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Biological Control

BIOLOGY AND BIOLOGICAL CONTROL OF YELLOW STARTHISTLE

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Cover Photos: (a) Yellow starthistle flower head (Peggy Grebb, USDA ARS, bugwood.org); (b) *Bangasternus orientalis* adult; (c) *Eustenopus villosus* adult; (d) *Larinus curtus* adult; (e) *Chaetorellia* spp. adult; (f) *Urophora sirunaseva* adult (b-f Laura Parsons & Mark Schwarzländer, University of Idaho); (g) *Puccinia jaceae* var. *solstitialis* (Stephen Ausmus, USDA ARS, bugwood.org)

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Biology and Biological Control of Yellow Starthistle

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CHAPTER 1: INTRODUCTION

Overview

Yellow starthistle (*Centaurea solstitialis* L., Figure 1-1a,b) is an invasive weed native to the Mediterranean region. It was introduced to North America in the 1800s. Though it is present throughout much of the United States (Figure 1-2a), yellow starthistle is most problematic in rangelands and grasslands in the western USA where it occupies more than 18 million acres (7.3 million ha, Figure 1-2b).

Figure 1-1. Yellow starthistle, a. plant; b. infestation (Credits: a Mark Schwarzländer, University of Idaho; b Charles Turner, USDA ARS)

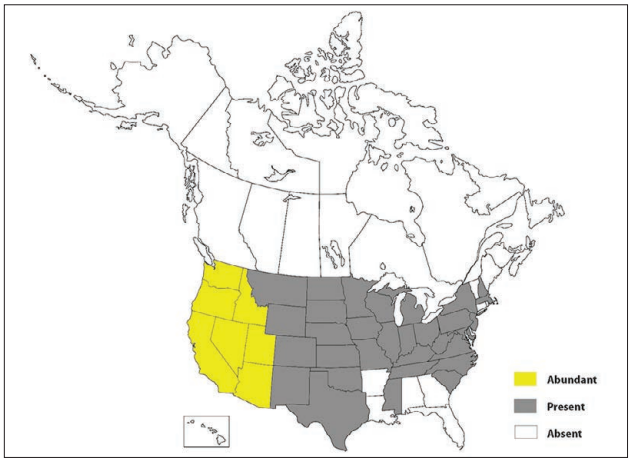


Figure 1-2. Yellow starthistle presence and abundance in North America (Credit: USDA PLANTS Database, EDDMapS; states with over 100 different reports of yellow starthistle have been marked as abundant) Please note, many plant distribution databases report yellow starthistle as present in Canada; however, while a few plants were previously found in Alberta, British Columbia, Ontario, and Saskatchewan, no populations have persisted to date.

Throughout its native and introduced ranges, yellow starthistle is found in annual and perennial grasslands, pastures, shrub steppe, open woodlands, and disturbed habitats such as hayfields, orchards, vineyards, roadsides and abandoned areas. It is most commonly found in Mediterranean and steppe climates characterized by cool winters and hot, dry summers, and in relatively dry, fertile soils.

Yellow starthistle is one of the most problematic exotic plant species currently threatening rangeland and conservation areas in the western USA. It reduces biodiversity by displacing native vegetation in grasslands and woodlands. The thorny spines that surround the flower heads of starthistle interfere with grazing by livestock, recreation, and wildlife management. It is toxic to horses, causing a chronic and potentially fatal neurological disorder known as "chewing disease". Because of its excessive water usage, yellow starthistle threatens both human economic interests and native plant ecosystems.

Responding to the Threat of Yellow Starthistle

Yellow starthistle is an invasive species not native to North America whose introduction causes or is likely to cause economic or environmental harm. Yellow starthistle is responsible for millions of dollars of damage annually resulting from lowered quality of range forage, a decrease of land value, disruption of natural ecosystems, and a reduction of water available to recreation, agriculture, and native vegetation.

A general management response to the threat of yellow starthistle and other 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/map new yellow starthistle infestations and evaluate how yellow starthistle responds 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 yellow starthistle prevention and management activities in its 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, getting rid of an invasive species completely, is generally only possible in the early stages of establishment when the 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 where containment would provide a low return on investment. The asset-based approach is used to manage the species only where reducing its 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. 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 yellow starthistle 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.

