowspan="2">Adults are inactive in foliage of gorse</td><td rowspan="2">Some adults are inactive overwinter, others feed on gorse flowers and foliage; eggs are laid in young gorse seedpods; hatching larvae feed on developing seeds</td><td rowspan="2">At some cold, high-elevation sites, adults are inactive in gorse foliage; at warmer sites, adults and nymphs are active throughout winter</td><td rowspan="15">Larvae, nymphs, and adults feed on stems and spines of gorse underneath webbing covering large colonies; life cycle repeated for up to six generations per year</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td><td>Eggs are laid in gorse spine and leaf axils</td><td>Larvae feed on developing seeds; pupation begins at some locations</td><td rowspan="9">Multiple generations completed in warmer months of the year; adults and nymphs feed on gorse green cells; eggs are laid in slits in gorse stems</td></tr>
<tr><td>April</td><td>Seedpods begin to split at maturity; seed dispersal commences; juvenile plants have small, 3-parted leaves; leaves reduced to spines as plants age</td><td rowspan="2">Larvae spin silken feeding tubes on gorse buds; larvae feed on new shoots and spines</td><td rowspan="2">New adults emerge in seedpods; adults escape when pods split naturally</td></tr>
<tr><td>May</td><td rowspan="2">Seed dispersal continues as seedpods split with maturity</td></tr>
<tr><td>June</td><td>Pupation occurs in feeding tubes</td></tr>
<tr><td>July</td><td rowspan="2">Plants continue growing/ producing spines; seed dispersal continues</td><td rowspan="2">New adults emerge</td><td rowspan="4">Adults feed on gorse foliage</td></tr>
<tr><td>August</td></tr>
<tr><td>September</td><td rowspan="2">Flowering begins at some low-elevation sites for individuals ≥18 months old; seed dispersal continues</td><td rowspan="4">Adults become inactive in foliage of gorse</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td><td rowspan="2">Flowering begins at high elevation sites for individuals ≥18 months old; seedpods begin to develop at low-elevation sites; previous-year seeds germinate</td><td rowspan="2">Some adults become inactive overwinter, others feed on gorse flowers and foliage; eggs are laid in young gorse seedpods</td></tr>
<tr><td>December</td><td>At some cold, high-elevation sites, adults are inactive in gorse foliage; at warmer sites, adults and nymphs are active throughout winter</td></tr>
</table>

Chapter 4: Elements of a Gorse and Scotch Broom Biological Control Program

Before You Begin

Biological control is one of many weed control methods available to land managers, but biological control is not appropriate for areas where gorse or Scotch broom are not present or where a small number of localized populations occur. Biological control as a control method is best suited to gorse or broom populations in the later phases of the invasion curve, where populations are experiencing a rapid increase in distribution and abundance, or where gorse and broom are widespread and abundant throughout their potential range (asset based protection, Figure 1-3 repeated here in Figure 4-1).

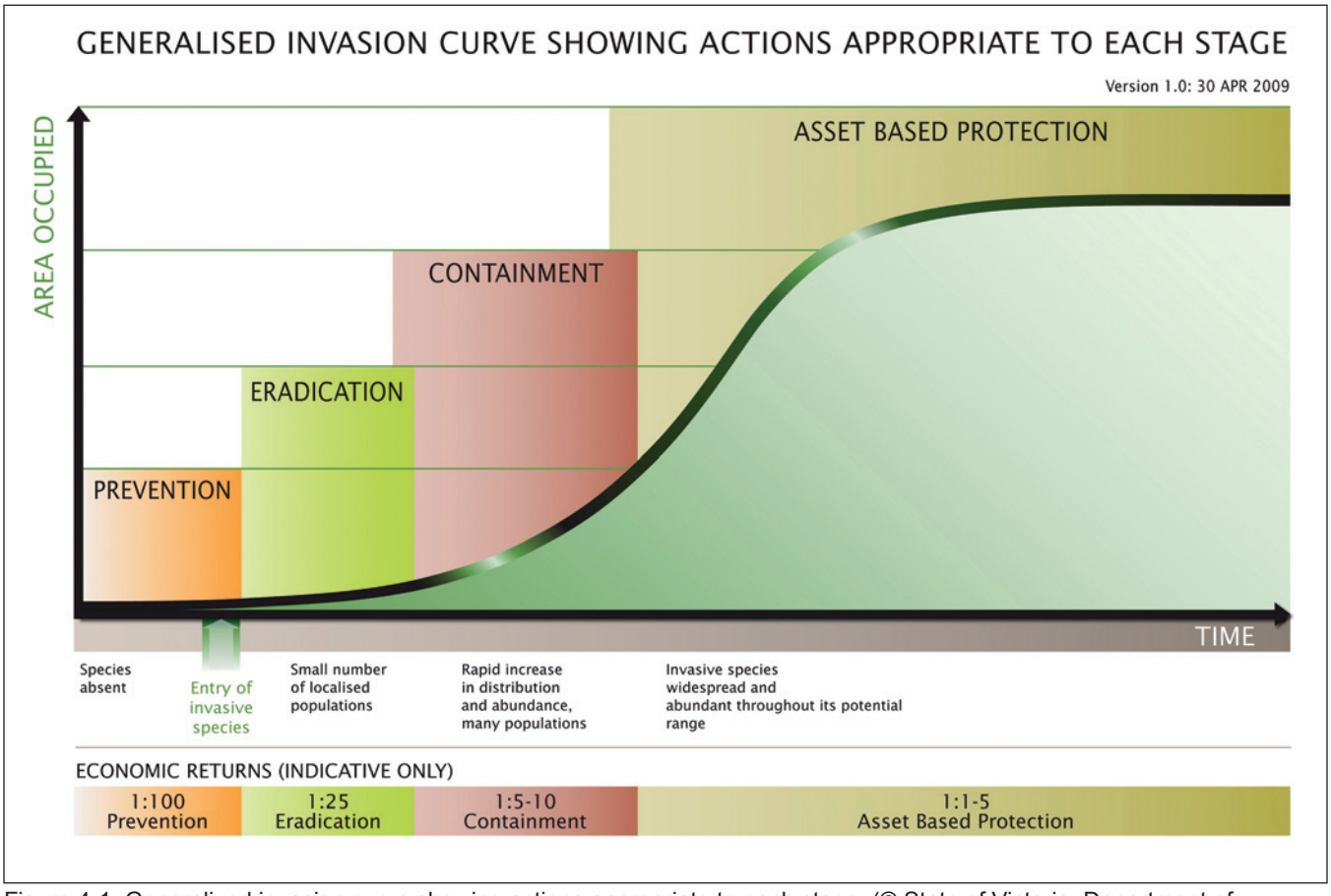


Figure 4-1. Generalized invasion curve showing actions appropriate to each stage. (© State of Victoria, Department of Economic Development, Jobs, Transport and Resources. Reproduced with permission.)

The results of using biological control to treat gorse and Scotch broom may vary greatly from site to site for a variety of reasons. Land managers should develop treatment programs that complement management activities and objectives unique to the area. This is accomplished by first understanding the scope of the gorse and Scotch broom problem, defining overall goals for the gorse and broom management program, and understanding the control methods available for accomplishing the goals.

Determining the Scope of the Problem

The first step should be to develop a distribution map of gorse and Scotch broom at a scale that will allow you to address the problem in a manner consistent with your overall land-management objectives and available weed management resources. The most appropriate scale may encompass a large landscape with a variety of site characteristics and land uses managed by many different land owners/managers—all of whom contribute to mapping efforts (Figure 4-2a). In large management areas with significant gorse and Scotch broom infestations and limited resources, aerial mapping of large patches of gorse and broom may be sufficient to identify priority areas for additional survey and weed management activities. In other management areas with small, discrete gorse and broom infestations, or where an infestation's characteristics affect your ability to meet management objectives, your weed management strategy might have to include more extensive mapping and analysis of the scope of the infestations (e.g., size, density, cover, or location in relation to roads and waterways over time) (Figure 4-2b).

In many cases, it may prove useful to check for existing gorse and broom distribution data before collecting your own. Several different agencies and organizations maintain weed distribution databases, including state agricultural

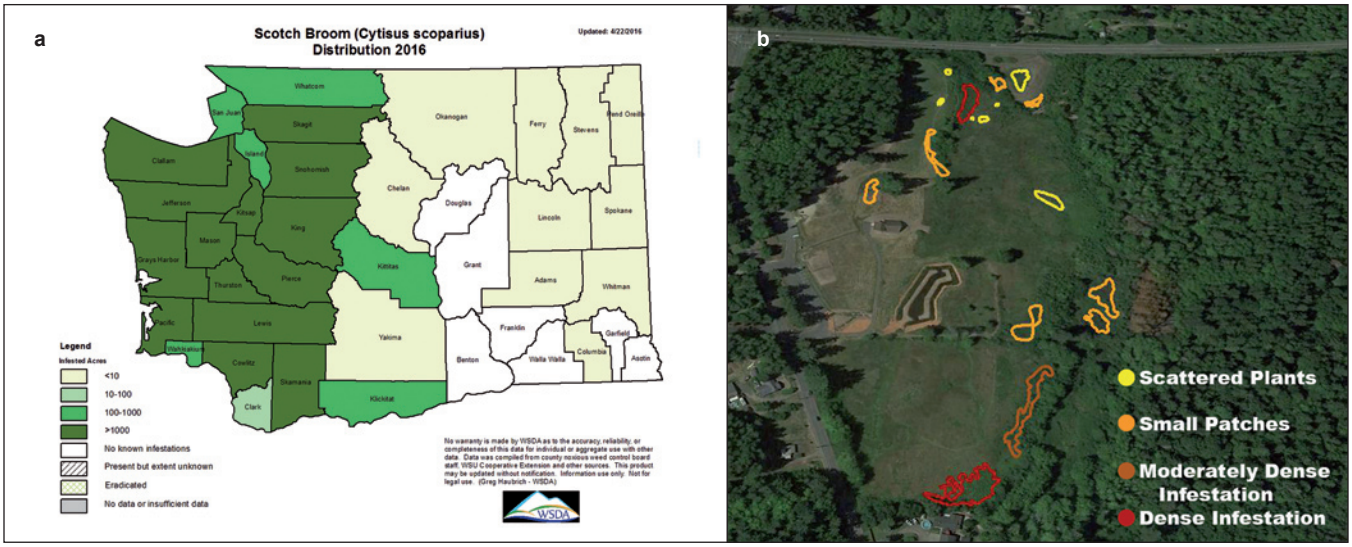


Figure 4-2. Scotch broom data for: a. counties with Scotch broom in the state of Washington; b. infestations of differing densities at Howe Farm in Kitsap County, Washington. (a. Washington State Department of Agriculture; b. Kitsap County Parks)

departments, provincial ministries (e.g. British Columbia IAPP Application), invasive plant/species councils, USDA PLANTS database, EDDMapS, and many others. EDDMapS can be particularly useful for land mangers interested in creating gorse and Scotch broom distribution maps for their area. By visiting www.eddmaps.org and creating a free account, users can view existing distribution maps for gorse and Scotch broom or other weeds at the state, county, or point level. By selecting the GIS view option, users can view gorse and broom data on various backgrounds and zoom into different scales, add hand drawn labels, boundaries, points and other shapes to the map, perform measurements such as perimeter estimates or distance between points, add new gorse and broom data from user shapefiles, edit the management status of various infestations, and print finished maps (see page 100 for more information on EDDMapS).

Defining Goals and Objectives

Goals broadly define the "what" or desired outcome of management; objectives define the "how" or specific activities through which desired outcomes can be achieved. To be effective, objectives must be SMART: specific, measurable, achievable, realistic, and timely. Defining **your** weed management goals and objectives is the crucial first step in developing a successful biological control program. By defining what you want to achieve, you will be able to determine if, when, and where you should use biological control.

As precisely as possible, you must define what will constitute a successful gorse and broom management program. For example, the objective of "…a noticeable reduction in gorse and Scotch broom density over the next ten years…" might be achievable, but it uses a subjective measurement of success that is open to observer bias. Alternatively, the objective of "…a 50 percent reduction in gorse and Scotch broom stems over the next three years…" is objectively measurable (and therefore SMART). If your goal is to reduce the abundance of gorse and broom, then biological control might be an appropriate weed management tool; however, by itself biological control will not completely and permanently remove gorse and broom from the landscape. If your goal is to eradicate gorse and broom, then you should plan to employ other weed control techniques instead of, or in addition to, biological control (see Chapter 5 for more details).

Understanding Gorse and Scotch Broom Management Options

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

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

With a map of gorse and broom infestations in your management area, an understanding of your land management goals, well defined weed management objectives, and a list of the weed control methods available with the level of control you can realistically expect from each, you can identify sites where biological control would be a good fit, alone or in combination with other control methods.

Developing, Implementing, and Managing a Gorse and Scotch Broom Biological Control Program

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

Selecting Biological Control Agent Release Sites

Establish goals for your release site

You must consider your overall management goals for a given site when you evaluate its suitability for the release of biological control agents. Suitability factors will differ depending on whether the release is to be:

1. a general release, where biological control agents are simply released for gorse and broom management,
2. a field insectary (nursery) release, used primarily to mass produce biological control agents for redistribution to other sites, or
3. a research release, used to investigate biological control agent biology and/or the biocontrol agent's impact on the target weed and nontarget plant community.

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

Determine site characteristics

For practical purposes, no gorse and broom infestation is too large for biocontrol releases; however, it might not be large enough (Figure 4-3a). Very small, isolated patches of gorse and broom may not be adequate for biological control

agent populations to build up and persist and are often better treated with other weed control methods, such as physical control or herbicides. An area with at least 1 acre (0.40 hectares) of gorse or Scotch broom is the minimum size to better ensure a successful biological control agent release site, but larger infestations are more desirable (Figure 4-3b), especially if the land manager hopes to someday use the release site as a field insectary. However, smaller infestations may be acceptable release sites in some cases, such as critical habitat zones where disturbance from physical control would be detrimental or sites where herbicides are prohibited. If the Scotch broom or gorse populations are extensive within a region but the individual population is below an acre, biocontrol agents can be released to establish populations and encourage spread throughout the region. In addition, control of Scotch broom and gorse may be considered a low priority in some regions and is often overlooked for intensive management. In these cases, land managers may wish to use biocontrol as a way to reduce further weed spread. Nevertheless, biocontrol agents disperse more easily in contiguous gorse and broom infestations than in infestations with only a few scattered plants and distant patches. If your biological control program goals involve evaluating the program's efficacy, establish permanent monitoring sites before you release any biocontrol agents. The monitoring sites will require regular inspections, so consider the site's ease of accessibility, terrain, and slope.

Note land use and disturbance factors

Release sites should experience little to no regular disturbance. Abandoned fields/pastures, vacant lots, and natural areas are good choices for biological control agent releases. Sites where insecticides are used should not be utilized for biocontrol agent releases. Such sites include those near wetlands that are subject to mosquito abatement or near agricultural fields or orchards where pesticide applications occur regularly. Roadside infestations along dirt or gravel roads with heavy traffic should also be avoided; extensive dust makes gorse and broom

Figure 4-3. Gorse infestations: a. too small for biological control; b. appropriate for biological control. (a. Jennifer Andreas, Washington State University Extension; b. Nancy Ness, Grays Harbor Noxious Weed Control Board)

plants less attractive to biocontrol agents. Do not use sites where significant land use changes will take place, such as intensive reforestation, road construction, cultivation, building construction, and mineral or petroleum extraction. If supply of biocontrol agents is limited, prioritize release sites that are not regularly mowed, pulled, burned, or treated with herbicides.

Survey for presence of biological control agents

Always examine your prospective release sites to determine if gorse and Scotch broom biological control agents are already present. Many of the biological control agents currently approved for use in North America and/or Hawaii are already widespread. If a biocontrol agent you are planning to release is already established at a site, you may want to consider making the release at another site where the biocontrol agent is not yet present. If observed biocontrol agent populations are low at a site, you can release additional biocontrol agents at that site to augment the existing population.

Record ownership and access

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

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

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

You may wish to restrict access to release locations, especially research sites and insectaries, and allow only authorized project partners to visit the sites and collect biocontrol agents. The simplest approach is to select locations that are not visible to or accessible by the general public. To be practical, most if not all of your sites will be readily accessible, so in order to restrict access you should formalize arrangements with the landowner or manager. This will require you to post no-trespassing signs, install locks on gates, etc. (Figure 4-4).

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

Choosing the Appropriate Biological Control Agents for Release

You should consider several factors when considering which biological control agent to release at a site, including biocontrol agent efficacy, availability, and site preferences (Tables 4-1 and 4-2).

Figure 4-4. "No disturbance" sign. (Alan Martinson, Latah County Weed Control, and Paul Brusven, Nez Perce BioControl Center)

Table 4-1. Summary of general characteristics and site preferences of gorse and Scotch broom biological control agents established in North America. Species in red are not approved for redistribution in the USA; they are included in this table to aid in proper identification to ensure they are not inadvertently collected and redistributed along with approved biocontrol agents.