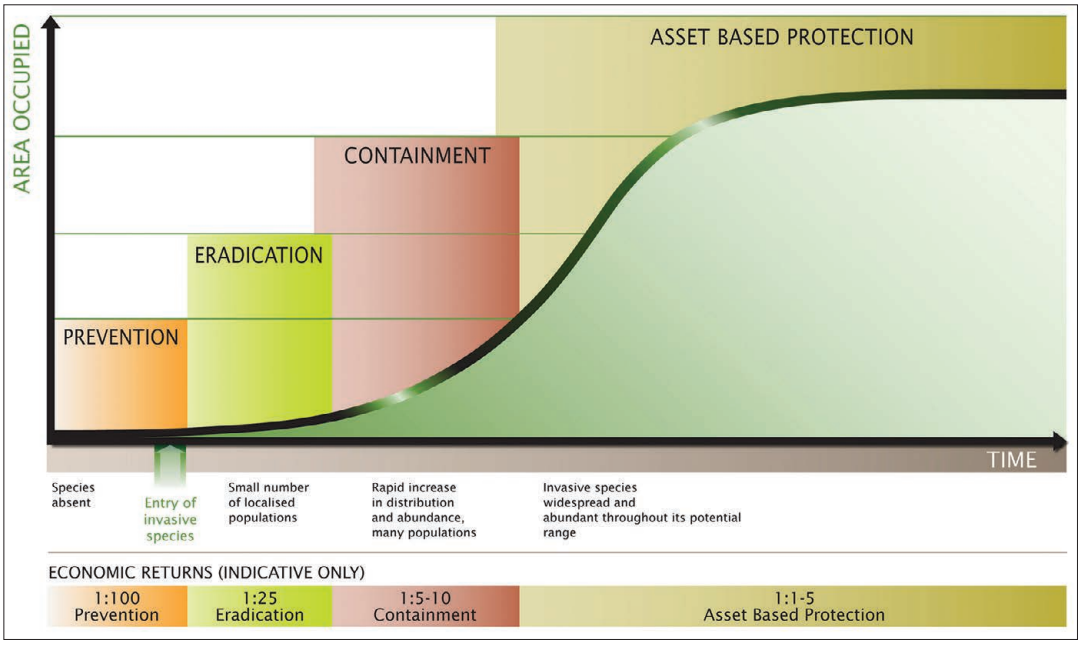


Figure 1-3. Generalized invasion curve showing actions appropriate to each stage (Credit: © State of Victoria, Department of Economic Development, Jobs, Transport and Resources. Reproduced with permission)

While yellow starthistle currently infests large acreages in some regions, there are entire states and provinces where yellow starthistle is absent or is present at very low levels. The diversity of yellow starthistle populations, from absent to widespread and abundant, throughout its potential range requires land managers to coordinate their management response to yellow starthistle across larger landscapes to prevent current infestations from spreading into uninfested areas.

Identifying where yellow starthistle is on the invasion curve in a particular area is the first step to taking management action. Inventorying and mapping current yellow starthistle populations, coupled with research efforts to predict where yellow starthistle is most likely to inhabit, enables land managers to concentrate resources in areas where yellow starthistle is 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 generally not appropriate for areas on the left side of the invasion curve (species absent [prevention] - small number of localized populations [eradication]) because biological control alone will not result in yellow starthistle eradication. Biological control as a control method is best suited to yellow starthistle 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])

Management of Yellow Starthistle Infestations

Successful management of yellow starthistle is an intensive process which requires land managers to continuously inventory, map, and assess the extent and severity of yellow starthistle infestations. Land managers must also understand the benefits and shortcomings of each weed control method available, alone and in combination, when applied to yellow starthistle. Chemical control (using herbicides) may be used to successfully control small yellow starthistle infestations (left side of the invasion curve, Figure 1-3) where land managers are committed to annual monitoring and, when necessary, re-treatment; however, chemical control can be impractical, prohibitively expensive, and damaging to desired vegetation when treating large yellow starthistle infestations. Hand pulling small, individual yellow starthistle plants may again be feasible for small infestations on the left side of the invasion curve; however, new yellow starthistle plants may germinate throughout the growing season, and the extensive taproots on larger plants are difficult to remove. Repeated mowing can be utilized in the containment and asset-based portions of the invasion curve by reducing yellow starthistle vigor and seed production, but it may exacerbate the problem by triggering re-growth and spreading seeds. Burning may be used to decrease the yellow starthistle seed bank, but in the long term burning is a generally ineffective control method because it favors the germination of yellow starthistle and may have severe negative, long-term consequences for desired plants and wildlife. Grazing yellow starthistle can be an effective control method in certain circumstances (typically asset-based protection of the invasion curve), but grazing can be difficult and/or time-consuming, and may have severe negative, long-term consequences for plant communities. Because chemical, physical, and cultural control methods are not universally effective in managing yellow starthistle throughout its invaded range, a biological control program was initiated in the 1960s. Biological control as a control method is best suited to yellow starthistle populations in the later phases of the invasion curve. This manual discusses the biological control of yellow starthistle in North America, within the larger context of an integrated yellow starthistle management strategy.

The most effective weed management strategies are based on regular inventory and monitoring of target weed populations, application of one or many 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 yellow starthistle invasions in infested as well as uninfested areas across a landscape. IPM activities include education and outreach, inventory and mapping, prevention methods, and control methods (physical control [hand 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 yellow starthistle management goals.

Land managers choose control methods, either alone or in combination that enable them to achieve their yellow starthistle management goals or objectives in the most cost-effective manner. No single control method will enable managers to meet their yellow starthistle 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 yellow starthistle 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 yellow starthistle.

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 (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 on 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 yellow starthistle 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.

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, non-target 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

To be approved for release in North America, weed biocontrol agents must be host-specific, meaning they must develop only on the target weed. Rigorous 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. Though not currently found in Canada, if yellow starthistle were to become established in Canada, The Canadian Food Inspection Agency (CFIA) serves the same regulatory role in Canada. Federal laws and regulations are in place to identify and avoid potential risks to native and economically valuable plants and animals that could result from exotic organisms introduced to manage weeds. The Technical Advisory Group (TAG) for Biological Control Agents of Weeds is an expert committee with representatives from USA federal regulatory, resource management, and environmental protection agencies, and regulatory counterparts from Canada and Mexico. TAG members review all petitions to import new biocontrol agents into the USA, and make recommendations to USDA-APHIS-PPQ regarding the safety and potential impact of prospective biocontrol agents. Weed biocontrol researchers work closely with USDA-APHIS-PPQ and TAG to accurately assess the environmental safety of potential weed biocontrol agents and programs. In addition, some states in the USA have their own approval process to permit field release of weed biocontrol agents. In Canada, the Biological Control Review Committee (BCRC) draws upon the expertise and perspectives of Canadian-based researchers (e.g., entomologists, botanists, ecologists, weed biological control scientists) from academic, government, and private sectors for scientific review of petitions submitted to the CFIA. The BCRC reviews submissions 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 reduce the potential for causing environmental damage through the use of weed biological control by voluntarily restricting biocontrol activities to those most likely to result in success and least likely to cause harm.

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

1. Ensure that the target weed's potential impact justifies release of non-endemic biocontrol agents
2. Obtain multi-agency approval for biocontrol 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 non-targets
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

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 Yellow Starthistle

In 1969, what was first identified as the banded yellow starthistle gall fly, *Urophora sirunaseva* Hering, became the first biocontrol agent approved and released in North America on yellow starthistle (Figure 1-4). By 2003, six additional species had been approved and released in the United States, including a rust fungus, two flies, and three beetles. None of these biological control agents have been released in Canada because the weed does not occur in Canada. Though a few plants have been reported from Alberta, British Columbia, Ontario, and Saskatchewan in the past, no Canadian yellow starthistle populations have persisted to date.

Figure 1-4. Adult *Urophora sirunaseva*, the banded yellow starthistle gall fly (Credit: Mark Schwarzländer, University of Idaho)

Is Biological Control of Yellow Starthistle 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. 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 and vigor 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 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 yellow starthistle problem (< 1 acre [0.4 ha] or much smaller), weed control methods such as hand 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 weed from spreading and infesting additional areas, especially when infestations occur in high-priority treatment areas such as travel corridors where the weed is more likely to readily disperse. If yellow starthistle is well established over a large area (>1 acre, 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 the best option based on available resources and weed management objectives
4. Has realistic weed management goals and timetables
5. Includes resources to ensure adequate monitoring of the target weed, the vegetation community, and populations of biological control agents

About This Manual

This manual provides information on the biology and ecology of yellow starthistle and each of its biological control agents. It also presents guidelines to establish and manage approved biological control agents as part of an integrated yellow starthistle management program. Throughout this manual, English units are given first for descriptions of plants and areas, followed by their metric system equivalents in parentheses. Metric units are the preferred and traditional reference for insects and are used throughout Chapter 3 for describing the yellow starthistle biological control agents. Table 1-2 provides English/metric conversions and abbreviations.

Table 1-2. English/metric conversion table

English System	Metric System
1/16 inch (in)	3.2 millimeters (mm)
1 inch (in)	2.54 centimeters (cm)
1 foot (ft)	30 centimeters (cm)
1 yard (yd)	0.9 meters (m)
1 mile (mi)	1.6 kilometers (km)
1 acre (ac)	0.4 hectares (ha)

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

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

Chapter 3: Biology of Yellow Starthistle Biological Control Agents describes biological control agents of yellow starthistle, including details on each biocontrol agent's native range, original source of releases

in North America, parts of yellow starthistle plants attacked, life cycle, description, host specificity, known non-target effects, habitat preferences, and availability. This chapter is particularly useful for identifying biological control agents in the field.

Chapter 4: Elements of a Yellow Starthistle Biological Control Program includes detailed information and guidelines on how to plan, implement, monitor, and evaluate an effective yellow starthistle 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 Yellow Starthistle Management Program discusses the role of biological control in the context of an integrated yellow starthistle management program.

The **Glossary** defines technical terms frequently used by those involved in yellow starthistle 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. Sample Biological Control Agent Release Form
III. Yellow Starthistle Standardized Impact Monitoring Protocol
IV. General Biological Control Agent Monitoring Form
V. Yellow Starthistle Qualitative Monitoring Form
VI. Yellow Starthistle Quantitative Monitoring Form

CHAPTER 2: GETTING TO KNOW YELLOW STARTHISTLE

Taxonomy and Related Species

Yellow starthistle belongs to the sunflower family (Asteraceae). Members of the sunflower family produce flower heads, or capitula, that are an aggregation of many individual flowers (Figure 2-1a). These flowers, called florets, are clustered together and attached to a receptacle. There are two types of florets: disc and ray (Figure 2-1b, 2-1c). Some species produce both types of florets, while others (like yellow starthistle) produce only disc florets. The receptacle and florets are enclosed by modified leaves called involucral bracts. Each floret produces one seed (achene) from early to late summer. Seeds often have a tuft of whitish hairs (pappus) on one end, similar to those on dandelion seeds (Figure 2-1d).