Biocontrol Agent Characteristics				Site Characteristics	
Species	**Plant Species and Part Attacked**	**Efficacy**	**Availability**	**Favorable Conditions**	**Unfavorable Conditions**
Bruchidius villosus Broom seed beetle	Seeds of Scotch broom, French broom	Reduces viable seed production; unclear if densities and attack rates are high enough to decrease plant populations	Widespread and high abundance in OR,WA and BC; low abundance in CA	Open areas, meadows and hillsides with southern exposure	Heavy shade, cold, damp, possibly high elevations
Exapion fuscirostre Scotch broom seed weevil	Seeds of Scotch broom	Reduces viable seed production, but often insufficient to control Scotch broom populations	Widespread but moderately abundant in CA, ID, OR, WA; low abundance in BC, it is less effective than *B. villosus*	Open areas, meadows and hillsides with southern exposure	Heavy shade, cold, damp, high elevations
Exapion ulicis Gorse seed weevil	Seeds of gorse	Reduces viable seed production, but insufficient to control gorse populations	Widespread and abundant in CA, OR, WA; **not known to be present in Canada**	Open, sunny, dense gorse infestations	Cold winters, shade, scattered gorse plants, salt spray zones
Leucoptera spartifoliella Scotch broom twig miner	Stems of Scotch broom	Mining causes dieback of stems; however plants often re-sprout below sites of damage so overall impact is negligible; parasitized	Widespread in CA, OR but limited in WA; **not known to be present in Canada**	Low elevations, moist, moderate temperatures	Dry, high elevations, cold winters
Tetranychus lintearius Gorse spider mite	Stems, spines, leaves of gorse	Stunts branch growth, reduces flowering; initially very effective by killing heavily infested plants; heavy predation now makes it ineffective	Limited abundance in CA, OR, WA; **not known to be present in Canada**	Warm, open, away from the ocean	Damp, ocean-side, shade
Aceria genistae	Stems and stem buds of Scotch broom	Mite galls reduce seed production, plant biomass and may cause stem or plant mortality; medium impact overall in WA, less abundant in CA, OR and BC where impact is limited	Widespread in WA; established but abundant only locally in OR, CA, and BC; **not approved for redistribution in USA**	Hot, dry, mild winter temperatures; spreads quickly through windy corridors	Extreme winter temperatures, excessive precipitation
Agonopterix nervosa	Shoot tips, flowers of gorse, Scotch broom, Portuguese broom	Stunts stem growth and reduces seed production; most effective on gorse, but overall impact to any attacked species is limited	Widespread in OR and WA, uncommon in CA; highly parasitized; abundance in BC unknown; **not approved for redistribution in USA**	Sunny, below 2,600 feet (800m) in elevation	High elevation, shade or excessive overcast conditions
Arytainilla spartiophila	Stems and new growth of Scotch broom	At high densities reduces growth and weakens plants, making them more susceptible to pathogens; overall impact is likely limited	Widespread in CA, OR and WA; **not approved for redistribution in USA; not known to be present in Canada**	Adapted to variety of conditions throughout northwestern North America	No specific unfavorable conditions determined to date

Table 4-2. Summary of general characteristics and site preferences of gorse biological control agents established in Hawaii

Biocontrol Agent Characteristics				Site Characteristics	
Species	**Plant Species and Part Attacked**	**Efficacy**	**Availability**	**Favorable Conditions**	**Unfavorable Conditions**
Agonopterix umbellana Gorse soft shoot moth	Shoots and spines of Scotch broom	High populations defoliate stems, destroy shoot tips, and can lead to plant dieback; however most attacked plants recover after the moths are no longer active	Widespread on Hawaii Island; abundant on Maui only at high elevations (> 3,280 feet or 1,000 m)	High elevations, cool temperatures	Low elevations, hot
Exapion ulicis Gorse seed weevil	Gorse	Reduces viable seed production, but insufficient to control gorse populations	Variable abundance from year to year on Maui and Hawaii Island	Open, sunny, dense gorse infestations	Cold winters, shade, scattered gorse plants, salt spray zones
Sericothrips staphylinus Gorse thrips	Stems of gorse	At high densities, reduces gorse growth and flowering; however, only limited impact has been observed in the field	Established only on Hawaii Island and with low abundance, possibly due to predation	No specific favorable conditions determined to date	No specific unfavorable conditions determined to date
Tetranychus lintearius Gorse spider mite	Stems, spines, leaves of gorse	Stunts branch growth, reduces flowering; initially very effective by killing heavily infested plants; heavy predation now makes it ineffective	Limited abundance on Maui and Hawaii Island, likely due to predation	Warm, open, away from the ocean	Damp, ocean-side, shade

Biocontrol agent efficacy

Efficacy refers to the ability of the biological control agent to directly or indirectly reduce the population of the target weed below acceptable damage thresholds or cause weed mortality resulting in control. It is preferable to release only the most effective biocontrol agents rather than releasing all biocontrol agents that might be available for a target weed. Consult with local weed biological control experts, neighboring land managers, and landowners to identify the biocontrol agent(s) that appear(s) most effective given local site characteristics and management scenarios.

Biocontrol agent availability

Five approved biological control agents are currently established on gorse or Scotch broom in the continental United States, though their availability varies greatly between species and sites. The seed weevil *Exapion ulicis* is the most

widespread biocontrol agent on gorse and is readily available for collection in California, Oregon, and Washington. The spider mite *Tetranychus lintearius* is also established on gorse in California, Oregon, and Washington, but its abundance is limited by predation. Neither species is overly effective in controlling gorse.

Of the Scotch broom biological control agents approved for redistribution, the seed beetle *Bruchidius villosus* is the most widespread. Though abundant in Oregon and Washington, it remains to be seen if densities and attack rates are sufficiently high to decrease Scotch broom populations. The twig-mining moth *Leucoptera spartifoliella* is widespread in California and Oregon but limited in Washington, while the seed weevil *Exapion fuscirostre* is moderately abundant in California, Idaho, Oregon, and Washington. The overall impact of both *L. spartifoliella* and *E. fuscirostre* on Scotch broom is minimal.

Several unintentionally introduced species are established on gorse and/or broom in the United States. Refer to "Unapproved Natural Enemies of Gorse and Broom" (pages 60-64) for more information. **None are approved for redistribution in the United States; three are mentioned herein to prevent their inadvertent collection and redistribution as they are commonly encountered when working with the approved biocontrol agents.** The moth *Agonopterix nervosa* attacks both gorse and Scotch broom, though its impact is limited on both species. Populations of *A. nervosa* are widespread in Oregon and Washington and limited in California. The psyllid *Arytainilla spartiophila* is widespread on Scotch broom; however, it has limited impact on Scotch broom populations. The mite *Aceria genistae* is also widespread on Scotch broom in portions of northwestern North America where its impact varies from slight to heavy.

Four of the species established in the continental United States are also established in Canada; *A. genistae*, *B. villosus*, and *E. fuscirostre* are established on Scotch broom while *A. nervosa* is established on both gorse and Scotch broom. None were intentionally introduced to Canada, though two of these species (*B. villosus* and *E. fuscirostre*) were intentionally redistributed for a short time within British Columbia. *Bruchidius villosus* is widespread in British Columbia, though it remains to be seen if densities and attack rates are sufficiently high to decrease Scotch broom populations. The impact of the other three established species on gorse and Scotch broom in Canada is either limited or unknown.

Since 1926, eight biological control agents have been released on gorse in Hawaii. The two weevils *Apion* sp. and *Stenopterapion scutellare*, the shoot moth *Pempelia genistella*, and the rust *Uromyces pisi* f. sp. *europaei* all failed to establish. The moth *Agonopterix umbellana* and the weevil *E. ulicis* are both widespread and abundant on Hawaii Island and Maui at different times and locations, though both have limited impact on gorse populations. The thrips *Sericothrips staphylinus* and the mite *T. lintearius* are both limited in Hawaii, likely due to predation.

Federal and state departments or commercial biological control suppliers may be able to assist you in acquiring biocontrol agents not yet available but permitted for use in your area (see Obtaining and Releasing Gorse and Broom Biological Control Agents, below). In the United States, state departments of agriculture, county weed managers, extension educators, or federal and university weed biological control specialists should be able to recommend in-state collection sites where appropriate. Remember that in the United States, interstate transport of biological control agents requires a USDA-APHIS-PPQ 526 Permit (see Regulations for the Transfer of Gorse and Scotch Broom Biological Control Agents, page 99). Get your permits early to avoid delays.

Release site characteristics

General physical site and biological preferences for each biocontrol agent have been developed from anecdotal observations and experimental data. These are listed in Tables 4-1 and 4-2 to help land managers ensure that biocontrol agents are released in sites with suitable conditions.

Obtaining and Releasing Gorse and Scotch Broom Biological Control Agents

You can obtain gorse and Scotch broom biological control agents by collecting or rearing them yourself, having someone collect them for you, or by purchasing them from a commercial supplier. This section provides information on collecting and purchasing gorse and broom biocontrol agents, with emphasis on *Bruchidius villosus* (continental United States). *Exapion fuscirostre* and *E. ulicis* are both already moderately abundant in Northwestern North America, but both have limited impact on gorse or Scotch broom so are not the highest priority for redistribution. *Tetranychus lintearius* and *Leucoptera spartifoliella* are heavily preyed upon or parasitized in the continental United States so are not highly recommended for further redistribution. ***Aceria genistae*, *Agonopterix nervosa*, and *Arytainilla spartiophila* are not approved for redistribution in the United States, but they are widely distributed at many sites.**

All four gorse biological control agents established in Hawaii are not highly effective against their target weed and are likely most effective when combined with complementary control methods. *Agonopterix umbellana* and *Exapion ulicis* are both at least moderately abundant on Hawaii Island and Maui, but both have limited impact on gorse populations so are not the highest priority for redistribution. *Sericothrips staphylinus* and *Tetranychus lintearius* populations are limited due to predation, so are not highly recommended for further redistribution.

Factors to consider when looking for sources of biological control agents

You do not need to take a lottery approach and release all approved biological control agents at a site in the hopes that one of them will work. Some biological control agents will not be available even if you want them, and some are already widespread and/or have been shown to have little or no effectiveness in certain

areas. The best strategy is to release the best biocontrol agent. Ask the county, state, or federal biological control experts in your area for recommendations of biocontrol agents for your particular project.

If available, biological control agents from local sources are best. Using local sources increases the likelihood that biocontrol agents are adapted to the climate and site conditions present and are available at appropriate times for release at your target infestation. Using locally sourced biological control agents also reduces the possibility of accidentally introducing biocontrol agent pathogens or natural enemies to your area. Local sources may include neighboring properties or other locations in adjacent counties/districts. Remember that in the United States, interstate transport of biological control agents requires a USDA-APHIS-PPQ 526 Permit (see Regulations for the Transfer of Gorse and Scotch Broom Biological Control Agents, page 99). Get your permits early to avoid delays.

Some USA states, counties, and universities have field collection days at productive insectary sites (Figure 4-5). On these days, land managers and landowners are invited to collect or receive locally collected gorse and Scotch broom biological control agents for quick release at other sites. These sessions are an easy and often inexpensive way for you to acquire biological control agents. They are good educational opportunities as well, because you may see first-hand any impacts the various biocontrol agents might be having on gorse and broom plant communities.

Figure 4-5. Scotch broom field day. (Jennifer Andreas, Washington State University Extension)

Typically, field days are conducted at several sites in a state and on several dates. Although designed for intrastate collection and redistribution, out-of-state participants may be welcome to participate (remember that USDA-APHIS-PPQ 526 Permits are required for interstate movement and release of biological control agents). Contact county weed supervisors, university weed or biological control specialists, or federal weed managers for information about field days in your region.

Collecting Gorse and Scotch Broom Biological Control Agents

Planning and timing of collection is critical. For all species, it is usually most efficient to scout the potential collection site well in advance to ensure your desired species is present at suitable densities. The species of biological control agent and weather characteristics at your collection and release site will determine the best time in the season to collect. Ensure that all necessary collection supplies are on hand. Also, accurate identification of the biological control agents is essential. General guidelines for collecting gorse and broom biological control agents are listed in the following sections and in Tables 4-3 and 4-4.

For all species, collect only on a day with good weather. Do not collect in the rain; arthropods will hide and become difficult to find in rainy weather, excess moisture causes adverse effects, and biocontrol agents may drown in wet collection containers.

Collection methods

Racket and beat sheet: The most common method for collecting gorse and Scotch broom biocontrol agents is to use a tool such as a racket to tap the biocontrol agents off of their host plant foliage and onto a beat sheet (Figure 4-6a), tray (Figure 4-6b), or sweep net (Figure 4-6c) placed strategically beneath the branch being tapped. Biocontrol agents thus tapped off the foliage can then be gathered directly using an aspirator or sorted later using a sorting tray and aspirator (see below). Avoid disturbing the gorse or broom before tapping because this will often cause beetles to fly away. While this method is most commonly used for *Bruchidius villosus*, *Exapion fuscirostre*, and *E. ulicis*, it can also be useful for collecting *Sericothrips staphylinus* (established only in Hawaii). *Bruchidius villosus* is quick to fly when warm, which can make collections challenging. It is best to collect in cool temperatures (e.g., early morning), and keep the beat sheet in the shade while aspirating.

Sweep netting: A sweep net consists of a conical canvas or muslin bag held open on one end by a sturdy wire hoop 10-15 inches (25-38 cm) in diameter attached to a handle 3 feet (0.9 m) long (Figure 4-6c). They can be purchased from entomological, forestry, and biological supply companies, or you can construct them yourself. Sweeps are made by swinging the net through the plant canopy and collecting insects off the foliage. It is best to use no more than 25 sweeps (10 sweeps for delicate biocontrol agents such as moths and thrips) before removing the biocontrol agents from the net. Removing material at regular intervals reduces the potential harm that could result from knocking biocontrol

Table 4-3. Recommended timetable and methods for collecting approved gorse and Scotch broom biological control agents in North America. Methods are listed in the order of ease of collection. Plant and biocontrol agent stages will vary by climate and location.

Biocontrol Agent	Biocontrol Agent Stage	Target Plant	Plant Stage	Timing	Method	Notes
Bruchidius villosus Broom seed beetle	Adult	Scotch broom	Flowering; seedpods forming	April to May	Use a racket to tap adults from flowers and stems onto a beat sheet or tray, then aspirate, or tap adults into a sweep net and sort beetles in cages	Already widespread, but should be redistributed to Scotch broom infestations where not currently established; most effective biocontrol agent
Exapion fuscirostre Scotch broom seed weevil	Adult	Scotch broom	Flowering; seedpods forming	April to May	Use a racket to tap adults from flowers and stems onto a beat sheet or tray, then aspirate, or tap adults into a sweep net and sort beetles in cages	Already moderately abundant and (often) limited impact makes it a lower priority for redistribution compared to *B. villosus*
Exapion ulicis Gorse seed weevil	Adult	Gorse	Flowering; seedpods forming	March to mid-April	Use a racket to tap adults from flowers and stems onto a beat sheet or tray, then aspirate, or tap adults into a sweep net and sort beetles in cages	Already widespread and limited impact makes it a low priority for redistribution
Leucoptera spartifoliella Scotch broom twig miner	Pupa	Scotch broom	Flowering	April to June	Hand collect pupae from broom foliage and rear in cages	Low impact, already widespread, and heavy parasitism make it a very low priority for redistribution
	Adult	Scotch broom	Flowering to seedpods maturing	June to August	Use light traps to attract adults	
Tetranychus lintearius Gorse spider mite	All stages	Gorse	Throughout growing season	March to October; most abundant August to September	Clip infested stems and transfer to uninfested sites	Heavy predation makes this a low priority for redistribution

Table 4-4. Recommended timetable and methods for collecting established gorse biological control agents in Hawaii. Methods are listed in the order of ease of collection. Plant and biocontrol agent stages will vary by location.

Biocontrol Agent	Biocontrol Agent Stage	Target Plant	Plant Stage	Timing	Method	Notes
Agonopterix umbellana Gorse soft shoot moth	Larva	Gorse	Seedpods maturing; seeds dispersing	April to May	Clip stems infested with larvae and transfer to uninfested sites	Already moderately widespread and limited impact makes it a low priority for redistribution
Exapion ulicis Gorse seed weevil	Adult	Gorse	Flowering; seedpods forming	November to February	Use a racket to tap adults from flowers and stems onto a beat sheet or tray, then aspirate, or collect using a sweep net	Already widespread and limited impact makes it a low priority for redistribution
Sericothrips staphylinus Gorse thrips	Adults and Nymphs	Gorse	All stages	Most abundant March to November	Use a racket to tap adults and nymphs from stems and flowers onto a white beat sheet or tray, then aspirate, or clip infested stems and transfer to uninfested sites	If low observed impact is due to predation, then low priority for redistribution; otherwise could be redistributed to Maui and other sites on Hawaii Island
Tetranychus lintearius Gorse spider mite	All stages	Gorse	All stages	Throughout the year	Clip infested stems and transfer to uninfested sites	Heavy predation makes this a low priority for redistribution

Figure 4-6. Gorse and Scotch broom collection methods: a. racket and beat sheet; b. racket and tray; c. sweep net. (a.,b. Eric Coombs, Oregon Department of Agriculture, bugwood.org; c. Laura Parsons, University of Idaho, bugwood.org)

agents around with debris, and reduces the opportunity for predator insects and spiders swept up with the biocontrol agents from incapacitating or devouring the biocontrol agents.

Because Scotch broom and gorse plants are stiff and large, it can be difficult and inefficient to sweep the plants for adults. Rather, plants can be tapped (as mentioned in the section above) to collect adults in the sweep net and sorted later in a controlled environment. A large amount of flowers, other insects, and spiders are also collected when tapping material into a sweep net. This material can be transferred into other bags (cloth or plastic) and kept in a cool environment until it can be sorted through to retrieve the biocontrol agents. Using sieves to sort through the largest material can be helpful. Cages are recommended for sorting *Bruchidius villosus* since they are quick to fly when warm and can become unmanageable. The presence of spiders creating webs and the honeydew from the broom psyllid can damage or kill biocontrol agents, so it is important to sort through the material quickly. This method is good for large scale collections but may be more labor intensive. This method can be useful for *B. villosus*, *Exapion fuscirostre*, *E. ulicis*, and *Sericothrips staphylinus*.

Aspirating: An aspirator is a device used to suck biocontrol agents from a surface into a collection vial. Aspirators can be used to collect insects out of a sweep net or cage or off a sorting tray or sheet (see below). A variety of aspirators can be purchased from entomological, forestry, and biological supply companies, or you can construct one yourself. Simple aspirators are powered by mouth suction, manually by using an aspirating bulb, or mechanically using a modified hand vacuum. Mouth-powered aspirators contain rubber tubing for inhaling (Figure 4-7a) and an insect tube for collecting insects (Figure 4-7b) into a storage vial. Inline filters (e.g. HEPA filters, Figure 4-7c) are commercially available to prevent unintentional inhalation or swallowing of particles or debris during mouth aspiration. At the very least, mouth aspirators should be equipped with fine-mesh screening on the vial end of the tubing held in the mouth (Figure 4-7d) so that insects and small particles are not inhaled.