Yellow starthistle is in the genus *Centaurea*. There are approximately 500 species in this genus worldwide, all of which are annual, biennial or perennial forbs. This genus can be found on all continents of the Northern Hemisphere, but it is particularly species-rich in the Middle East. No species of *Centaurea* are native to North America. Two species native to the southern USA and northern Mexico (*Plectocephalus americanus* [Nutt.] D. Don and *P. rothrockii* [Greenman] D.J.N. Hind) were once assigned to the genus *Centaurea*, but have recently been recognized as belonging to *Plectocephalus*. Taxonomic classification within the *Centaurea* is still uncertain; this variable group includes the knapweeds and cornflowers as well as the starthistles. Representatives from all three groups are among the 20 *Centaurea* species and two additional hybrids currently listed as established outside of cultivation in North America. Five of these species and one hybrid are starthistles.

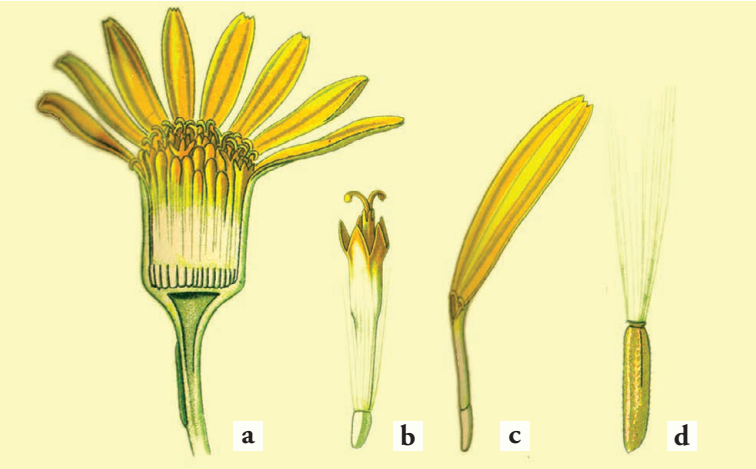


Figure 2-1. Sunflower family, a. capitulum; b. disc floret; c. ray floret; d. seed with pappus (Credits: a-d Prof. Dr. Otto Wilhelm Thomé Flora von Deutschland, Österreich und der Schweiz 1885, Gera, Germany, www.biolib.de; © expired)

Unlike cornflowers, starthistles typically have grayish-green and often rough or hairy leaves sometimes deeply divided into irregular lobes. Some knapweed species are similar to starthistles in that bracts subtending flower heads can end in stiff spines; however, unlike starthistles, the spines of knapweeds are never longer than the bracts. Only yellow starthistle is discussed in this manual.

Yellow Starthistle

Scientific Name

Centaurea solstitialis L.

Common Names

Yellow starthistle, yellow star-thistle, St. Barnaby's thistle, golden thistle, cotton-tip thistle

Classification

Ranking	Scientific Name	Common Name
Kingdom	Plantae	Plants
Subkingdom	Tracheobionta	Vascular plants
Superdivision	Spermatophyta	Seed plants
Division	Magnoliophyta	Flowering plants
Class	Magnoliopsida	Dicotyledons
Subclass	Asteridae	
Order	Asterales	
Family	Asteraceae	Sunflower family
Genus	*Centaurea*	Knapweed, starthistle
Species	*Centaurea solstitialis* L.	Yellow starthistle

History

Yellow starthistle is a native of Eurasia and the Mediterranean. Yellow starthistle seeds were found in adobe bricks in California beginning in the early 1800s. It was likely introduced to North America in the mid-1800s via contaminated alfalfa seed and other crops.

Description

At a Glance

Yellow starthistle is an herbaceous winter annual typically growing 1-3 feet (0.3-0.9 m) tall from a deep taproot. Rosettes have deeply lobed leaves up to 6 inches (15 cm) long. Plants produce one or more rigid, upright stems with multiple spreading and ascending branches (Figure 2-2, 2-6). Stem leaves are typically narrow, unlobed, and attach directly to plant stems by wings that run down the sides of the stems. All stems, leaves, and wings are densely covered with cobwebby hairs, resulting in a characteristic gray-green color. Flower heads are up to 0.6 inches (1.4 cm) across and consist of 10-80 bright yellow florets. Flower heads are produced at tips of branches, and sometimes at leaf or branch axils. The bracts are spiny and up to 1 inch (2.5 cm) long. Seeds are oblong and up to 1/8

inch (3 mm) long. Plumed seeds are tan to brown, located at the center of the seed head, and have a ring of pappus consisting of fine, white bristles. Plumeless seeds are dark brown to black, fewer in number, occur around the periphery of the seed head, and lack pappus.

Roots

Yellow starthistle develops taproots that are slender and deep, growing more than 3.3 feet (1 m) long. Roots have fine, thread-like extensions from the main stem.

Stems

Plant height varies depending on site conditions. While most rangeland plants are 1-3 feet (0.3-0.9 m) tall, individuals growing in wet locations can reach up to 6 feet (1.8 m) tall (Figure 2-3a), and those growing in hot, dry areas can be as short as 6 inches (15 cm, Figure 2-3b). Plants have one or more flowering stems with multiple spreading and ascending branches. Stems are upright, rigid, and winged (Figure 2-3c). Stems and wings are covered with dense hair, resulting in a characteristic gray-green color.