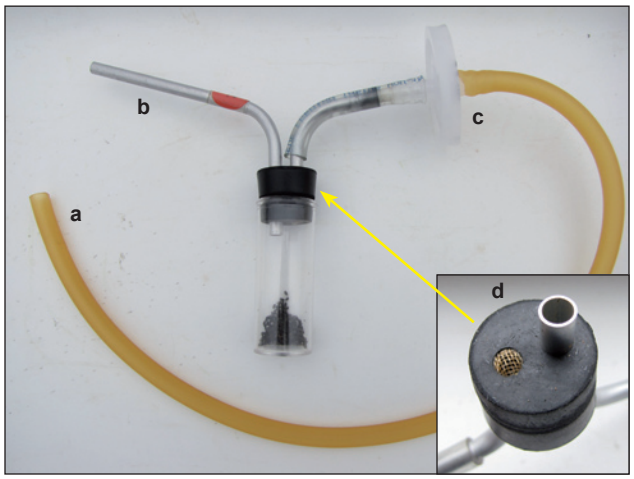


Figure 4-7. Aspirator components: a. suction tube; b. insect tube; c. fine particle filter; d. larger particle screen. (Jennifer Andreas, Washington State University Extension)

Sorting: The racket/beat sheet and sweep net collection methods are not selective, so other insects and spiders are usually collected along with the biocontrol agents. Sorting separates the biocontrol agents from unwanted organisms and debris (such as unapproved insects/mites, predators, or weed seeds) collected along with the biocontrol agents. The easiest way to sort is to empty the contents of the net or tray into a plastic tub and aspirate the biocontrol agents out of the debris. If the collected material is first chilled in a cooler, the biocontrol agents will move more slowly and will be easier to catch and sort. *Bruchidius villosus* and *Exapion fuscirostre* adults both move very quickly so cages are often the most efficient environments for sorting (Figure 4-8a,b). Use an aspirator (described above) to sort the biocontrol agents. To speed up the sorting process, count out a set number of biocontrol agents 2-5 times (for example, 200 or 500 adult *Bruchidius villosus* beetles) into separate collecting vials. Tap the bottom of vial to knock down all the beetles, then mark the fill level on the vial. Use the average fill level based on those 2-5 collection vials to collect approximate release-size densities of biocontrol agents without needing to count out each individual insect. Remember that adults of the various gorse and broom biocontrol species are different in size, so different release density fill levels should be used for each species.

Transferring infested plant material: This method is applicable for the mite *Tetranychus lintearius*, the moth *Agonopterix umbellana* (established only in Hawaii), and the thrips *Sericothrips staphylinus* (established only in Hawaii). Gorse stems infested either with the mite, thrips, or larvae of *A. umbellana* can be clipped (Figure 4-9a), stored in a breathable but sealable container (described further on page 90), and moved to new sites where the mite, moth, or thrips are not yet present. Care should be taken not to spread gorse seeds to new sites as this may introduce new genetic material. Care should also be taken to avoid spreading other plant or insect species to new sites as this may inadvertently create future problems.

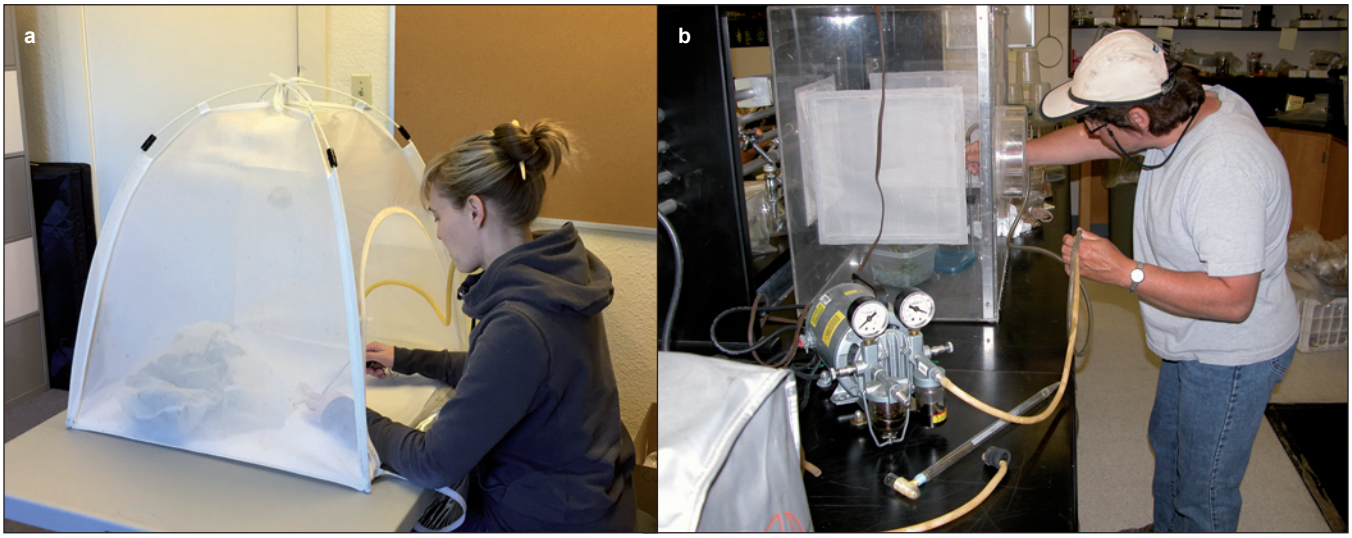


Figure 4-8. Sorting gorse and Scotch broom biocontrol agents: a. in a cage with a mouth-suction aspirator; b. in a cage with a mechanical aspirator. (a. Jennifer Andreas, Washington State University Extension; b. Sharlene E. Sing, USDA FS RMRS)

Light traps: Light traps are used to collect nocturnal biocontrol agents (typically moths) that are otherwise difficult to collect during the day. This method is not often used for collecting *Leucoptera spartifoliella*, but can be used for adults. 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 Scotch broom plant material in the bottom (Figure 4-9b). Place it in a sheltered place near a Scotch broom 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 moths attracted to the sheet as they land on the surface. Many similar-looking moths may be attracted with this method, so it is important all moths are properly identified as *L. spartifoliella* before being transferred.

Methods by species

Gorse soft shoot moth (*Agonopterix umbellana*, established only in Hawaii): Gorse stems infested with *A. umbellana* can be gathered during early spring when larvae are active on gorse stems, shoots, and spines. Depending on location, the collecting period is generally from March to May. Stems should be contained in a sealable but breathable container (described further in the next section) and then transferred to new gorse sites where they should be placed in direct contact with uninfested gorse stems (taking care not to spread gorse seeds to new sites as this may introduce new genetic material). Once at the new sites, the moth larvae will relocate to living, uninfested stems.

Figure 4-9. Gorse and Scotch broom collection methods: a. clipping and collecting gorse stems infested with the gorse spider mite, *Tetranychus lintearius*; b. light trap for collecting adult moths. (a. Eric Coombs, Oregon Department of Agriculture, bugwood.org; b. Jerry Payne, USDA ARS, bugwood.org)

Broom seed beetle (*Bruchidius villosus*): Collect adult beetles by tapping stems over beat sheets or trays with tools such as rackets to dislodge the insects, or by sweeping the ends of broom stems and branches. Collection material should then be sorted as soon as possible and the adult *B. villosus* aspirated. Collect the seed beetles during cool temperatures, usually early in the morning. The seed beetle is quick to fly when warm and will be challenging to aspirate. A cage is the most efficient sorting environment, and first chilling the collected material may make the insects move more slowly. Do not collect during and immediately after rain events. Water sitting on the flowers will soak the beat sheet or sweep net and make sorting the seed beetle difficult. Adults can also drown if too much water is present. The optimal time to collect is in early spring when Scotch broom flowers; depending on location, the collecting period is generally from April to May. This beetle is already widespread throughout much of northwestern North America, but it should be redistributed to Scotch broom sites where it is not already established.

Scotch broom seed weevil (*Exapion fuscirostre*): Collect adult beetles by tapping stems over beat sheets or trays with tools such as rackets to dislodge the insects, or by sweeping the ends of broom stems and branches. Collection material should then be sorted as soon as possible and the adult *E. fuscirostre* aspirated. Collect the seed weevils during cool temperatures, usually early in the morning. While *E. fuscirostre* is not as quick to fly as *B. villosus*, it can still move quickly when warm and will be challenging to aspirate. A cage is the most efficient sorting environment, and first chilling the collected material may make the insects move more slowly. Do not collect during and immediately after rain events. Water sitting on the flowers will soak the beat sheet or sweep net and make sorting the seed weevil difficult. Adults can also drown if too much water is present. The optimal time to collect is in early spring when Scotch broom flowers; depending on location, the collecting period is generally from April to May. This weevil is already moderately widespread throughout much of northwestern North America but has limited overall impact to Scotch broom populations. Consequently, it is a low priority for redistribution.

Gorse seed weevil (*Exapion ulicis*): Collect adult beetles by tapping stems over beat sheets or trays with tools such as rackets to dislodge the insects, or by sweeping the ends of gorse stems and branches. Collection material should then be sorted and the adult *E. ulicis* aspirated. Collect the seed weevils during cool temperatures, usually early in the morning. The optimal time to collect is in early spring when gorse flowers; depending on location, the collecting period is generally from February to March. This beetle is already widespread throughout much of the northwestern United States but has limited overall impact to gorse populations. Consequently, it is a low priority for redistribution.

Scotch broom twig miner (*Leucoptera spartifoliella*): Because larvae are heavily parasitized, it is best to collect this biocontrol agent in either the pupal or adult stage. Pupae can be hand-collected in late spring (mid-April to mid-June depending on location) and reared out in cages or in breathable, clear containers. Any parasitoids that emerge should be separated and destroyed. Emerging adults can then be safely transferred to new Scotch broom patches. Alternatively, light traps can be used to trap the nocturnal adults. The optimal time to collect is in summer when Scotch broom is flowering to seedpod maturation; depending on location, the collecting period is generally from June to August. This species is already widely distributed throughout the northwestern United States with limited impact, so it is a low priority for redistribution.

Gorse thrips (*Sericothrips staphylinus*, established only in Hawaii): Collect all stages by tapping stems over beat sheets or trays with tools such as rackets to dislodge the insects, or by sweeping the ends of gorse stems and branches. Breathing on stems may increase collection success as CO_2 will cause the thrips to drop from places where they may have been hiding. Collection material should then be sorted and the *S. staphylinus* aspirated. Alternatively, clip gorse stems infested with *S. staphylinus*, place them in a sealable but breathable container (described further in the next section), and then transfer them to new gorse sites where they should be placed in direct contact with uninfested gorse stems (taking care not to spread gorse seeds to new sites as this may introduce new genetic material). The downfall with the stem collection method is not knowing the number of thrips being transferred to the new site. Collect the thrips during the heat of the day. The optimal time to collect is during the warmest months of the growing season when all stages of the thrips are most active; depending on location, the collecting period is generally from March to November. This biocontrol agent was initially widespread in Hawaii, but populations have since decreased, and very little impact to gorse populations has been observed. If the population reduction is due to predation, this species is a low priority for redistribution. Otherwise, the biocontrol agent should be redistributed throughout Maui and Hawaii Island.

Gorse spider mite (*Tetranychus lintearius*): Gorse stems infested with *T. lintearius* can be gathered throughout the growing season. Depending on location, the collecting period is generally from March to November. *Tetranychus lintearius* is heavily impacted by predatory mites and beetles, and care should be taken to ensure predators are not transferred along with *T. lintearius*. Weak *T. lintearius* webbing indicates predators are likely present. Collected stems should be contained in a sealable but breathable container (described further in the next section) and then transferred to new gorse sites where they should be placed in direct contact with uninfested gorse stems (taking care not to spread gorse seeds to new sites as this may introduce new genetic material). Once at the new sites, the mites will relocate to living, uninfested stems.

Release Containers for Gorse and Scotch Broom Biological Control Agents

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

Following collection, biocontrol agents should be transferred to release containers intended to protect them (and to prevent insects and mites from escaping en route). When large sections of infected stems are transferred between sites to redistribute *Tetranychus lintearius* or *Agonopterix umbellana* (established only in Hawaii), the stems should be stored in large, breathable bags made of paper or gauze. Paper and gauze bags provide sufficient ventilation while plastic bags may cause moist plant material to rot or drown the biocontrol agents. When only smaller infected plant segments are used in the transfer of the beetles *Bruchidius villosus*, *Exapion fuscirostre*, and *E. ulicis*, the moth *Leucoptera spartifoliella*, or the thrips *Sericothrips staphylinus*, release containers should be rigid enough to resist crushing but also ventilated to provide adequate airflow and reduce condensation. Un-waxed paperboard cartons are ideal; they are rigid, permeable to air and water vapor, and are available in many sizes. As an alternative, you can use release containers made of either light-colored lined or waxed paper (e.g. ice cream cartons are particularly suitable; see Figure 4-10a) or plastic, providing they are ventilated; simply poke numerous holes in the container or its lid with an ordinary push pin or thumb tack, and cover the holes with a fine mesh screen. Be sure the holes are not large enough to allow the biocontrol agents to escape. Untreated paper bags (lunch bags) work well for transporting biocontrol agents short distances; however, they are fragile and offer little physical protection for the material within, must be sealed tightly to prevent biocontrol agents from escaping, and some biocontrol agents are capable of chewing through them. **Do not use glass or metal release containers**; they are breakable and make it difficult to regulate temperature, airflow, and humidity.

Fill release containers half full with loosely crumpled paper towels or tissue paper to provide a substrate for biocontrol agents to rest on and hide in, and to help regulate humidity. Include a small amount of Scotch broom or gorse sprigs, depending on the biocontrol agent's preferred host. Sprigs should be free of seeds, flowers, dirt, spiders, and other insects and should not be placed in water in the release container. Seal the release container lids with masking or label tape or with tightly fitting rubber bands. If you are using paper bags, fold over the tops several times and staple them shut. Be sure to label each container with (at least) the biological control agent(s) name, the number of biological control agents in the container, the collection date and site, and the name of the person(s) who did the collecting (Figure 4-10b).

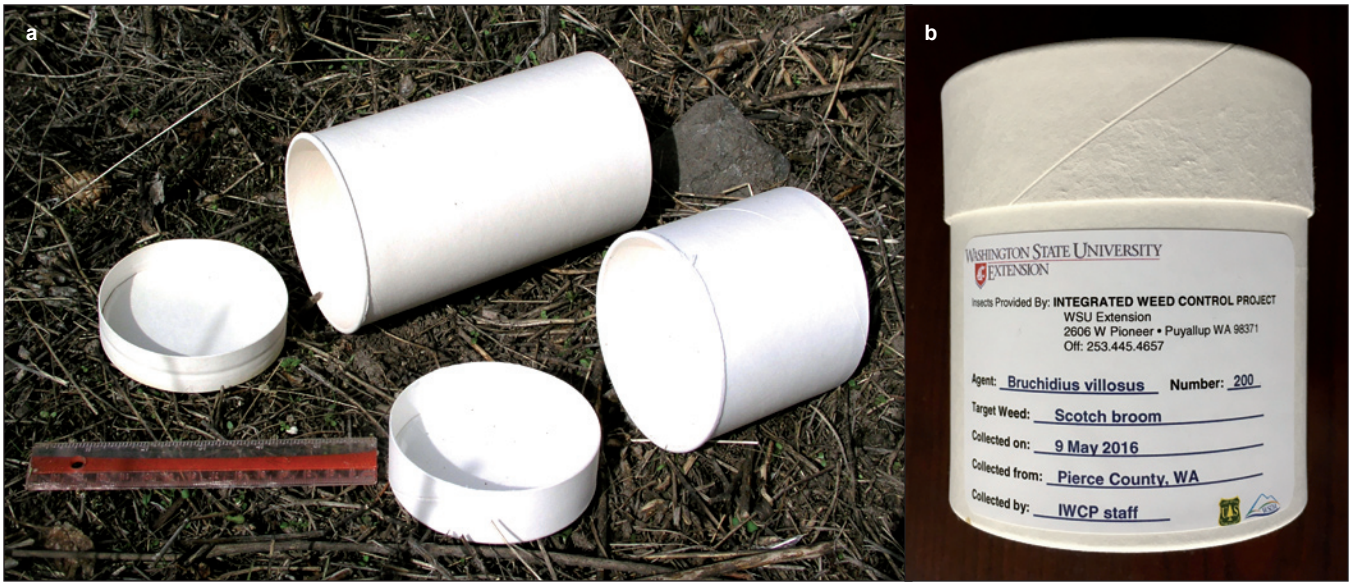


Figure 4-10. Cardboard release containers: a. for transporting gorse and Scotch broom biocontrol agents; b. properly labelled. (a. Martin Moses, University of Idaho, bugwood.org; b. Jennifer Andreas, Washington State University Extension)

Transporting Gorse and Scotch Broom Biological Control Agents

Keep the containers cool at all times

Once you collect and package the biocontrol agents, maintain them at temperatures between 50 and 65 °F (10-18 °C). If possible, place the release containers in large coolers equipped with frozen ice packs. Do not use ice cubes unless they are contained in a separate, closed, leak-proof container. Wrap the ice packs in crumpled newspaper or bubble wrap to prevent direct contact with release containers and to absorb any condensation that forms. Place extra packing material in coolers to prevent ice packs from shifting and damaging biocontrol agent containers. As an alternative to coolers with ice packs, electric car-charged coolers may be utilized, provided the cycle is set to cool and not warm. Always keep coolers out of direct sun, and only open them when you are ready to release the biocontrol agents. If you cannot release them immediately, place them in a refrigerator for short-term storage (no lower than 40 °F [4.4 °C]) until you transport or ship them (which should occur as soon as possible and preferably not longer than 48 hours).

Transporting short distances

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

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) and send the recipient the tracking number for the package. In such cases, the release containers should be placed in insulated shipping containers with one or more ice packs. Some specially designed foam shippers have pre-cut slots to hold small biocontrol agent containers and ice packs (Figure 4-11). This construction allows cool air to circulate but prevents direct contact between the ice and the release containers. Laboratory and medical suppliers sell foam "bioshippers" that are used to transport medical specimens or frozen foods. If neither foam product is available, you can use a heavy-duty plastic cooler which also may be better suited to large gorse or broom stems infected with *Tetranychus lintearius* or *Agonopterix umbellana* (established only in Hawaii). **Please note that for safety reasons, dry ice cannot be used for transporting biocontrol agents.**

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

Figure 4-11. Commercially made shipping container. (University of Idaho, bugwood.org)

Other factors to consider

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

Avoiding Common Packaging Mistakes

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

Escape: Close release containers lids securely with rubber bands or easily removable/resealable tape (e.g., masking tape) to prevent biocontrol agents from escaping into the shipping container.

Excess heat: Do not expose release containers to direct sunlight or temperatures above 65 °F (18 °C). Avoid shipping delays that can expose biocontrol agents to high temperatures.

Excess moisture: Remove spilled or excess water in release and shipping containers. Do not ship weed sprigs with any type of water source (e.g., floral foam or tubes) inside release containers. Add crumpled paper towels to release containers to absorb incidental moisture or condensation.

Lack of ventilation: Provide adequate ventilation; use air-permeable release containers or make air holes in plastic containers with push pins or other small diameter tools, covering the holes with a fine mesh screen to prevent the escape of mobile biocontrol agents.