Figure 2-2. Yellow starthistle flowering plant (Credit: Laura Parsons, University of Idaho)

Figure 2-3. Yellow starthistle, a. plant growing over 6 feet (1.8 m) tall after a moist winter and spring; b. plants growing less than 6 inches (15 cm) tall at a dry site; c. winged stem (Credits: a,c Rachel Winston, MIA Consulting; b Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Leaves

Rosettes consist of numerous leaves. At open sites these lie close to the ground (Figure 2-4a); where numerous yellow starthistle plants are crowded together, rosette leaves grow more upright (Figure 2-4b). Each basal leaf is 2-6 inches (5-15 cm) long with lobed margins. The lobes are irregular, they may be opposite or alternate from each other, and the terminal lobe is larger than the side lobes. Stem leaves attach directly to plant stems by wings that run down the sides of the stems (Figure 2-4c). Stem leaves may be lobed but are more often narrow with smooth margins. Stem leaves are typically smaller than rosette leaves; they may be 0.4-4 inches (1-10 cm) long. All leaves and wings are densely covered with cobwebby hairs, resulting in a characteristic gray-green color.

Figure 2-4. Yellow starthistle, a. rosette leaves lying close to the ground; b. rosette leaves growing more upright in a dense infestation; c. stem leaf and wing (Credits: a,c Steve Dewey, Utah State University, bugwood.org; b John D. Byrd, Mississippi State University, bugwood.org)

Flowers

Solitary flower heads are produced at the tips of branches, though vigorous plants may also produce solitary flower heads at leaf and branch axils. Each flower head consists of 10-80 disc florets (Figure 2-5a). Each floret consists of five bright yellow fused petals. The involucre (base of the flower head) is 0.16-0.6 inches (0.4-1.4 cm) wide. Bracts occur in shingle-like layers around the involucre and are densely to sparsely covered with hairs. Each bract has one long central spine 0.4-1 inch (1-2.5 cm) long and two or more pairs of short side spines.

Fruits and Seeds

Fruits are oblong achenes (hereafter referred to as seeds) up to 1/8 inch (3 mm) long. Two types of seeds are produced: plumed and plumeless in an average ratio of 3:1, respectively. Plumed seeds are tan to brown, located at the center of the seed head, and have a ring of pappus consisting of fine, white bristles (Figure 2-5b top). Plumeless seeds are dark brown to black, fewer in number, occur around the periphery of the seed head, and lack pappus (Figure 2-5b bottom). Seed production varies greatly depending on soil moisture, nutrients, and plant competition. A mature plant produces 1-200 capitula, and seed heads yield between 1 and 80 seeds each (an average of 30). Consequently, a single mature plant can produce 1-6,000 seeds.

Figure 2-5. Yellow starthistle, a. flower head and spines; b. seed with pappus (above) and without pappus (below) (Credits: a Peggy Grebb, USDA ARS, bugwood.org; b C. Roché)

Figure 2-6. Artist's rendition of yellow starthistle key traits (Credit: Reichenbach, H. G. (1852-3) Icones florae Germanicae et Helveticae. 15. Band. Ambrosius Abel, Leipzig. Tafel 64/795; © expired)

Biology and Ecology

Yellow starthistle spreads only by seed. It is mostly self-incompatible, relying on outcrossing through pollination for successful seed production. Most seeds fall within 3.3 feet (1 m) of the parent plant. Short to medium dispersal of plumed seeds is facilitated by animals and humans; the seed pappus readily tangles in fur, feathers, and clothing. Long distance dispersal typically occurs with the movement of seed-contaminated livestock, vehicles, equipment, and hay and crop seed. Birds also contribute to long distance dispersal when some seeds pass through their digestive tracts still viable.

Germination typically begins in the fall and winter following autumn rains in regions with a Mediterranean climate (mild wet winters and dry summers), though early spring germination also occurs. Most seeds germinate at low temperatures and days with short amounts of daylight, provided sufficient soil moisture is present. During periods of higher temperatures and longer amounts of daylight, the seeds often enter an induced dormancy. Later, if openings form in the plant canopy, subsequent yellow starthistle germination will often occur to fill in these open patches. Plumed and plumeless seeds respond differently to varying temperature, light, and moisture regimes. These differences are believed to aid yellow starthistle in exploiting variable conditions in semiarid environments. While the majority of yellow starthistle seeds germinate within three years, the soil seed bank can at times yield seedlings up to 10 years after seed drop.

After germination, two oblong cotyledons or seed leaves appear on seedlings, followed by 5 or more elliptic leaves (Figure 2-7a). Rosettes develop from fall through spring, consisting of 7-20 lobed basal leaves (Figure 2-7b). In wet years, the roots of overwintering rosettes grow rapidly, often extending 3.3 feet (1 m) before the plants bolt in spring. In dry years with reduced soil moisture recharge, root growth is limited to shallow depths of less than 2 feet (<0.60 m). Starthistle roots typically grow faster and to greater depths than do potentially competitive species, both weedy and native, allowing yellow starthistle to utilize limited resources. A deep root system also prolongs the period of resource availability for yellow starthistle, supporting the water-dependent production of seeds well into the dry months of summer when many competing species have already senesced.

Stems bolt from spring through the summer, sending up rigid, winged flower stalks (Figure 2-7c). Flower heads then develop through four distinct bud stages:

BU-1 (Figure 2-7d) Small buds with yellow-green spines begin to be visible at the top.
BU-2 (Figure 2-7e) Spines protrude more than half of the bud length.
BU-3 (Figure 2-7f) Spines are equal to or greater than 45° angle from the stem.
BU-4 (Figure 2-7g) Spines are straw-colored and equal to or greater than 90° angle from the stem.