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

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

Purchasing Gorse and Scotch Broom Biological Control Agents

While gorse and Scotch broom biocontrol agents are currently not available commercially, suppliers may provide these species in the future. At that time, county weed managers, extension educators, or university weed or biological control specialists may be able to recommend one or more suppliers. Make sure that a prospective supplier is reputable, can provide healthy individuals of the species you want (parasite- and pathogen-free), and can deliver them to your area at a time appropriate for field release (you will want to know where and when the biocontrol agents were collected). Avoid purchasing biocontrol agents from a supplier who collects biocontrol agents from an environment significantly different from your planned release location. Interstate shipments of gorse and broom biological control agents by commercial suppliers also require a USDA PPQ 526 Permit (see page 99), a copy of which should be enclosed in the shipping box. It is the responsibility of the person receiving and releasing biocontrol agents to secure the required permits, though some vendors will help buyers with this process. Confirm in advance that there is a permit in place for the species you are acquiring as well as the region in which the release will occur. DO NOT purchase or release unapproved or non-permitted biological control organisms. Note that before any biocontrol agents can be taken across national borders, whether collected or purchased, an importation permit from the regulatory agency of the receiving country is required (USDA-APHIS in the USA and CFIA in Canada).

Releasing Gorse and Scotch Broom Biological Control Agents

Establish permanent location marker

Place a steel fence post or plastic/fiberglass pole as a marker at the release point (Figure 4-12a). Because gorse and Scotch broom can both grow tall, 13-foot (4 m) markers should be used wherever possible. Avoid wooden posts; they are vulnerable to weather and decay. Markers should be colorful and conspicuous. White, bright orange, pink, and red are preferred over yellow and green, which may blend into surrounding vegetation. In addition, white posts will not fade over time. Where conspicuous posts may encourage vandalism, mark your release sites with short, colorful plastic tent/surveyor's stakes or steel plates that can be tagged with release information and located later with a metal detector and GPS. Depending on the land ownership or management status at the release site, it may be necessary to attach a sign to the post or pole indicating a biological control release has occurred there and that the site should not be sprayed with chemicals or be mechanically disturbed (see Figure 4-4 on page 76). Where a sign is appropriate, the landowner/land manager and the local weed management authority (county, state, federal, and/or provincial) should be notified and given a map of the release location.

Record geographical coordinates at release point using GPS

Map coordinates of the site marker should be determined using a global positioning system device (GPS) or a GPS-capable tablet/smartphone. There

are numerous free apps available for recording GPS coordinates on a tablet/smartphone (Figure 4-12b). Coordinates should complement but not replace a physical marker. Accurate coordinates will help re-locate release points if markers are damaged or removed. Along with the coordinates, be sure to record what coordinate system and datum you are using, e.g. latitude/longitude in WGS 84 or UTM in NAD83.

Prepare map

The map should be detailed and describe access to the release site, including roads, trails, and unique landmarks/terrain features that are not likely to change through time (e.g., large rocks or rocky outcrops, creeks, valleys, etc.). Avoid using ephemeral landmarks such as "red bush", "grazing cows", etc. and descriptors which may not be obvious to everyone, such as "the Miller place", or "where the old barn used to be", etc. Use your vehicle's trip odometer to measure and record mileage between specified locations on your map, e.g., when you turn on to a new road, at cattle guards along the route, and where you park. The map should complement but not replace a physical marker and GPS coordinates. Maps are especially useful for long-term biological control programs in which more than one person will be involved or participants are likely to change. Maps are often necessary to locate release sites in remote locations or places physically difficult or confusing to access.

Figure 4-12. Biocontrol agent release site tools: a. permanent marker; b. smartphone with free weed and biocontrol agent mapping app iBioControl. (a. Jennifer Andreas, Washington State University Extension; b. Rachel Winston, MIA Consulting)

Complete relevant paperwork at site

Your local land management agency/authority may have standard biocontrol agent release forms for you to complete. Typically, the information you provide includes a description of the site's physical location, including GPS-derived latitude, longitude, and elevation; a summary of its biological and physical characteristics and land use; the name(s) of the target weed and biocontrol agent(s) released; the number and life cycle stage of the 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 biocontrol agents (see Sample Biological Control Agent Release Form in Appendix II). The best time to record this information is while you are at the field site. Consider using a smartphone and reporting app such as iBioControl. This free application uses EDDMapS (see page 100 for more information) to help county, state, and federal agencies track releases and occurrences of biological control agents of noxious weeds. Once back in the office, submit the information to your local weed control office, land management agency, or other relevant authority/database. **Always keep a copy for your own records.**

Set up photo point

A photo point is used to visually document changes in gorse and Scotch broom infestations and other components of 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; many smartphone and tablet apps such as GrassSnap or Theodolite do this automatically or with minimal input. Keep in mind that it may take a long time (e.g., 30 years) to see changes in Scotch broom or gorse populations because available biocontrol agents do not significantly impact current broom and gorse plants; rather, they impact future infestations by reducing seed production.

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 gorse or Scotch broom infestation than it is to spread those individuals too thinly over multiple gorse or broom infestations. Releasing all the 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. Guidelines for a minimum release size are uncertain for most biocontrol agents, but releases of 100-200 individuals of the beetles *Bruchidius villosus*, *Exapion fuscirostre*, and *E. ulicis*, 50-100 individuals of the moth *Leucoptera spartifoliella*, and 200-300 individuals of the thrips *Sericothrips staphylinus* (established only in Hawaii) are encouraged; releasing more individuals would be advantageous, but should not be necessary.

Often, a single release will be sufficient to establish a biocontrol agent population, especially if a large number of individuals are released. The only way to determine if biocontrol agents have established is to inspect release sites annually for up to 5 years (or more) after releases are made. Additional biocontrol agent releases may be necessary after a few years if initial releases fail to establish. For species or locations where establishment is likely to be slow (e.g., sites with high levels of overwintering mortality or large, dense infestations where biocontrol agents are easily missed), planning to make releases on the same site for 2 or 3 consecutive years may increase successful establishment and reduce the time until biocontrol agent impact on target weed populations is visible. If more than one release of a biocontrol agent is available in a given year, be sure to put some distance between releases; 2/3 mile (1 km) is ideal. If possible, make more than one release per drainage or in adjoining drainages; if one of your release sites is wiped out by flooding, fire, herbicide application or other catastrophic disturbance, then biocontrol agents from adjoining release sites can repopulate it.

In general, you can release biocontrol agents either in open releases or cages. For open releases, get to the desired release location and open the release container. When releasing adult *Bruchidius villosus*, *Exapion fuscirostre*, *E. ulicis*, *Leucoptera spartifoliella*, or *Sericothrips staphylinus* (established only in Hawaii), gently shake out all biocontrol agents in a dense lower section of a single plant. Placing the biocontrol agents on their host plant and a paper towel gives them a place to acclimate to their new temperature and surroundings without falling to the ground. Take care to dislodge any individuals hiding in or clinging to the paper towels in the release containers. Because *B. villosus* takes to flight so rapidly, it is beneficial to release in cool temperatures or in the shade. When releasing small gorse or broom segments infested with *Tetranychus lintearius*, *S. staphylinus*, or *Agonopterix umbellana* larvae (the latter two established only in Hawaii), first ensure the segments have no gorse or broom root fragments or seeds and that there are no other insect or plant species in the release containers. Gently shake out all infested plant segments in one small area. **Do not scatter biocontrol agents or small plant segments throughout the infestation. Do not walk back through the area where you just made a release.**

When transferring large stem segments infested with *Tetranychus lintearius*, *Sericothrips staphylinus*, or *Agonopterix umbellana* larvae (the latter two established only in Hawaii), take bundles of 20-50 stems and remove the ties on one end of each bundle so that stems can be fanned out at the loose end, providing a supportive base. Place the fanned bundles upright within dense stands of uninfested gorse or Scotch broom. In less dense infestations or at windy locations, tying the fanned bundle against uninfested gorse or broom may aid in successful establishment. Four to five bundles should be used per site, though more or fewer may be required, depending on the infestation size. Care should be taken not to spread gorse seeds to new sites as this may introduce new genetic material. Care should also be taken to avoid spreading other plant or insect species to new sites as this may inadvertently create future problems.

Caged releases confine biocontrol agents for a period of time so they adjust to the site and easily find one another. They may help increase establishment success at new locations, but they require you to put up and take down equipment. For caged releases, place a mesh bag over a gorse or Scotch broom plant or a small area containing multiple plants (Figure 4-13), release biocontrol agents into the cage, and secure the bottom of the cage to either the stem or the ground. Cages should be removed within a few days (for plants) or weeks (for areas).

Releases of all biocontrol agents should be made under moderate weather conditions (mornings or evenings of hot summer days, mid-day for cold season releases). Making releases under these conditions reduces the immediate dispersal of stressed biocontrol agents when they are dumped out of release containers; appropriately timed releases can significantly enhance the probability of establishment. Avoid making releases on rainy days. If you encounter an extended period of poor weather, it is better to release the biocontrol agents than wait three or more days for conditions to improve as the biocontrol agents' vitality may decline with extended storage. Avoid transferring biocontrol agents to areas with obvious ant mounds or ground dwelling animals that may prey upon some species of biocontrol agents.

Figure 4-13. Caged releases on gorse. (Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Regulations for the Transfer of Gorse and Scotch Broom Biological Control Agents

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

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

Canada: Canada requires an import permit for any new biological control agent or shipment of previously-released biocontrol agents entering the country. These 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 biological control 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 biological control 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.

Documenting, Monitoring, and Evaluating a Biological Control Program

The Need for Documentation

The purpose of monitoring is to evaluate the success of your gorse and broom biological control program and to determine if you are meeting your weed management goals. Documenting outcomes (both successes and failures) of biocontrol release programs will help generate a more complete picture of biocontrol impacts, guide future management strategies, and serve education and public relations functions. Monitoring can provide critical information for other land managers by helping them predict where and when biological control might be successful, helping them avoid releasing ineffective biocontrol agents or the same biocontrol agent in an area where they were previously released, and/or helping them avoid land management activities that would harm local biocontrol agent populations or worsen the gorse and broom problem. (See the Code of Best Practices for Classical Biological Control of Weeds on page 9.)

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

- If the biological control agents have become established at the release site
- If biological control agent populations are increasing or decreasing and how far they have spread from the initial release point
- If biological control agent populations are sufficiently abundant to allow for collection and redistribution
- If the biological control agents are having an impact on gorse and broom
- 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 the biocontrol agents established, while multiple years of monitoring may allow you to identify trends in 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.

Information Databases

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

Biological Control of Weeds: A World Catalogue of Agents and their Target Weeds (database)

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

EDDMapS

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

In addition, some states/provinces have county/district weed departments or employ weed biocontrol specialists, often affiliated with state/province departments of agriculture, county extension offices, or Animal and Plant Health Inspection Service Plant Protection and Quarantine (APHIS-PPQ) offices. Contact local entities for more information.

Monitoring Methods

There are three main components to measure in a gorse and broom monitoring program: biological control agent populations, gorse and broom populations, and the rest of the plant community (including nontarget plants). More detailed monitoring might also examine effects on other biotic community components (such as other insects, birds, mammals, etc.) or abiotic factors (such as erosion, soil chemistry, etc.). Only the three main monitoring components are discussed in this manual. While most established biocontrol agents attack either gorse or Scotch broom, *Bruchidius villosus* also attacks French broom. Because the monitoring methods described herein could apply to all three weed species, the generic "broom" is used throughout this monitoring section to encompass both Scotch and French broom.

Assessing biological control 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 (Tables 4-5, 4-6). Begin looking for biocontrol agents where they were first released, and then expand to the area around the release site.

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

A systematic monitoring approach is required to determine the changing densities of biocontrol agent populations. A systematic yet simplified gorse and broom biocontrol agent monitoring form can be found in Appendix III. This may be modified to meet the needs of each land manager by adding extra columns, descriptive classes, etc.

Assessing the status of gorse and broom and co-occurring plants

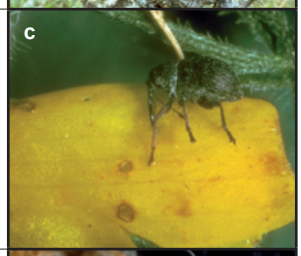
The ultimate goal of a gorse and broom management program is to permanently reduce the abundance of gorse and broom and enable the recovery of more desirable vegetation on the site. To determine the efficacy of biocontrol efforts, there must be monitoring of plant community attributes, such as target weed distribution and density. Ideally, monitoring begins before biological control efforts are started (pre-release) and 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.

Table 4-5. Life stages and damage to look for to determine establishment of gorse and broom biological control agents.

Biocontrol Agent	Life Stage	Where to Look	When to Look	Damage	Appearance
Bruchidius villosus Broom seed beetle	Adults	Flowers, foliage, on young seedpods	Spring to summer (Apr-Jun)	Do not cause direct damage; eggs laid into seedpod wall readily visible; attacked seeds are hollowed; tap plants on beat sheet to confirm adult presence	
	Larvae	Inside seedpods	Late spring-summer (May-Jul)	Feeding damage completely within seeds; press thumb nail through seed: milky-white juice exudes = *B. villosus* present, no juice = *B. villosus* absent	
Exapion fuscirostre Scotch broom seed weevil	Adults	Flowers, foliage, on young seedpods	Spring to summer (Apr-Jun)	Stems and flowers with small feeding holes or pits, but tap plants on beat sheet to confirm adult presence	
	Larvae	Inside seedpods	Late spring-early summer (May-Jul)	Feeding damage to external and internal seed tissue	
Exapion ulicis Gorse seed weevil	Adults	Flowers, foliage, on young seedpods	Early spring to summer (Mar-Apr)	Stems, flowers, leaves, seedpods with small feeding holes, but tap plants on beat sheet to confirm adult presence	
	Larvae	Inside seedpods	Late spring-early summer (Apr-May)	Feeding damage to external and internal seed tissue	
Leucoptera spartifoliella Scotch broom twig miner	Adults	On stems	Summer (Jun-Aug)	Adults do not cause any direct damage to Scotch broom; confirm adult presence by using light traps	
	Larvae	Inside stems	Summer-Spring (Aug-May)	Feeding mines inside and outside stems; attacked stems often dead above the point of damage	
Tetranychus lintearius Gorse spider mite	All stages	Terminal branches	Year-round (Aug-Sep best)	Extensive webbing covering mite colonies; attacked stems are stunted and have reduced flowering	

Photos and credits: a. *B. villosus* eggs laid onto seedpod wall; b. *B. villosus* larva feeding completely within the left seed; c. *E. fuscirostre* adult feeding marks on Scotch broom stem (bottom stem); d. *E. fuscirostre* larva feeding damage in/on seed; e. *E. ulicis* adult with feeding holes on gorse flower; f. *E. ulicis* larvae and feeding damage on seeds within gorse seedpod; g. *L. spartifoliella* adult; h. *L. spartifoliella* cocoon and larval mining on Scotch broom stem; i. *T. lintearius* webbing covering gorse stems with *T. lintearius* feeding damage. (a.,b. Jennifer Andreas, Washington State University Extension; c.,e.,g.,h. Eric Coombs, Oregon Department of Agriculture, bugwood.org; d. Thomas Shahan, Oregon Department of Agriculture; f. George Markin, USDA Forest Service, bugwood.org; i. Steven Conaway, Penn State University, bugwood.org)

Table 4-6. Life stages/damage to look for to determine establishment of gorse biological control agents confirmed present in Hawaii.

Biocontrol Agent	Life Stage	Where to Look	When to Look	Most Frequently Observed Damage	Appearance
Agonopterix umbellana Gorse soft shoot moth	Adults	Among foliage at center of shrub	Late summer-spring (Jul-Mar)	Adults typically do not cause any direct damage to gorse	
	Larvae	Stems and foliage	Spring (Apr-May)	Silken feeding tubes covering feeding damage to buds, shoots, spines	
Exapion ulicis Gorse seed weevil	Adults	Flowers, foliage, on young seedpods	Winter (Nov-Feb)	Stems, flowers, leaves, seedpods with small feeding holes, but tap plants on beat sheet to confirm adult presence	
	Larvae	Inside seedpods	Winter-spring (Feb-Mar)	Feeding damage to external and internal seed tissue	
Sericothrips staphylinus Gorse thrips	Adults/ Nymphs	On stems	Year-round (best spring-fall; Mar-Nov)	Attacked stem and spine tissue mottled and blotchy in appearance	
Tetranychus lintearius Gorse spider mite	All stages	Terminal branches	Year-round	Extensive webbing covering mite colonies; attacked stems are stunted and have reduced flowering	

Photos and credits: a. *A. umbellana* adult; b. *A. umbellana* silken feeding tubes and damage to gorse; c. *E. ulicis* adult with feeding holes on gorse flower; d. *E. ulicis* larvae and feeding damage on seeds within gorse seedpod; e. *S. staphylinus* feeding damage on gorse spines; f. *T. lintearius* webbing covering gorse stems with *T. lintearius* feeding damage. (a. Janet Graham; b. Fritzi Grevstad, Oregon State University; c. Eric Coombs, Oregon Department of Agriculture, bugwood.org; d.,e. George Markin, USDA Forest Service, bugwood.org; f. Steven Conaway, Penn State University, bugwood.org)

Qualitative (descriptive) vegetation monitoring

Qualitative monitoring uses subjective measurements to describe gorse and/or broom and the rest of the plant community at the management site. Examples include listing plant species occurring at the site, estimates of density, age and distribution classes, visual infestation mapping (as opposed to mapping with a GPS unit), and maintaining a series of photos from designated photo points over time.

Qualitative monitoring provides insight into the status or change of gorse and broom populations; however, its descriptive nature does not generally allow for detailed statistical analyses. Data obtained in qualitative monitoring may trigger more quantitative monitoring later. A qualitative vegetation monitoring example applicable to gorse and broom is included in Appendix IV.

Quantitative (numeric) vegetation monitoring

Quantitative monitoring measures changes in the gorse and/or broom population as well as the vegetative community as a whole before and after a biocontrol agent release using numbers and statistics. It may be as simple as counting the number of gorse and broom plants in a small sample area (Figure 4-15), or as complex as measuring gorse and broom plant height and width, flower and seed production, biomass, species diversity, and species cover. Quantitative sampling data can be more readily analyzed using statistical methods and demonstrate significant plant community changes. Pre- and post-release monitoring should follow the same protocol and be employed at the same time of year. Post-release assessments should be planned annually for at least three to five years after the initial biocontrol agent release (and ideally longer than that).

Figure 4-15. Measuring features of a gorse infestation. (Forest and Kim Starr, Starr Environmental, bugwood.org)

Gorse and broom are particularly problematic to monitor for many reasons. Their large size and longevity make monitoring individual plants or even patches difficult. The most effective approved and established biocontrol agents attack the seeds of gorse and broom. This does not hinder existing plants; it only reduces their reproductive output. While this may eventually reduce plant recruitment and population size, the existing extensive seedbank and the longevity of unattacked seeds (30+ years) mean seed reduction impacts might not be visible for 30 years or more. Still, diligently monitoring the presence and attack rates of the seed-feeding biocontrol agents for several years (in combination with qualitative gorse and broom population monitoring) will help researchers quantify the long-term impacts of gorse and broom biological control. See Appendix V for a quantitative Scotch broom seedpod monitoring protocol.

Assessing impacts on nontarget plants

To address possible nontarget attacks on species related to or just growing adjacent to gorse and broom, you must become familiar with the plant communities present at and around your release sites and be aware of species related to gorse and broom. Start by compiling a list of other species in the Fabaceae (pea family) that are present at the site. The Fabaceae species most closely related to gorse and broom include other exotic broom species (see Table 2-1 on page 31 and Table 2-2 on page 32 in addition to other exotic brooms in the genera *Cytisus* and *Genista*). The most closely related species that are native to North America are lupines in the genus *Lupinus*. There are over 200 species of lupine, most of which are native to North America. You may need to consult with local, state, or regional botanical experts, or review local herbarium records for guidance on areas where related nontarget plants might be growing and additional information on how you can identify them.

Care should be taken in the management of your gorse and broom biocontrol program to ensure that all closely related native species are identified and monitored along with gorse and broom. If lupines are found growing near your gorse or broom biocontrol site, wait until most of their flowers have finished blooming and their pods begin forming. Place mesh bags over individual lupine plants or inflorescences, taking care to stake the bag bottoms to the ground or around the stem. When the pods have dehisced, the mesh bags can be searched for *Bruchidius villosus* or *Exapion* spp. adults. Ensure that all seedpod fragments and any seeds recovered are thoroughly checked for feeding damage.

Please be aware that there are many “look-alike” native arthropods that feed on related native plants. Correct identification by biocontrol specialists is needed to confirm such records. If you observe approved biological control agents feeding on and/or developing on nontarget species, collect samples and take them to a biocontrol specialist in your area. Alternatively, you may send the specialist the site data and/or pictures so he or she can survey the site for nontarget impacts. Be sure not to ascribe any damage you observe on nontarget species to any specific biocontrol agent/species and thus bias the confirmation of attack and the identification of the species causing the attack.

Chapter 5: An Integrated Gorse and Scotch Broom Management Program

Introduction

The invasion curve (Figure 1-3, repeated here in Figure 5-1) shows that eradication of an invasive species such as gorse and Scotch broom becomes less likely and control costs increase as an invasive species spreads over time. Prevention is the most cost-effective solution, followed by eradication. If a species is not detected and removed early, intense and long-term control efforts will be unavoidable. Identifying where gorse or Scotch broom are on the invasion curve in a particular area is the first step to taking management action. Inventorying and mapping current gorse and broom populations, coupled with research efforts to predict where gorse and broom are most likely to move, enables land managers to concentrate resources in areas which are likely to be invaded, and then to treat individual plants and small populations of gorse and broom before it is too late to remove them.

Classical biological control has been applied to many invasive plant species, but biological control is not appropriate for areas on the left side (species absent [prevention] - small number of localized populations [eradication]) of the invasion curve. Biological control as a control method is best suited to gorse or Scotch broom populations in the later phases of the invasion curve (rapid increase in distribution and abundance [containment] - widespread and abundant throughout its potential range [asset based protection]).

There are several examples in which both single- and multiple-biocontrol agent introductions have successfully controlled the targeted weeds. Where ideally suited, biological control may help maintain gorse and Scotch broom densities below economically or ecologically significant levels, enabling land managers to live with these weeds; however, at many locations, established biological control agents appear to be having little effect on gorse and/or broom. Depending on the infestation, integration with other weed control methods or resorting to other control measures entirely may be required to attain gorse and Scotch broom management objectives.

A wide variety of successful weed control methods have been developed and may be useful for helping meet management goals for gorse and broom. The most successful, long-term gorse and Scotch broom management efforts have a number of common features, including:

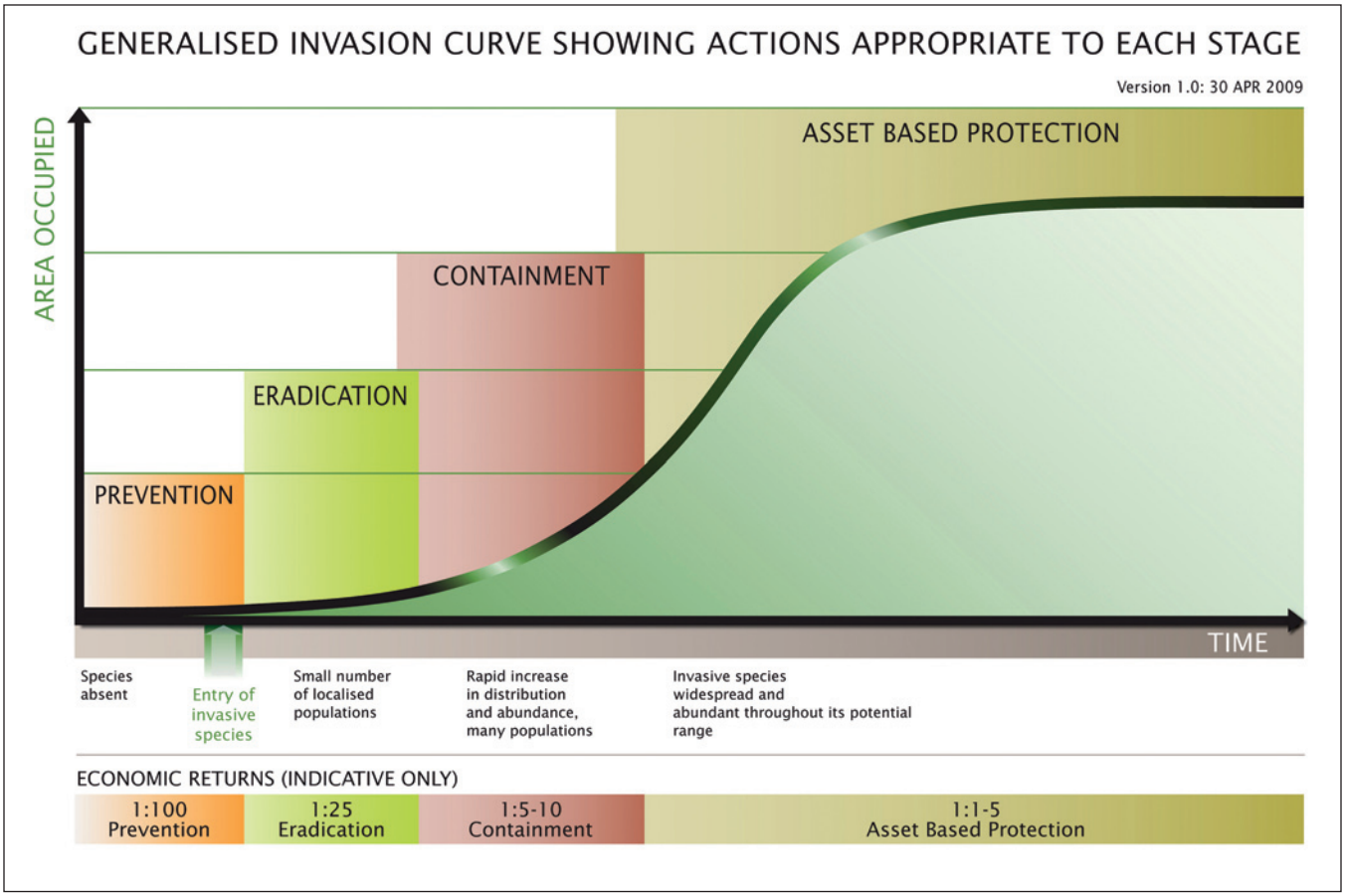


Figure 5-1. Generalized invasion curve showing actions appropriate to each stage. (© State of Victoria, Department of Economic Development, Jobs, Transport and Resources. Reproduced with permission.)

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

Integrated Pest Management (IPM) incorporates all efforts noted above, and addresses several aspects of land management, not just how to get rid of weed populations. Land managers or landowners engaged in IPM take the time to educate themselves and others about the threat invasive species pose to the land and how management may facilitate invasion. IPM requires land managers to regularly inventory and map the land they manage, identifying areas where the vegetation is not meeting their management objectives and identifying reasons

why. When a weed infestation is found, IPM dictates that land managers map and make plans to address it utilizing control methods most appropriate for their particular infestation and land use. After initiating control activities, IPM encourages land managers to monitor the site to determine if the control activity was successful in subsequent years. If re-treatment or additional treatments are necessary, these are applied in a timely manner with appropriate post-treatment monitoring to ensure that management objectives are being met.

Integrated Pest Management programs undertaken on a landscape level over many years can at times prove logistically difficult, expensive, and time-consuming. The concept of Cooperative Weed Management Areas (CWMA) was created in the western USA in order to erase jurisdictional boundaries as an impediment to weed control and make a landscape IPM approach to weed management more feasible and successful. CWMAs consist of federal, state and local land managers, as well as concerned private landowners, within a designated zone who join efforts against exotic plants, pooling and stretching limited resources and labor for managing invasive species and protecting/restoring habitat. Cooperation between neighboring CWMAs helps transfer knowledge and experience between heavily treated regions and places not yet as impacted by gorse or Scotch broom. Sharing successes and failures in gorse and Scotch broom management saves time and funding and reduces the incidence of negative impacts from management efforts, such as herbicide resistance. Numerous CWMAs exist throughout the western states of the USA and are excellent sources of information, experience, and resources for treating gorse and Scotch broom infestations using an IPM approach. These groups often hold local meetings that landowners can attend to gain access to local programs and information.

Components of Successful Integrated Weed Management Programs to Manage Gorse and Scotch Broom

Though each component of IPM is an important tool for managing gorse and Scotch broom, it is important to note that these components work best when used in a combined approach. Rather than applying only one tool per site (e.g., applying herbicides at one infestation, mowing at another, and using biological control at still another), the most effective IPM strategy is to employ as many tools as necessary at a single site in order to maximize the efficacy of each tool and ultimately reduce gorse and broom infestations. Education, inventorying/mapping, and prevention are important and applicable across all landscapes, whether or not gorse or Scotch broom are already present. When gorse or broom are established and control methods are warranted, long-term management success is greatly improved when control methods are identified according to infested habitat type, land use, ownership, and available resources and then integrated where appropriate. As described above, biological control is most appropriately used on large infestations where multiple years may be required before impacts are realized. During this time, chemical and physical control methods are best applied to smaller new or satellite populations where immediate eradication is warranted, and to the edges of large infestations to prevent further spread. Cultural control methods work to enhance the growth of more desirable vegetation and are best applied as complements to all other control methods.

The components of gorse and Scotch broom IPM are described individually below. Because the focus of this manual is the biological control of gorse and Scotch broom, the potential to integrate biocontrol with other weed control methods is described at the end of each control method's section.

Education and Outreach

Education and outreach activities increase public awareness of noxious weeds, the problems they cause, their distribution, and ways to manage them (Figure 5-2). Ideally, education and outreach activities also foster cooperation and collaboration across land ownership boundaries to facilitate the development of a landscape-level weed management response. Education efforts should be an important component of any weed management plan, regardless of the target weed or weed control method employed.

Gorse and Scotch broom education and outreach should focus on conveying to the public:

- the threats gorse and broom pose
- how to identify gorse and broom in different stages
- ways in which they can help in gorse and broom management

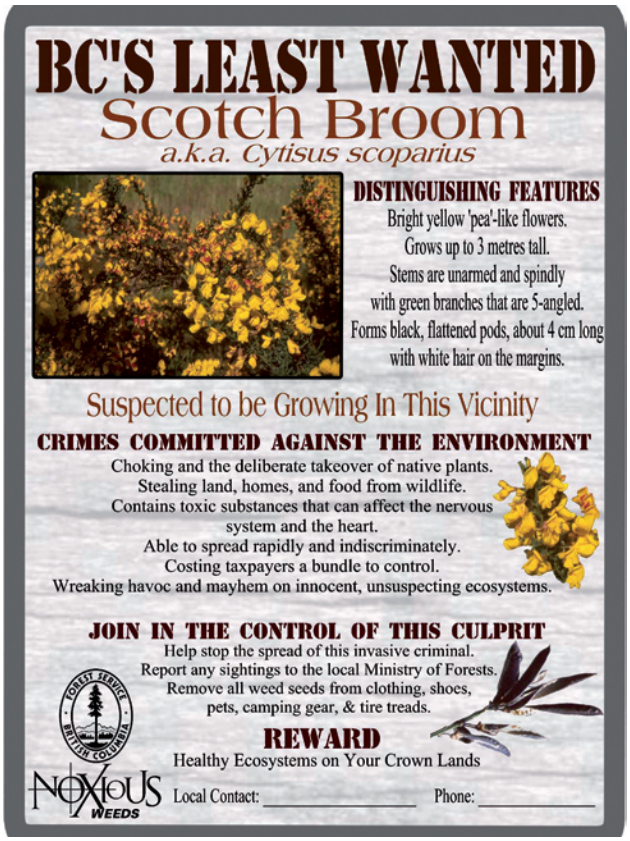


Figure 5-2. Scotch broom education brochure. (British Columbia Ministry of Forests, Lands, and Natural Resources)

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

Inventory and Mapping

Inventory and mapping are key elements of a successful weed management program. It is imperative to accurately characterize the size and extent of weed infestations before control activities are identified, prioritized, and implemented because the best treatment methods are often determined by the size and location of the infestation. Education and outreach activities that foster collaboration between adjacent landowners are particularly useful when developing landscape-level maps of weed infestations. Once land managers and landowners fully understand the threats gorse and Scotch broom pose to their land, they are often more willing to participate to ensure that their land is inventoried and accurate maps of gorse and broom are developed so the best control activities can be implemented.

Gorse and Scotch broom infestations are often mapped by foot, vehicle, or airplane using a global positioning system unit (GPS) and a geographical information system (GIS), though hard copy maps made by hand are suitable for some locations. For very large infestations, GoogleEarth can be a useful tool for providing birds-eye-view imagery that allows for visual delineation of broom/gorse patch boundaries; however, image quality and timing can make it difficult to make comparisons. An increasing number of free smartphone and tablet apps help make accurate, detailed, and versatile weed mapping available to anyone (e.g., the apps available from EDDMapS, see page 100 for more information). Inventory efforts should document the following for each infestation: location coordinates, boundaries, estimated density (number of plants of target weed per area, e.g. 10 m^2 or yd^2), land usage, treatment history, disturbance history (e.g., fire, flooding, grazing, logging), habitat type (coastal bluff, upland, shrubland, grassland, forest margin), and date. Photos of the infestation and a list of co-occurring species are also very useful. Documenting inventory and mapping efforts enables land managers to determine if all known gorse and Scotch broom infestations have been treated, and facilitates post-treatment monitoring. In turn, this allows land managers to judge the effectiveness of various treatment methods. See Chapter 4 for suggested techniques of monitoring infestations.

Prevention

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

Gorse and Scotch broom are spread by the movement of seeds, which are usually transported by contaminated sand/gravel, vehicles/equipment, ants, birds, humans, other animals, and waterways. Preventing the spread of gorse and Scotch broom requires cooperation among all landowners and land managers. In areas where gorse and broom are not yet present, it is important to ensure that possible invasion avenues are identified and management actions taken to reduce the risk of spread. This includes minimizing soil disturbances and regularly monitoring uninfested sites to confirm that they have remained uninfested.

Cultivation, soil erosion (especially following flooding events and prescribed or wild fire), road grading, recreational activities (e.g., riding dirt bikes or four wheelers), and overgrazing all weaken existing plant communities, decrease plant cover, and cause disturbance, conditions that favor gorse and Scotch broom establishment, spread, and persistence (Figure 5-3). Because such activities are also potential ways of spreading gorse and Scotch broom seeds, they should either be avoided or closely monitored in invasion-prone areas. Where grazing does occur, proper livestock management (such as strategic timing and stocking rates) will allow grazed vegetation to recover and competitive plants to increase which, in turn, will help prevent the establishment of gorse and Scotch broom. If possible, livestock should be kept off weed-infested land when they are most likely to spread viable seeds (e.g., after seed formation). If it is not possible to avoid driving vehicles and machinery (e.g., logging, construction, or rangeland fire-fighting equipment) through gorse and Scotch broom infestations, it is crucial that a thorough cleaning take place before equipment leaves the contaminated area.

Figure 5-3. Gorse covering an overgrazed hillside. (George Markin, U.S. Forest Service, bugwood.org)

Prevention and exclusion activities are typically paired with education efforts. Examples of exclusion efforts include weed-free forage programs, state and provincial seed laws, and mandatory equipment cleaning when leaving infested sites and before entering uninfested sites.

EDRR

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

Weed Control Activities

Biological Control

Biological control involves the use of living organisms, usually insects, mites, or pathogens, to control a weed infestation and regain the balance among coexisting plant species. Classical biological control focuses on the introduction of host specific natural enemies from the invasive weed's native range. This method of gorse and Scotch broom management is the most economical and suitable for larger infestations (tens to hundreds of acres). For small patches (less than 2 acres or 0.8 hectares) of new satellite (those growing outside of well-established) gorse and Scotch broom infestations, more aggressive control methods should be utilized (e.g. physical control or herbicides). Refer to Chapter 3 for detailed descriptions of the biological control agents currently approved for use on gorse and Scotch broom and Chapter 4 for how to implement a gorse and broom biological control program in your area.

Physical Treatment

Physical treatment utilizes pulling, cutting, or mowing to remove or disrupt the growth of weeds and is the oldest method of weed control. Physical methods have had variable success in controlling gorse and Scotch broom, depending on specific site and infestation characteristics. All physical control methods are labor-intensive and not suitable for the more rugged and inaccessible sites where both weeds have invaded. Due to the ability of gorse and Scotch broom to regenerate from severed roots and from how long-lived their seeds can be, all physical treatments require repeat monitoring and treatment. Integrating physical methods with other control methods may increase success (e.g., see cutting below). Physical control activities should be planned to minimize ground disturbance to reduce recruitment from the seedbank. Regardless of the physical method employed, it is imperative that all equipment be thoroughly cleaned following use to prevent the spread of gorse and Scotch broom seeds.