Flowering occurs throughout summer, and each flower head produces 10-80 bright yellow florets (Figure 2-7h). During the seed formation stage, there is a progressive loss of color throughout the plant, though the involucre still retains some green (Figure 2-7i). By late summer as plants mature, the leaves wither and dry, the bright yellow flowers fade, and the plants take on a straw-colored appearance (Figure 2-7j). The size of the plant at maturity will depend, in part, on soil type, nutrients, water availability, the genetic potential of the plant, and plant density. Growth is most typically limited by low moisture and nitrogen.

During the seed dissemination stage from late summer to early fall, the flower head dries to a tan color, and the bracts dry and release the plumed seeds for dispersal (Figure 2-7k). Senescence (Figure 2-7l) begins in autumn and continues through the following spring as the plants wither and lose their leaves, becoming

silver-gray skeletons with decaying capitula that resemble white, cottony tufts by December or January. The flower heads have lost most of their spines and the plumeless seeds by this time. Eventually the head disintegrates and plumed seeds are shed.

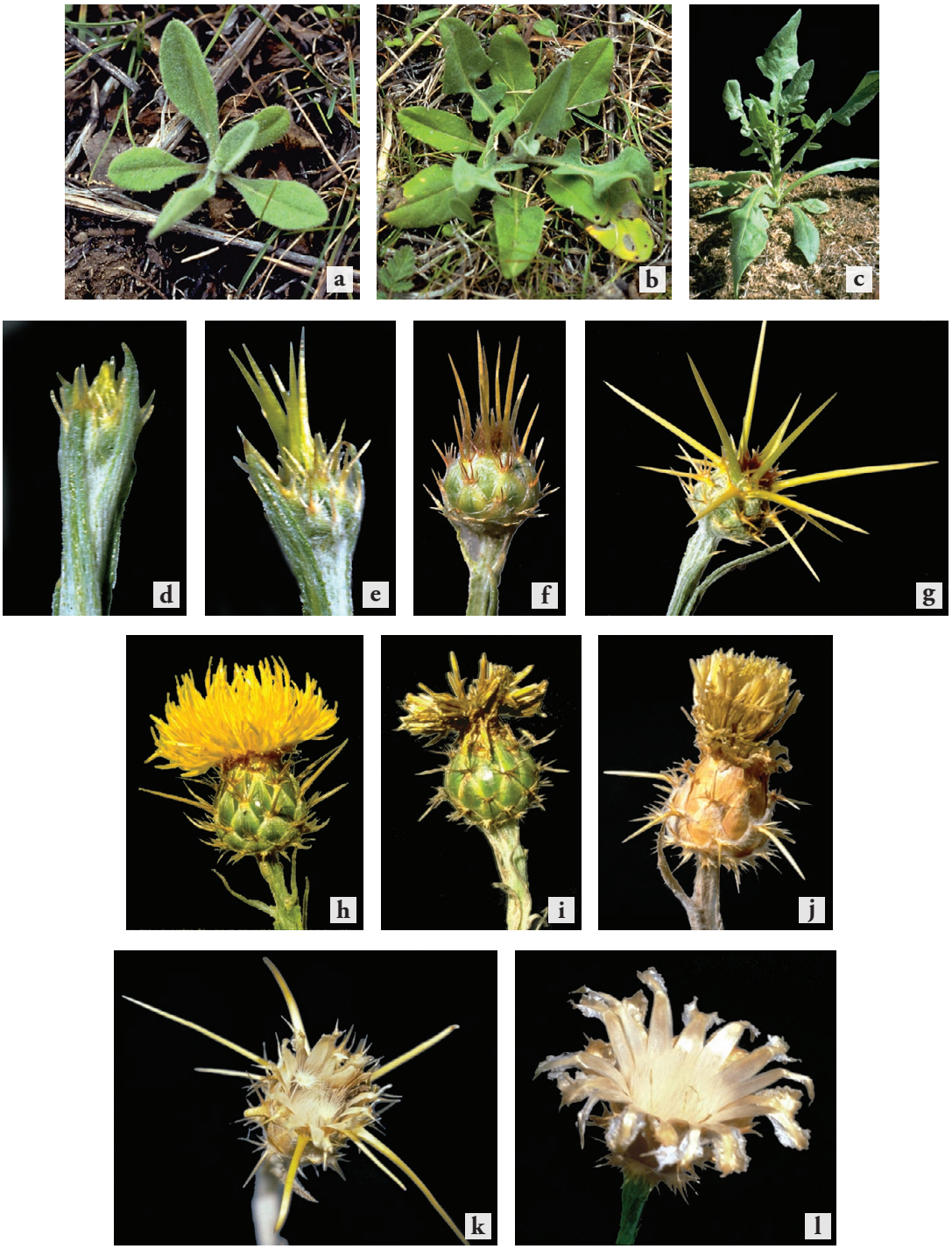


Figure 2-7. Yellow starthistle life cycle, a. seedling; b. rosette; c. bolting; d. BU-1; e. BU-2; f. BU-3; g. BU-4; h. flowering; i. seed formation; j. mature; k. dissemination; l. senescence (Credits: a-l C. Roché)

Habitat

Yellow starthistle capitalizes on soil disturbance, but can spread into undisturbed sites as well. It is a serious weed of roadsides, rangeland, pastures, shrub steppe, abandoned cropland, and disturbed places (Figure 2-8a-c). Yellow starthistle occurs in a variety of soils and conditions but is most common below 4000 feet (1200 m) in elevation on south-facing slopes in areas with more than 6 inches (15 cm) of rain annually.