Pulling

Pulling is most appropriate in the EDRR stage of a gorse or Scotch broom infestation or on satellite populations occurring outside larger containment areas. Pulling can provide successful control of small infestations (under 1 acre or 0.4 ha) if applied persistently. It is especially effective in coarse-textured and moist soils so that the entire root system is removed. Small plants less than 3.2 feet (1 m) tall can be pulled by hand (Figure 5-4a), while larger plants are removed most effectively with the use of a weed wrench (Figure 5-4b,c). Weed wrenches are most effective on plants with a basal stem diameter of 0.5 inches (1.25 cm) or less, since pulling plants with a larger stem diameter can lead to considerable soil disturbance. If gorse or Scotch broom plants are densely branched, loppers or pruning tools can be used to remove the lower limbs before pulling. When gorse or Scotch broom plants have seedpods present, cut off and bag all seeding stems prior to pulling. Otherwise, the jarring action of pulling may dislodge and distribute seeds at the site. **All plant parts containing seeds should be securely bagged and taken to the trash or a transfer site to prevent possible gorse or Scotch broom seed dispersal from pulled material.**

When root sections of pulled plants remain in the soil, some may re-sprout new stems. Re-sprouting occurs less frequently when plants are pulled during times of moisture stress (typically July through September, depending on location). Pulling creates soil disturbance, which is ideal for the germination of gorse and Scotch broom seeds. While this may increase the gorse or Scotch broom problem, it can also reduce the gorse/broom seedbank more quickly and help lead to population decreases if germinating plants are regularly pulled. Caution should be used because pulling actions frequently damage more desirable species growing around gorse and Scotch broom, again favoring re-invasion by gorse, broom, or other weedy species. Re-seeding the open space resulting from gorse and Scotch broom removal with seeds of desirable vegetation can provide competition to decrease gorse and broom seedling germination and persistence.

Figure 5-4. Physical control with pulling: a. gorse seedlings suitable for hand pulling; b. weed wrench on gorse stem; c. large gorse plant being pulled with weed wrench. (a. John M. Randall, The Nature Conservancy, bugwood.org; b. Nancy Ness, Grays Harbor Noxious Weed Control Board; c. Snohomish County Noxious Weed Control Board)

Any site where pulling is utilized on gorse or Scotch broom should be monitored repeatedly for multiple years for stem re-sprouting and seedling germination, and should be re-treated as needed.

Due to the destructive nature of pulling, this control method is not compatible with biological control. Pulling is most appropriate for small infestations where immediate eradication is feasible, while biological control is more appropriate for much larger, established infestations. One way to successfully combine these two methods is to release biological control agents in a large, main infestation while employing pulling to remove individual plants and to control small, satellite patches arising outside of the main gorse or Scotch broom infestation.

Cutting

Individually cutting gorse or Scotch broom plants (Figure 5-5a) may reduce seed production and may, under some circumstances, result in plant death. However, cutting frequently results in stems re-sprouting from remaining stumps, which may make future physical removal challenging and must be repeated regularly. Cutting is most effective when done during times of moisture stress (typically July through September, depending on location) and when plants are cut just above or below ground level. Large, old plants are less likely to re-sprout after cutting during this time. Weed control can be increased if cutting is immediately followed by herbicide applications made to remaining stumps. When gorse or Scotch broom plants have seedpods present, cut off and bag all seeding stems. Otherwise, the jarring action of cutting and removing larger plant sections may dislodge and distribute seeds at the site. **All plant parts containing seeds should be securely bagged and taken to the trash or a transfer site to prevent possible gorse or Scotch broom seed dispersal from cut material.**

Due to the destructive nature of cutting and removing all aboveground growth of gorse and Scotch broom, this control method is not compatible with the biological control agents presently established in North America and Hawaii. Cutting is most appropriate for small infestations where follow-up treatments and eradication are feasible, while biological control is more appropriate for much larger, established infestations. One way to successfully combine these two methods is to release biological control agents in a large, main infestation while employing cutting to remove individual plants and to control small, satellite patches arising outside of the main gorse or Scotch broom infestation.

Mowing

Mowing gorse and Scotch broom infestations (Figure 5-5b,c) is typically not effective in the long term as mowing usually stimulates stem re-growth (and subsequent flowering), increases seed germination, and reduces competition from surrounding vegetation. Regular mowing throughout the year utilizes much of gorse and broom's stored root reserves, and over time decreases their root regenerative capacity and subsequent seed production. Frequent mowing of gorse and Scotch broom is not feasible at remote, rugged, or rangeland sites where these weeds have readily invaded, but it may provide control to gorse and broom along roadsides and rights-of-way. Alternatively, mowing can be used to reduce

Figure 5-5. Physical weed treatments: a. cutting a single-stemmed Scotch broom plant; b. mowing Scotch broom; c. gorse plants following mowing. (a. Jennifer Andreas, Washington State University Extension; b. Ray Willard, Washington State Department of Transportation; c. Nancy Ness, Grays Harbor Noxious Weed Control Board)

nontarget plant cover and litter prior to herbicide applications. When mowing is used as a form of gorse or Scotch broom control, it is important that treatments occur before seed maturation (May-September for gorse, July-September for Scotch broom) because mowing can facilitate seed dispersal.

The destructive nature of mowing is damaging to the seed beetles *Bruchidius villosus*, *Exapion fuscirostre*, and *E. ulicis* as well as the Scotch broom twig miner *Leucoptera spartifoliella* and the gorse soft shoot moth *Agonopterix umbellana* (established only in Hawaii). Mowing may actually help distribute the gorse spider mite *Tetranychus lintearius*, and this biocontrol agent can re-establish on gorse plants recovering from mowing efforts. Mowing is likely damaging to the gorse thrips *Sericothrips staphylinus*, though it may aid in thrips dispersal in some situations.

Cultural Practices

Cultural methods of weed control (including flooding, burning, grazing, and seeding with competitive species) can enhance the growth of desired vegetation, which may slow the invasion of noxious weeds onto a site. For gorse and Scotch broom management, flooding is typically not applicable due to the non-wetland locations gorse and broom frequently infest. Regardless of which method is used, all cultural control techniques are more successful when combined with other control methods, such as pulling or cutting gorse or Scotch broom prior to re-seeding.

Burning

Burning has yielded mixed results when used as a form of controlling gorse and Scotch broom (Figure 5-6a). Both species contain flammable oils, and older individuals have large amounts of dead growth/litter at their centers. The combination of these traits makes both gorse and Scotch broom extreme fire hazards. While the aboveground biomass of gorse and broom burns readily in very hot fires, some plants recover and re-sprout from their roots post-fire. When fires burn sufficiently long or hot enough to remove aboveground biomass, the bare soil left from fire events is ideal for sprouting new gorse and Scotch broom plants (Figure 5-6b).

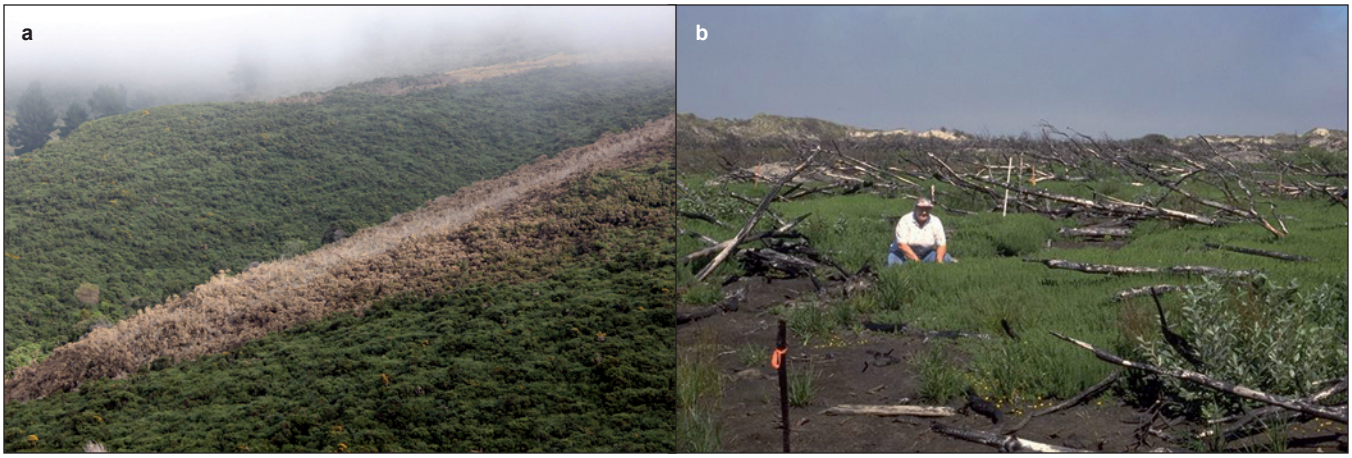


Figure 5-6. Fire used for the control of gorse: a. in a thick hillside infestation; b. resulting in a flush of new gorse seedlings. (a. Whitney Cranshaw, bugwood.org; b. Eric Coombs, Oregon Department of Agriculture, bugwood.org)

While fire sometimes exacerbates the problem, it has been used intentionally in some locations to burn off plant litter in order to make re-sprouting gorse and Scotch broom easier to see when applying herbicides and to help reduce the seedbank by causing mass germination. When prescribed fire kills off competing vegetation, it will only increase the gorse or Scotch broom problem, even with subsequent herbicide applications. Revegetation with desired vegetation is recommended wherever fire is utilized to aid in gorse and Scotch broom chemical control.

The destructive nature of fire makes it incompatible with all biological control agents currently established on gorse or Scotch broom in North America and Hawaii.

Grazing

Both gorse and Scotch broom are considered largely unpalatable to cattle. Scotch broom may be mildly toxic to cattle and sheep. Domestic goats and sheep have been used for both gorse and broom control (Figure 5-7) with varying success. Gorse is generally more readily fed upon when leaves are present and stems are young and soft. Once leaves give way to hardened spines, grazing is less effective. Some studies have found goats eradicate even old growth of gorse and Scotch broom, and that sheep help maintain this control. Other studies have found no control with either grazing species, even at high stocking rates. Overgrazing infested pastures reduces gorse and Scotch broom competition and increases soil disturbance, enhancing the establishment and spread of gorse and broom. Consequently, utilizing livestock for gorse and Scotch broom management must be done with caution, close observation, and only under the right circumstances. Where it is feasible to utilize livestock to manage gorse and Scotch broom, it's important that the animals do not graze during seed set, as this can assist in the distribution of gorse and broom seeds.

Figure 5-7. Cultural control method: goats grazing Scotch broom. (San Juan County Noxious Weed Control Board)

The combination of grazing with biological control is largely unknown, though it can be assumed that feeding on gorse and Scotch broom stems, leaves, and seedpods infested with currently established biocontrol agents would destroy populations of the insects and mites.

Seeding competitive species

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

Both gorse and Scotch broom are very sensitive to competition for light and resources during all growth stages. Planting rapidly growing grasses and overstory trees have been proven effective at some sites where the competitive grasses impede gorse and broom spread, and the trees provide shade detrimental to gorse and Scotch broom. The most suitable plant species to use for competition with gorse and Scotch broom depends on habitat, site conditions, climate, management goals, and future land use. Ideally, planted seeds should contain a mix of species, some of which should be quick to germinate and others to provide more long-term competition to gorse and Scotch broom seedlings. Utilizing ecologically equivalent species (those with root and growth patterns similar to gorse and broom) may provide the best competition. Because both gorse and Scotch broom are nitrogen-fixing species, re-seeding with other, more desirable nitrogen-fixing species (e.g. lupines or clovers) can provide significant competition for gorse and broom seedlings growing in sandy and/or low nutrient soil. Inventorying nearby sites that are uninvaded by gorse and Scotch broom may provide insight into the best replacement species. Consult your local county extension educator or Natural Resource Conservation Service (NRCS) representative for additional help in determining the best alternatives in your

area. Further suggestions for ecoregions throughout the United States may be found on the Native Seed Network website (please see Chapter 5 References for the URL). Likewise, the "links" section of the USDA PLANTS website offers numerous revegetation guideline manuals specific to different regions of both the United States and Canada. This site also provides access to a program and fact sheets that utilize soil, plant, and climate data to select plant species that are site-specifically adapted, suitable for the selected practice, and appropriate for the goals and objectives of the revegetation project.

Control of gorse and Scotch broom prior to seeding more desirable species is important because established gorse and broom plants are highly competitive. Seeding of competitors should take place immediately following exposure of soil to maximize their competitive abilities (Figure 5-8). For example, seeding should occur in bare soil following burning or after young gorse or broom plants have been pulled or killed with herbicides. Some herbicides have residual activity which could injure or kill seedlings of some desirable plant species, so care should be taken if seeding/transplanting is done on herbicide-treated sites. Because high populations of rodents can reduce the success of re-seeding, erecting a raptor perch/pole may discourage rodent habitation and help ensure seeded species successfully germinate and establish.

Scotch broom, in particular, has been shown to have negative effects on revegetation efforts long after it has been removed. This has been attributed to allelopathy and increased soil nitrogen levels, as well as to negative impacts on ectomycorrhizal fungi. Applying activated carbon and sucrose to soils previously

Figure 5-8. Cultural control method: revegetation efforts following soil disturbance (Lassen Volcanic National Park)

invaded by Scotch broom may help alleviate the allelopathic and nitrogen effects, although these results are still experimental and in need of further confirmation.

Incorporating biocontrol agents with re-seeding has not been studied explicitly for gorse or Scotch broom, but could be difficult, primarily because the methods used to establish a productive stand of competitive species are not always compatible with the establishment and survival of biological control agents. Any method used to initially reduce gorse or broom stems and foliage to promote the growth of competitive species would hinder the survival of all gorse and broom biocontrol agents currently established in North America and Hawaii. Consequently, many successful revegetation programs establish competitive plant species first, using biological control agents after the seeded species have become established and gorse or Scotch broom begin to reappear. Alternatively, revegetation projects can target only a small portion of the infestation annually, leaving a reservoir of gorse or Scotch broom plants to support biocontrol agent populations. In some settings, it may be the biological control agents that open up the competing plant canopy, allowing for subsequent re-seeding to occur.

Chemical Control

Many herbicides are registered for use on gorse and Scotch broom growing in a variety of locations. Herbicides are most effective when applied to small infestations, including newly established populations and recently established satellite patches arising from nearby older, larger gorse and broom infestations. If utilized appropriately, herbicides are also useful on the leading edge of large, advancing gorse and Scotch broom infestations.

Herbicides may be too costly to be of practical use in treating extensive infestations of gorse and broom and, similar to physical and cultural control methods, are also impractical in hard-to-access and environmentally sensitive areas. Repeated herbicide applications are often required over time as gorse and Scotch broom stems can re-sprout from their root system if not completely killed (Figure 5-9a), and new gorse and Scotch broom plants can germinate from the seedbank. Potential nontarget damage to associated vegetation must also be considered when using herbicides. For these reasons, herbicides are best used as part of a larger, integrated weed management program that employs other weed control methods in areas where herbicides are less likely to be cost effective or the most appropriate control choice.

Herbicides are generally applied in one of two ways: spot or broadcast applications. Spot treatments are used for individual gorse and Scotch broom plants or small patches. In spot applications, herbicide is applied to the foliage or stems of target plants only, thus reducing nontarget effects. Broadcast treatments are when herbicides are applied to an entire weed infestation rather than to single plants. Broadcast treatments should be used with caution as many herbicides may also impact plants that land managers may want to retain. If a broadcast treatment kills all plants in a treated area, the resulting bare soil may allow gorse and Scotch broom to reinvade from the seedbank, creating a denser infestation than was there originally. Selective herbicides are those that target selected species

(e.g., broadleaf forbs vs. grasses) while leaving other species virtually unharmed. The herbicide label should always be referenced to help determine the chance of nontarget species damage. Utilizing selective herbicides in spot treatments helps reduce the nontarget impacts of herbicide applications, and is the recommended approach for treating gorse and Scotch broom infestations with herbicides. Some of the best results (with minimal nontarget effects) have been achieved by applying selective herbicides to stumps of gorse or Scotch broom immediately after the stems are cut (Figure 5-9b).

The optimal timing for herbicide application depends on site-specific variables including the stage of growth of the gorse or Scotch broom plants at the time of application and the climatic conditions present at the site. Most herbicides used for foliar treatments have the highest efficacy when gorse and broom are rapidly growing (from spring through early fall). Cut stump herbicide treatments can be useful most times of the year, but are particularly effective from late summer through the dormant season, provided the herbicides are applied immediately after gorse and broom stems are cut. Most herbicides currently registered for use on gorse and Scotch broom work best when applied with a surfactant. For both species, repeat applications and careful attention to the timing of application are typically required.

Some of the most widely used herbicides to combat gorse and Scotch broom in North America include:

Broadleaf selective herbicides:

- **Aminocyclopyrachlor + metsulfuron methyl.** Aminocyclopyrachlor is a relatively new broadleaf selective herbicide which is currently being packaged for sale with metsulfuron methyl in uncultivated non-agricultural land, industrial sites, and natural areas. Aminocyclopyrachlor + metsulfuron should be applied to foliage of actively growing gorse and

Figure 5-9. Chemical control: a. re-growth and missed growth in Scotch broom infestation treated with herbicides; b. Scotch broom stump treated with herbicide and blue dye immediately after cutting. (a.,b. Jennifer Andreas, Washington State University Extension)

Scotch broom from early bloom to post bloom. It should be applied with a surfactant to improve herbicide uptake. This product has the potential to be mobile in the soil and may demonstrate residual activity several years after application, which will reduce re-growth from remaining gorse roots or seedlings. **Low rates of aminocyclopyrachlor can kill nontarget tree and shrub species, so do not apply within the dripline of trees or shrubs, to a distance equal to the height of the species of concern. Aminocyclopyrachlor may also injure a number of desirable grass species depending on the product rate.**

- **Dicamba.** Dicamba should be applied to foliage of actively growing gorse from spring to early fall. It should be applied with a surfactant to improve herbicide uptake. Dicamba used alone is usually not the most effective herbicide for the control of gorse because although it kills aboveground growth, plants re-sprout from the roots, and repeated applications are required. There is slight residual activity of dicamba that may give short-term control of germinating gorse seeds. Dicamba is often mixed with other herbicides (such as picloram or diflufenzopyr) to improve efficacy on many perennial weed species. When mixed with diflufenzopyr, dicamba is accumulated in the plant and is more effective on the root system, although data are lacking for this combination on gorse or Scotch broom. **Dicamba will likely kill desirable broadleaf species, including legumes.** Alone, it does not kill grasses, sedges, or other monocots, although combination treatments may cause injury to nontarget vegetation.
- **Metsulfuron.** Metsulfuron should be applied to foliage of actively growing gorse from early bloom to post bloom. Foliar treatments should be applied with a surfactant to improve herbicide uptake. Metsulfuron has a soil residual activity, which will reduce re-growth from remaining gorse roots or seedlings. Metsulfuron is not as active on Scotch broom as on gorse. **While some formulations may be broadleaf-specific, there are restrictions on its use on some grasses, and it can kill desirable legume species.**
- **Picloram.** Picloram should be applied to foliage of actively growing gorse and Scotch broom from early bloom to post bloom. It should be applied with a surfactant to improve herbicide uptake. Picloram has a long soil residual, which will reduce re-growth from remaining gorse and broom roots or seedlings for a few years following application. **Picloram is mostly safe on grasses (young monocots may be affected), but it can kill many desirable legume and other broadleaf species.** Picloram is less useful in hot, sunny conditions or in sandy soil because it is degraded by sunlight and can leach below the root zone in sandy soils.
- **Triclopyr amine.** Triclopyr amine should be applied to foliage of actively growing gorse and Scotch broom from early bloom to post bloom. It should be applied with a surfactant to improve herbicide uptake. Cut stump treatments with triclopyr ester can be made anytime the ground is not frozen, but are best used in late summer to early fall immediately after

stems are cut. Cut stump treatments should be applied as a mixture with a crop oil or methylated seed oil concentrate as directed by the product label. **Triclopyr is a broadleaf herbicide so it will not harm grasses or other monocots, but it can kill many desirable legume and other broadleaf species.** Triclopyr is often combined with 2,4-D as a foliar treatment used on actively growing gorse and Scotch broom; this mixture should be agitated continuously to prevent herbicide separation in the spray tank. **2,4-D is a broadleaf herbicide** with a short soil residual. 2,4-D used alone generally does not provide full control, as treated plants often re-sprout from the roots and from the soil seedbank. Consequently, 2,4-D is best used on gorse and broom when combined with other herbicides. Triclopyr is sometimes combined in a premix with aminopyralid as a foliar treatment for Scotch broom. **Aminopyralid is a broadleaf herbicide with a moderate soil residual period** that will kill germinating seedlings and reduce re-growth from roots of treated Scotch broom plants for several months after application.

Non-selective herbicides:

- **Glyphosate.** Glyphosate should be applied to foliage of actively growing gorse and Scotch broom from spring to early fall. If an aquatically labelled glyphosate formulation is used, a surfactant should be mixed with spray solution prior to application to improve herbicide uptake. Glyphosate can also be used for cut stump treatments, which are most effective in late summer, early fall, or the dormant season; it should be applied immediately after stems are cut. Glyphosate has no residual activity in the soil, and repeated applications are often required. **It is a non-selective herbicide and will create bare ground. It should only be used in spot treatments and in situations where loss of nontarget vegetation is acceptable.** Glyphosate use should be accompanied by revegetation of desirable species.
- **Imazapyr.** Imazapyr should be applied to foliage of actively growing Scotch broom plants; best results are achieved in late summer or early fall. Imazapyr can also be used for cut stump treatments on Scotch broom in late summer, early fall, or the dormant season; it should be applied immediately after stems are cut. It should be applied with a surfactant to improve herbicide uptake. **It is a non-selective herbicide and should only be used in spot treatments and in situations where loss of nontarget vegetation is acceptable.** It is soil-active with moderate residual activity, so it may persist to kill germinating seedlings; **however, it can injure other plants rooted in, and downhill of, the treated areas and may persist to interfere with revegetation efforts.**

Use Herbicides Safely!

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

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

Bathe or shower after each herbicide application.

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

Follow all storage and disposal instructions on the herbicide label.

When herbicides are used for the control of gorse or Scotch broom, it is important that the applicator adheres to individual jurisdiction's legislation and to all label instructions to ensure the usage, surfactant requirement, application rate, application timing and location/site of herbicide application fall within label recommendations. Not all herbicides are registered for use on these plants in all settings (including on or near water), or for use in each US state or in Canada. Some herbicides are restricted use and can only be applied by a certified and licensed applicator, and then only under specific conditions. Herbicide effectiveness can vary depending upon geographic location, climatic conditions, and rate of application. Please consult your local weed control authority, county agricultural extension educator, forest invasive species coordinator, or invasive plant specialist to learn which herbicides work best for gorse and broom control and when to apply them in your area.

If treated areas are to be grazed by livestock, consult the herbicide label for any grazing restrictions, including re-entry periods, that might be applicable.

Heavy herbicide use will reduce the gorse and Scotch broom stems and leaves on which currently established biocontrol agents rely, thus hindering establishment of these species. In order to guarantee that biological control agent populations remain viable as the gorse or Scotch broom infestations are reduced, plants should either be sprayed late in the growing season when adults of the seed beetles (*Bruchidius villosus*, *Exapion fuscirostre*, and *E. ulicis*) are overwintering in soil and plant litter, or some of the infested area should not be treated with herbicides to serve as "refuges" for biological control agents.

The advantages and disadvantages of the most gorse and broom control methods are summarized in Table 5-1.

Table 5-1. Comparison of gorse and Scotch broom management options

Control Method	Advantage	Disadvantage	Compatibility with Biocontrol
Biological Control	Sustainable – biocontrol agents generally do not have to be reintroduced once established	Measurable changes in weed densities may take many years (eradication is not the goal)	**Gorse:** high populations of *Tetranychus lintearius* reduce food available for *Exapion ulicis*. Currently low *T. lintearius* populations likely make this impact minimal. In Hawaii, *Agonopterix umbellana* temporarily reduces food available to all established biocontrol agents, however plants recover when the moths are no longer active. High populations of *Sericothrips staphylinus* reduce food available for other species; however populations are currently too low for impact. **Scotch broom:** *Leucoptera spartifoliella* has little if any impact on *Bruchidius villosus* and *Exapion fuscirostre*. *B. villosus* appears to outcompete *E. fuscirostre*.
	Most economical option for large infestations	Some risk of adverse effects on nontarget plants	
	Public acceptance is generally higher than with other weed control methods	Permanent; cannot be undone	
	Selective	Not successful in all situations	
Physical Control (Pulling & Cutting)	Reduces seed production	Expensive and time consuming	Applicable only to very small infestations where biocontrol is not recommended. Pulling and cutting are not directly compatible with any biocontrol agent; however, biocontrol can be applied to large, main infestations while pulling and cutting can be used on surrounding small, satellite populations.
	Useful for small infestations that must be quickly eradicated	Must be repeated regularly to prevent re-establishment from seedbank or plants re-growing from root sections	
Physical Control (Mowing)	Repeated mowing may reduce seed production, and reducing photosynthesis impedes root carbohydrate storage essential for plant persistence and vigor	May spread gorse and broom if done during flowering or seeding; or lead to compensatory growth if done infrequently	Not compatible with *B. villosus*, *E. fuscirostre*, *E. ulicis*, *L. spartifoliella*, or *A. umbellana* (Hawaii only). Mowing likely aids in the dispersal of *T. lintearius*. Unknown if mowing hinders or aids dispersal of *S. staphylinus* (Hawaii only).
		Expensive and time consuming; requires proper timing and equipment	
Cultural Control (Flooding)	Not recommended for gorse or Scotch broom management		
Cultural Control (Burning)	May kill gorse or broom if done repeatedly and/or the right conditions	Expensive and time consuming; requires proper timing and equipment	Incompatible with all biocontrol agents established on gorse or Scotch broom in North America or Hawaii
	Causes flush of gorse and broom seed germination, helping reduce seedbank	Causes environmental and health hazards; especially problematic due to high flammable oil content in gorse/broom foliage	
		May make infestations worse due to flush of gorse and broom seed germination	
	Removes plant litter, making re-seeding or herbicide treatments more effective	Nonselective; can exacerbate the problem by reducing competing vegetation	

Table 5-1 (continued). Comparison of gorse and Scotch broom management options

Control Method	Advantage	Disadvantage	Compatibility with Biocontrol
Cultural Control (Grazing)	Allows use of the land even with heavy gorse and broom infestations	Cannot be used in many natural areas such as national parks and wilderness areas	Compatibility with biocontrol largely unknown. Livestock would likely wish to avoid gorse plants infested with the mite *T. lintearius*. Grazing stems and seedpods infested with all other established biocontrol species would destroy the insects.
		Nonselective; can exacerbate the problem	
	Can be used (under the right conditions) in combination with biological or chemical control methods	Can be expensive	
		Kills only above-ground growth; gorse and broom can recover rapidly post-grazing	
Cultural Control (Re-seeding)	Can be used to restore native or more desirable species	Expensive for large areas; requires regular maintenance initially	Compatible if biocontrol agents are introduced after competitive species are established. Also compatible if re-seeding is done only on small sections of the infestation annually, leaving gorse and broom "refuges" for the biocontrol agents. In some settings, it is biocontrol that may make re-seeding feasible.
	Can be self-perpetuating	May be ineffective if existing gorse and Scotch broom stand is dense	
Chemical Control	Fast acting	Expensive for large areas; repeat applications and monitoring often required	Herbicides are applicable to small infestations, which are typically unsuitable for biocontrol. Compatible when using biocontrol on a main infestation and herbicides on surrounding small, satellite infestations. Somewhat compatible if herbicides are applied late in the growing season when most biocontrol species are inactive and/or overwintering away from host plants.
	Successful for reducing gorse and broom densities in some settings, especially in combination with other control methods	May harm existing desirable vegetation, or impede revegetation efforts	
	If applied correctly and repeatedly, has the potential to eradicate some populations of gorse and broom	Public resistance to chemical controls	
	Useful along transportation corridors (roads, trails, occasionally waterways)	Regulations or policies may prohibit use in some areas	

Glossary

abdomen	The last of the three insect body regions; usually containing the digestive and reproductive organs
adventive	Species that arrived in the geographical area from elsewhere by any means
alternate	Where leaves appear singly at stem nodes, on alternate sides of the stem
annual	A plant that sprouts, flowers, and dies all in the same year
antenna (pl. antennae)	In arthropods, one of a pair of appendages on the head, normally many jointed and of sensory function
app (application)	A self-contained program or piece of software designed to fulfill a particular purpose; an application, especially as downloaded by a user to a mobile device
biennial	A plant that flowers and dies between its first and second years and does not flower in its first year
biological control	The reduction in the abundance of a pest through intentional use of its natural enemies (predators, parasitoids, and pathogens)
bolting	Plant stage at which the flower stalk begins to grow
caterpillar	The larval stage of a moth or butterfly
chrysalis	The pupal stage of a moth or butterfly
cocoon	A silk case that moth or butterfly larvae spin to contain the chrysalis
community	A naturally-occurring group of different species of organisms that live together and interact as a more or less self-contained ‘unit’
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
coordinates	A set of numbers used to specify a location
deciduous	Plant that sheds its leaves annually
dehisce	When seedpods dry out at maturity and burst open to scatter seeds
density	Number of individuals per unit area
dicot	Plant with two seed leaves upon germination, including most common flowering species, excluding grasses, sedges, cattails, lilies and orchids

dissemination	Dispersal. Can be applied to seeds or insects
emergence (insect)	Act of adult insect leaving the pupal exoskeleton, or leaving winter or summer dormancy
eradicate	To get rid of something completely, as in eliminate a weed population
erect	Grows upright and vertical as opposed to prostrate (spreading on the ground)
evergreen	A plant that retains green leaves (or green photosynthesizing parts) throughout the year
exoskeleton	Hard, external skeleton of the body of arthropods, including insects and mites
exotic	Originating in a distant foreign country; not native
field insectary	An area where host plants or animals are abundant and biological control agents are released and propagated with or without additional human manipulation
forb	Herbaceous plant (does not have solid woody stems)
gall	A plant tumor; a localized proliferation of abnormal plant tissue that is induced by an insect, nematode, fungus or other organism and usually exhibits a characteristic shape and color; gall-causing insects and mites usually live and feed within the gall
genus (pl. genera)	A taxonomic category ranking below family and above species and consisting of a group of species exhibiting similar characteristics. The genus name is followed by a Latin adjective or epithet to form the name of a species
GPS	Global Positioning System; a space-based navigational system providing location and time information by using four or more satellites
habit	The form or structure in which a plant grows (examples include shrubby, dwarf, and tree)
head	Insect body region with the mouthparts, antennae, and eyes
head capsule	Hardened covering of the head of an immature insect. They are especially prominent on larvae of some beetles and moths and noticeably reduced on larvae of many flies and wasps.
herbivory	Feeding on plants
host	The plant or animal on which an organism feeds; the organism utilized by a parasitoid; a plant or animal susceptible to attack by a pathogen
host specificity	The highly-evolved, often obligatory association between an insect and its host (i.e. 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)
instar	The phase of an arthropod's nymphal or larval development between molts
invasive	Tending to spread prolifically and undesirably or harmfully
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)
leaf axils	Where a leaf connects to the stem of a plant

leaflets	Leaf-like part of a compound leaf. Though it resembles an entire leaf, a leaflet is not borne on a main plant stem or branch as a leaf is, but rather on a branch of the leaf
legume	A plant in the family Fabaceae (pea family or Leguminosae), or the fruit or seed of such a plant
litter	Dead plant material, such as leaves, bark, needles, and twigs, that has fallen to the ground
margin (of leaf)	The edge of a leaf. Margins typically fall within a handful of categories and are useful in plant identification
membranous	Thin and transparent
molting	Process of arthropod development that involves shedding its exoskeleton and producing another as an arthropod grows
monocot	Plant with only one seed leaf upon germination, including grasses, sedges, cattails, lilies, and orchids
monoculture	An area vegetated by a single plant species
NAD 83	North American Datum, the official datum used for the UTM geographic coordinate system in North America
native	Of indigenous origin
node	Part of the stem of a plant from which a leaf, branch, or root grows
nontarget effect	When control efforts affect a species other than the species they were enacted to control (can be positive or negative)
noxious weed	A weed whose control is mandated, and whose movement is regulated by federal, state, provincial, or county law
nymph	Immature form of invertebrates, including mites and insects that undergo incomplete metamorphosis. Resembles adults
oviposit	To lay or deposit eggs
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
photosynthesis	Process used by plants and other organisms to convert light energy, normally from the sun, into chemical energy that can be later released to fuel the organisms' activities
plant cover	The portion of the vegetative canopy in a fixed area attributable to an individual or a single plant species
pupa (pl. pupae; v. pupate)	Non-feeding, inactive stage between larva and adult for an insect with complete metamorphosis
qualitative	Measurement of descriptive elements (e.g. age class, distribution)
quantitative	Measurement of quantity; the number or amount (e.g. seeds per capitula)
root crown	Part of a root system from which a stem arises; where a plant's stem meets the roots
scarification	Cutting the seed coat using abrasion, thermal stress, or chemicals to encourage germination

senescence	Final stage in a plant's life cycle
species	A fundamental category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding
surfactant	An additive often applied with an herbicide mix to help bring the herbicide into closer contact with the leaf surface in order to aid absorption
synchrony	Occurring at the same time (e.g. plant flowering and insect oviposition)
taxonomy	The classification of organisms in an ordered system that indicates natural relationships. The science, laws, or principles of classification; systematics
thorax	Body region of an insect behind the head and abdomen, bearing the legs and wings
toothed	Leaf margin that is regularly incised, similar to a saw
transect	A straight line of varying length along which plants are periodically sampled individually or in quadrants
UTM	Universal Transverse Mercator, a grid-based geographic coordinate system
viability	The proportion of propagules (e.g. seeds) that are alive and can germinate
weed	A plant growing where it is not wanted
WGS 84	The World Geodetic System, a datum for latitude/longitude geographic coordinate systems

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Chapter 1: Introduction

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Appendix I. Troubleshooting Guide: When Things Go Wrong

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

Problem	Probable Cause	Solution
Biological control agents unhealthy or dead when received	Physical damage to biocontrol agents in transport	Provide adequate packing material to minimize movement of containers and ice packs.
	Drowning	Do not put water in containers during transport; prevent accumulation of excess moisture; too much plant material causes condensation.
	Excess or prolonged heat or cold	Keep containers cool at all times; use coolers and ice packs; avoid exposure to direct sunlight while in transit.
	Starvation	Put gorse and Scotch broom foliage (no flowers, seeds, or roots) in containers.
	Release delay	Transport/ship biocontrol agents immediately after collection/sorting.
		Release biocontrol agents at new site immediately upon arrival/receipt.
	Parasitism and/or disease	Check source biocontrol agents. Ensure the insect population is disease-free when collecting or receiving shipment.
Reproductive problems	Biocontrol agents past reproductive stage	Collect at peak activity (i.e. insects are mating and ovipositing).
	Sex ratio: not enough males or females	Collect at peak activity; observe mating among target biocontrol agents before collecting; males often emerge earlier than females.
	Biocontrol agents not synchronized with the gorse and broom growth stage	Biological control agents require the weed to be at specific growth stage for optimal oviposition; collect biocontrol agents from sites with plants in similar stages.
Few biological control agents collected	Collection at wrong time	Refer to Tables 4-3, 4-4 for collection time and technique.
	Collection technique	Biological control agents can be killed/damaged during sweeping or aspirating so sweep lightly; avoid debris.
	Conditions at time of collection wrong	Refer to the Chapter 4 section “Collecting Gorse and Broom Biological Control Agents” for guidelines on desirable weather conditions.
	Population insufficient	Only collect from well-established populations.
Biological agents not found after release	Site is unsuitable or too small	Refer to the Chapter 4 section “Selecting Biological Control Agent Release Sites.”
	Not enough biocontrol agents released	Release at 100-200 adults of the gorse and broom seed beetles, 50-100 *L. spartifoliella*, 200-300 *S. staphylinus*; transfer as many stems as is possible infested with *T. lintearius*, *A. umbellana*.
	Pesticide use/mowing in area	Select sites where land use and management practices do not interfere with biological control agent life cycles.
	Released on wrong species	Ensure gorse and Scotch broom are targeted, and the correct biocontrol agent is used.
	Released at wrong time	Release only during the correct plant stage and in the cool hours of the day. Refer to Tables 4-3, 4-4 for guidelines.
	Insufficient time has passed since release	Populations of some biocontrol agents take two or more years to reach detectable levels
	Biocontrol agents not well adapted to conditions	Release field-collected biocontrol agents from local sources wherever possible rather than greenhouse-reared adults or insects collected from distant locations.
	Ants or other predators preyed upon biocontrol agents	Release only at sites with no obvious ant mounds or high insect predator populations (e.g. mice, voles, spiders).
Cannot locate release site	Location marker not obvious	Use bright-colored wooden, metal, or plastic stake.
	Site destroyed	Communicate with all direct and neighboring land users.
	Map poorly/incorrectly drawn	Check map; redraw with more detail or add landmarks; GPS.