Figure 2-8. Yellow starthistle infestations, a. open rangeland; b. fenced pastures; c. along a roadway (Credits: a,b Steve Dewey, Utah State University, bugwood.org; c John M. Randall, The Nature Conservancy, bugwood.org)

Distribution

As of 2016, yellow starthistle is considered established in 38 states but no Canadian provinces (Figure 1-2, repeated here in Figure 2-9a). While a few plants were previously found in Alberta, British Columbia, Ontario, and Saskatchewan Canada, no populations have persisted to date. Yellow starthistle has been declared noxious in eleven of the states in which it is currently found in the USA, as well as three Canadian provinces where it has not yet established (Figure 2-9b).

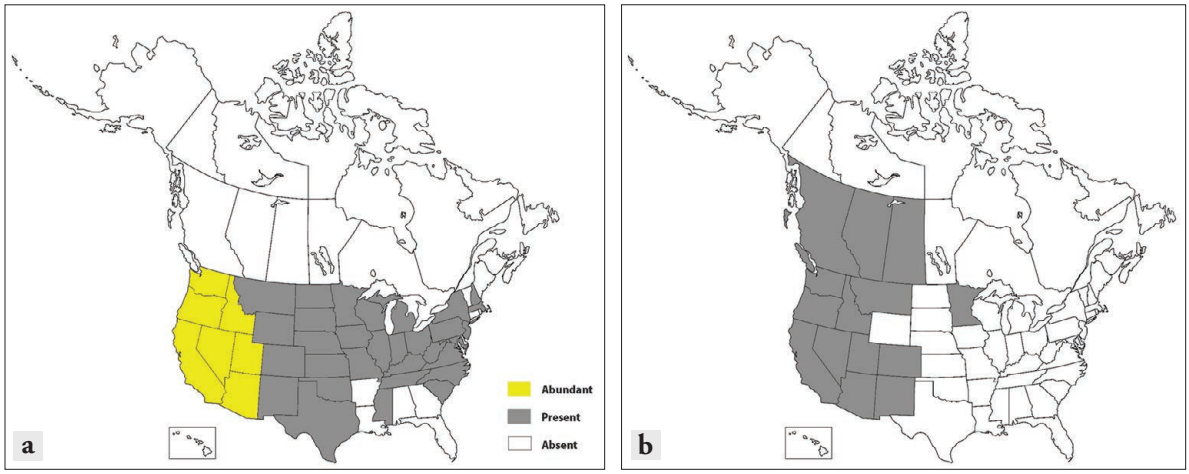


Figure 2-9. States and provinces where yellow starthistle is a. present and abundant in North America (Credit: USDA PLANTS Database, EDDMapS; states with over 100 different reports of yellow starthistle have been marked as abundant. Please note, many plant distribution databases report yellow starthistle as present in Canada; however, while a few plants were previously found in Alberta, British Columbia, Ontario, and Saskatchewan, no populations have persisted to date.); b. listed as noxious.

Comments

Yellow starthistle exhibits morphological and genetic variation throughout its range in the USA, and this variation is present among individuals at most infestations. This suggests that multiple introductions may have occurred, but that there is only one highly mixed population in the USA. High genetic diversity enables yellow starthistle to easily adapt to climate and soil differences between invaded sites, and it has likely contributed to yellow starthistle's invasion success in North America.

Commonly Confused Species

Numerous species present in North America have an appearance similar to yellow starthistle, especially those in the same family and genus. The species most closely resembling yellow starthistle are listed in Tables 2-1 and 2-2, along with key characteristics that can be used to differentiate the look-alikes.

Table 2-1. Non-native/invasive *Centaurea* species present in North America that are similar in appearance to yellow starthistle (YST), along with key traits for differentiation.

Species	Similarities to YST	Differences from YST
Yellow starthistle *Centaurea solstitialis* Exotic annual forb		
Iberian and Purple Starthistle *Centaurea iberica* and *C. calcitrapa* Exotic annuals to short-lived perennial forbs	Rosette leaves are lobed. Foliage is gray-green and covered with hairs. Involucral bracts end in long spines. Similar height under typical conditions.	Stems are not winged. Florets are pink or purple. All seeds of Iberian starthistle have pappus. All seeds of purple starthistle lack pappus.
Maltese starthistle *Centaurea melitensis* Exotic annual or biennial forb	Rosette leaves are lobed. Foliage is gray-green and covered with hairs. Stems are winged. Involucral bracts end in long spines. Florets are yellow.	Spiny bracts are smaller and purple-colored at their base. All seeds have pappus. Grows relatively shorter under typical conditions. Flowers earlier in the year.
Sicilian starthistle *Centaurea sulphurea* Exotic annual forb	Stems are winged. Florets are yellow. Involucral bracts end in long spines. Similar height under typical conditions. Florets are yellow.	Leaves are not lobed. Foliage is only sparsely covered with hairs; not gray-green. Flower heads are larger (up to 1 in or 2.5 cm) Seeds are twice as large and all have dark pappus.
Spotted knapweed *Centaurea stoebe* Exotic biennial or perennial forb	Rosette leaves are lobed. Foliage is gray-green and covered with hairs. Involucral bracts are in shingle-like layers and may be slightly spiny. Similar height under typical conditions.	Stems are not winged. Involucral bracts have black tips and lack long terminal spines. Florets are pink or purple. All seeds have pappus.