Appendix II. Sample Biological Control Agent Release Form

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

Biocontrol Agent:_____ **# Released:**_____

Target Weed:_____ **Date Collected:**____/____/____
(mm dd yy)

Source of Biocontrol Agents:_____

Biocontrol Agent Life Stage (circle all that apply): Eggs Larvae/Nymphs Pupae Adults

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

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

UTM: UTM Datum Zone_____ UTM Year_____ UTM Easting: _____ UTM Northing: _____

ENVIRONMENT

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

Weather (circle): Clear Ptly Cloudy Cloudy Rain Snow **Release Time:**_____ AM/PM

Site Aspect (circle): N, NE, E, SE, S, SW, W, NW **Elevation:**_____

Site Slope: Flat (0-10%) _____ Gentle (10-30%) _____ Moderate (30-60%) _____ Steep (>60%) _____

Topographic Position (circle): Valley Bottom Terrace Lower Slope Mid/Upper Slope Crest

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

SITE CHARACTERISTICS

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

Est. Weed Height (cm):_____ **Weed Density (# per m²):**_____ **Dominant Plant:**_____

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

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

Vegetation Type (circle):
Grassland
Pasture
Dry Meadow
Moist Meadow
Shrubland Steppe
Conifer Forest
Deciduous Forest

Estimate % Cover:
Tree _____
Shrub _____
Forb _____
Grass _____
Litter _____
Bare Ground _____
Rock _____

Soil Texture: (check) Sand___ Silt___ Clay___ Gravel___ Loam___

Appendix II. Sample Biological Control Agent Release Form (Side 2)

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

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

Road Map to Site

Site and Vegetation Map

Comments

Appendix III. Gorse/Broom Biological Control Agent Monitoring Form

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

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

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

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

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

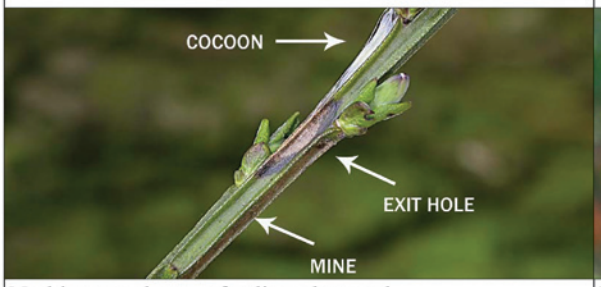
1. Counting Adult Beetles

Select a gorse or broom plant and tap the stems above a beat sheet 3 times. Count all adult beetles, separating between species. Take 10 steps (if possible) and come to the nearest gorse or broom plant. Repeat for a total of 6 different plants/counts. If both broom and gorse are present at the site, select 6 different plants for each plant species. Record your counts in the space provided beneath the beetle images, using commas to separate the 6 different plants (e.g. 6,21,0,8,0,0).

Bruchidius villosus **(Scotch or French broom)**	***Exapion fuscirostre*** **(Scotch broom)**	***Exapion ulicis*** **(Gorse)**
		

2. Estimating *Leucoptera spartifoliella* and *Tetranychus lintearius* feeding damage

Walk throughout the infestation and look closely at gorse or broom stems and foliage to identify feeding damage. *Leucoptera spartifoliella* moth larvae mine the stems of Scotch broom while *T. lintearius* mite colonies are covered by webbing and stunt the growth of gorse stems and reduce flowering. Estimate the overall damage by circling the most appropriate choice in the lists below.

Leucoptera spartifoliella **feeding damage (Scotch broom)**	***Tetranychus lintearius*** **feeding damage (Gorse)**
	
No biocontrol agent feeding observed	No biocontrol agent feeding observed
Occasional, scattered feeding damage observed	Occasional, scattered feeding damage observed
Conspicuous, widespread feeding damage observed	Conspicuous, widespread feeding damage observed

Notes: _____

Appendix IV. Gorse/Broom Qualitative Monitoring Form

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

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

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

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

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

Biocontrol Agent: _____ **Year of release:** _____

Target Weed: _____

Cover class estimate by plant category (Overall infestation, ✓check one for each row)							
Plant Group	**0%**	**1-5%**	**6-25%**	**26-50%**	**51-75%**	**76-95%**	**96-100%**
Target weed							
Grasses							
Forbs							
Shrubs							
Trees							

Dominant Plant Species on Site: _____

_____

_____

_____

Other Noxious Weeds: _____

_____

_____

Estimate target weed density class (check one)			
# Plants/10m²		**Target weed distribution**	
0		Isolated	
1-5		Scattered	
6-15		Scattered-Patchy	
15-30		Patchy	
>30		Continuous	

Target weed phenology class	
Target weed stage	**Estimated percent**
Seedling	
Leafing	
Flowering	
Seedpods maturing	
Seedpods dehiscing	
Dormant	

Detailed description of site, including infestation size and borders used in monitoring estimates:

_____

_____

_____

_____

Appendix V: Scotch Broom Seedpod Quantitative Monitoring Form

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

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

COLLECTION TIME:_____ **TEMP:**_____ **WEATHER:**_____

Collector's Name: _____ **Date Collected:** _____ _____ _____
year month day

Dissector's Name: _____ **Date Dissected:** _____ _____ _____
year month day

Bruchidius villosus = BRVI; *Exapion fuscirostre* = EXFU; Notes should include abbreviations for: pod splitting & how much/where split, more info on parasitoids, if larvae dead/potential viability of seeds, any anomalies, confusions etc.

Plant #	Pod #	Pod length (cm)	BRVI eggs (Y/N)	Parasitoid (Y/N)	Total Seeds	Seeds			Notes
						# Healthy	# EXFU	# BRVI	
1	1								
	2								
	3								
2	1								
	2								
	3								
3	1								
	2								
	3								
4	1								
	2								
	3								
5	1								
	2								
	3								
6	1								
	2								
	3								
7	1								
	2								
	3								
8	1								
	2								
	3								
9	1								
	2								
	3								
10	1								
	2								
	3								

Appendix V: Scotch Broom Seedpod Quantitative Monitoring Form Instructions

General:

The purpose of this activity is to estimate the abundance and attack rates of Scotch broom seed beetles. Seedpods can be dissected in the field; however, this may result in errors due to seed or beetle counts being missed or duplicated. It is recommended dissections occur in an office or lab setting to protect samples from inclement weather and to ensure all information is recorded accurately per pod. Data collection is easier with two people, one to make the observations and the other to record data.

Timing:

It is important to collect pods before they dry and crack open. Data will be lost if pods open, releasing seeds and/or beetles. Visit Scotch broom sites when seedpods are nearly entirely brown or black. They should not be green as the seeds and biocontrol agents are still developing, and pod dissections will be more difficult. In Washington, this corresponds to roughly early July, but watch local phenology as the pods will ripen and dehisce quickly, within a matter of days. **Collect pods that are fully intact and completely closed.** The best time to collect is the morning. If possible, avoid collecting pods during periods of rain or when the pods are wet. If pods are stored for later dissections and they are wet, add a paper towel to the collection bags to soak up moisture; remove it within 1-2 days to avoid mold issues. **Keep pods refrigerated if dissection cannot be done immediately.**

Supplies needed:

Seedpod collection: datasheet, clipboard, pen/pencil, compass, 100m tape measure (optional), flagging (optional) If storing seedpods for later dissections (highly recommended), additional supplies needed include: zip-top bags, paper towels, permanent marker for writing on bags or, alternatively, small pieces of paper to write on and insert in bags.

Seedpod dissection: datasheet (partially filled out after seedpod collections); tub or container to hold the seedpod being dissected; thumb nail, scalpel, or other sharp blade; bright lighting; microscope (if available).

Seedpod collection protocol:

At each site:

1) Fill out the site and collector information at the top of the datasheet.
2) Assess the Scotch broom infestation. Scope out a straight line transect at least 100 m long that crosses through the densest part of the population. For example, if the infestation is along a powerline corridor, the transect would follow the corridor through the middle of the infestation. Do your best to follow a straight line through the infestation, even if the Scotch broom is very dense. A tape measure or flagging can be used to help. Avoid collecting from the edge of an infestation even if it is easier, because this may skew the data.
3) Sample 10 Scotch broom plants at each site. Start at the beginning of the transect. This is plant #1. From there, walk 10 normal paces (or 10 m if using a tape measure) in a straight line along the transect and sample the closest plant to the pace line. This is plant #2. Repeat until 10 plants are chosen.

4) At each plant, and using a compass to help orientation, collect 3 pods in the following manner:
   a. On the north side of the plant (0° or 360°N), select one pod from the bottom of the canopy (0-33% total plant height). Try to be as random as possible when selecting individual pods. Select pods that are unopened but dark. Try not to select pods that are overly large or small or that look like they have been over- or under-attacked.
   b. Move to the southeast side of the plant (120°SE), and select one pod from the middle of the canopy (33-66% total plant height).
   c. Move to the southwest side of the plant (240°SW), and select one pod from the top of the canopy (66-100% total plant height).
   d. If you are dissecting the seedpods in the field, skip to the instructions below for Seedpod Dissection Protocol. If you are storing the pods for later dissection in a controlled setting (highly recommended), put all 3 pods in a zip top bag. Label the bag with the site name, plant #, collector name, and date by writing this directly on the bag or on a small piece of paper to insert into the bag. If the pods are wet, place a small amount of paper towel in the bag to help absorb moisture.
5) If storing the seedpods for later dissection, place all 10 bags (of 3 pods each) from a single site into one large bag. Label the large bag with site name, collection day, and collector. Keep the seedpods in a cooler with icepacks until returning to the dissection location; **store in a refrigerator until dissections are completed.**

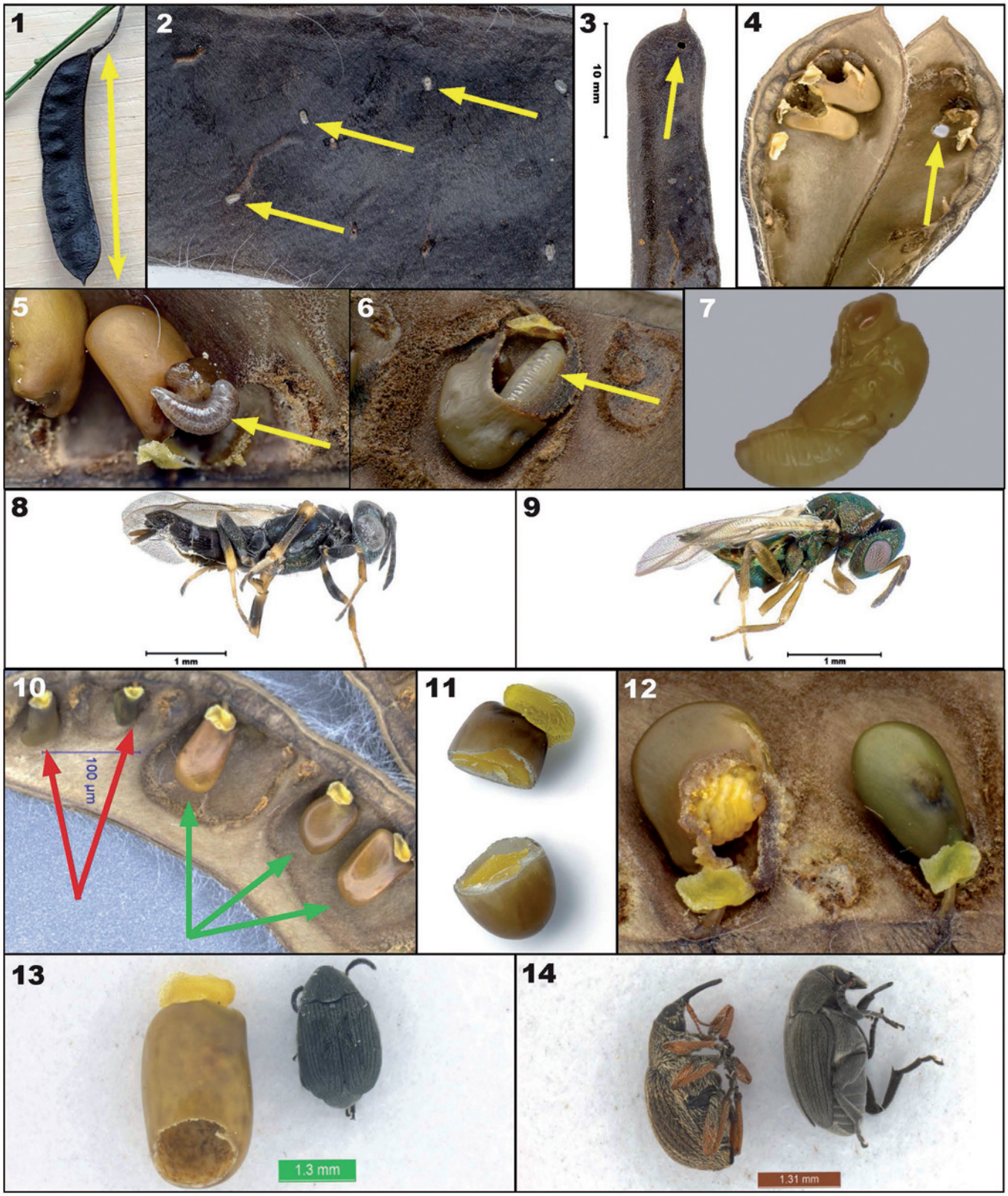
Seedpod dissection protocol:

Record information for all steps below on the same site datasheet used during the seedpod collection process. If possible, take bags of pods/site out one at a time. A small cooler with an ice pack can be used to keep the remainder of the pods cool and moist. Hold each pod being dissected in or over a tub or container to ensure the container catches all pod parts that may come away during dissection. *Bruchidius villosus* = BRVI; *Exapion fuscirostre* = EXFU.

Note on Parasitoids: Part of this monitoring protocol includes observing parasitoids, which are insects (e.g., wasps) whose larvae live as parasites, eventually killing their hosts (typically other insects). Scotch broom parasitoids deposit their eggs directly onto their BRVI or EXFU hosts. Parasitoid larvae feed externally on their hosts until host death, and adult parasitoids emerge from seedpods through holes they must cut in the seedpod walls. Because EXFU feeds externally on Scotch broom seeds, the parasitoids don't have to create an emergence hole through the seed to get out; they only must cut a hole through the seedpod wall. Because BRVI feeds internally within a seed, the parasitoids must cut emergence holes through both the seed coat and the seedpod wall to emerge. Observing emergence holes in Scotch broom seeds and seedpods can help determine if parasitoids are present, and what species of Scotch broom beetles they may have attacked.

1) Measure the length of the pod (cm) from tip to tip and note in the pod length column (image 1, page 149).
2) Look for BRVI eggs on both sides of the pod and note presence/absence in the BRVI eggs column (image 2).
3) Hold the pod firmly but gently so it won't burst apart once you have started to open it. Split the pod open on the inner-curved side of the pod using a thumb nail, scalpel, or other sharp blade. Some pods are tightly fused on one end and will require a little nudging with the scalpel.

4) Once the pod is open, look for parasitic wasps and/or their damage. Look for any small, circular parasitoid emergence holes in the seedpod wall (images 3 and 4) and/or parasitoids present in the pod as either larvae (images 5 and 6), pupae (image 7), or adults (images 8 and 9). Note presence (Y/N) in the Parasitoid presence column. Note: Parasitoid larvae are translucent and do not have a visible head capsule while the biocontrol agents are more opaque and have a brown head capsule.
5) When seed pods open, the seeds will lay to one side or the other, so seeds are most easily counted by lining the two pod halves side by side as if they were still attached.
6) Count the number of total seeds, regardless of attacked/not attacked (but DO NOT include aborted seeds since these are not viable) and write this in the Total Seeds column. Aborted seeds are shriveled and small and do not have biocontrol larvae in them when cut in half with a blade or fingernail (image 10, red arrows).
7) There are three types of normal seeds: healthy unattacked by biocontrol agents, attacked by EXFU, and attacked by BRVI. Write the number of each type in the appropriate column.
    a. Healthy seeds are hard, smooth, and typically brown in color (image 10, green arrows; image 11).
    b. EXFU-attacked seeds always show feeding damage on the outside of the seed coat. Some or all of the seed may also be eaten, and a larva or pupa may be present (image 12, left seed). Note the number of EXFU-attacked seeds in the column under EXFU.
    c. BRVI-attacked seeds do not have external feeding damage unless the adult has already emerged. Seeds with BRVI larvae or pupae inside will be smooth but often discolored (image 12, right seed). They are easily squished as opposed to hard, unattacked seeds, and they exude a milky juice when squeezed or cut with a blade or fingernail. Sometimes larvae are small and multiple cuts are required to reveal their presence in a seed. If BRVI has already emerged from the seed, there will be an oval hole at the bottom half of the seed (image 13). Note the number of BRVI-attacked seeds in the column under BRVI.
    d. If adult beetles have already emerged within seedpods, they can be used to confirm the number of healthy versus destroyed seeds and differentiate the seed damage between the two biocontrol agent species (image 14). The number of beetle-damaged seeds should correspond to the number of adults emerged, and this number(s) can be written in the appropriate species column(s). Ensure the numbers in the three categories of seeds add up to the number you wrote in the Total Seeds column.
8) Dump and wipe your dissection container after each pod to ensure that you only count the material once. If working in a lab or office, keep a neat working area. If a seed goes astray it is helpful to not have too many other seed pieces around that will make it harder to find the missing seed.
9) Once all pods have been dissected, make a copy of the data sheet; keep one copy for your files and send the other copy to either your state biocontrol specialist, entomologist, extension office, or county noxious weed program.



Seedpod monitoring images: 1. pod length; 2. BRVI eggs; 3., 4. parasitoid emergence holes; 5., 6. parasitoid larvae; 7. parasitoid pupa; 8., 9. parasitoid adults; 10. aborted (red arrow) vs. healthy (green arrow) seeds; 11. healthy seed cut in half; 12. EXFU-attacked seed (left), BRVI-attacked seed (right); 13. BRVI adult emerged from BRVI-attacked seed; 14. EXFU adult (left), BRVI adult (right). (Photo credits: 1.,13.,14. Jennifer Andreas, Washington State University Extension; 3.,4. Jessica Orr, Washington State Department of Agriculture; 7. James Moore, Washington State University Extension; 2.,5.,6.,10.,11.,12. Thomas Shanan, Oregon Department of Agriculture)