Credits: Yellow starthistle: 1 (Rachel Winston, MIA Consulting), 2 (Steve Dewey, Utah State University, bugwood.org), 3 (Peggy Greb, USDA ARS, bugwood.org), 4 (Cindy Roche, bugwood.org); Iberian and Purple Starthistle: 1 (Xemenendura), 2,4a top (©2001 CDFA), 3 (Joan Simon), 4b bottom (D. Walters and C. Southwick, USDA, bugwood.org); Maltese starthistle: 1 (David Thornburg, swbiodiversity.org), 2 (Max Licher, swbiodiversity.org), 3 (Franco Folini), 4 (CDFA Seed Laboratory); Sicilian starthistle: 1,2 (Joseph DiTomaso, University of California-Davis, bugwood.org), 3,4 (Daniel Montesinos); Spotted knapweed: 1 (Rob Routledge, Sault College, bugwood.org), 2 (James Miller, USDA Forest Service, bugwood.org), 3 (Michael Shephard, USDA Forest Service, bugwood.org), 4 (Ken Chamberlain, Ohio State University, bugwood.org)

Table 2-1. Continued

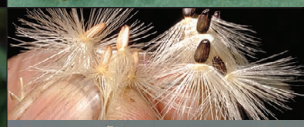
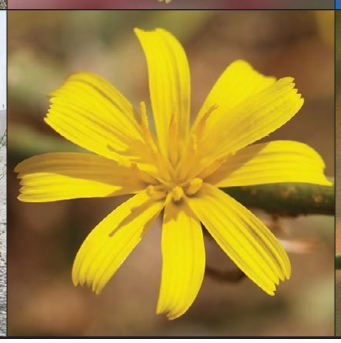
Look Alike Appearance			
Leaves	**Plant**	**Flower Head**	**Seeds**
			
			 
			
			
			

Table 2-2. Other species present in North America that are less related to yellow starthistle (YST) but that are in the same family (Asteraceae) and similar in appearance, along with key traits for differentiation.

Species	Similarities to YST	Differences from YST
Yellow starthistle *Centaurea solstitialis* Exotic annual forb		
Dandelion *Taraxacum officinale* Exotic and native perennial forb	Rosette leaves are lobed. Florets are yellow.	Foliage is not gray-green. Stems are hollow, leafless, unbranched, and non-winged. Flower heads are much larger and lack spines. All parts of the plant exude a milky latex when torn.
Prickly lettuce *Lactuca serriola* Exotic annual or biennial forb	Rosette leaves are lobed. Florets are yellow. The flowering stem is often branched.	Stiff hairs extend all along the stem and leaf undersides. Flower heads are much smaller and lack spines. All parts of the plant exude a milky latex when torn. Stems do not have wings.
Rush skeletonweed *Chondrilla juncea* Exotic perennial forb	Rosette leaves are lobed. Florets are yellow.	Foliage is not gray-green. Stems lack wings and have stiff, downward-pointing hairs. Flower heads are much smaller and lack spines. All parts of the plant exude a milky latex when torn.

Credits: Yellow starthistle: 1 (Rachel Winston, MIA Consulting), 2 (Steve Dewey, Utah State University, bugwood.org), 3 (Peggy Greb, USDA ARS, bugwood.org), 4 (Cindy Roche, bugwood.org); Dandelion: 1 (Bruce Ackley, Ohio State University, bugwood.org), 2 (Robert Vidéki, Doronicum Kft, bugwood.org), 3 (Chris Evans, Illinois Wildlife Action Plan, bugwood.org), 4 (Joseph Berger, bugwood.org); Prickly lettuce: 1 (Ohio State University Weed Lab Archive, bugwood.org), 2,3 (Mary Ellen (Mel) Harte, bugwood.org), 4 (Steve Dewey, Utah State University, bugwood.org); Rush skeletonweed: 1 (Richard Old, XID Services, Inc, www.xidservices.com, bugwood.org), 2 (Joseph Milan, BLM), 3 (Rachel Winston, MIA Consulting), 4 (Steve Dewey, Utah State University, bugwood.org)

Table 2-2. Continued

Look Alike Appearance			
Leaves	Plant	Flower Head	Seeds
			
			
			
			

CHAPTER 3: BIOLOGY OF YELLOW STARTHISTLE BIOLOGICAL CONTROL AGENTS

Introduction

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. Yellow starthistle biocontrol agents currently approved for use in North America include five species of insects (three beetles and two flies) and a rust fungus. One additional fly species was inadvertently introduced along with an approved species, and it is now widespread throughout the western USA. The taxonomic groups of yellow starthistle 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 cycles 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 3-1a). All insects have an exoskeleton (a hard external skeleton) and a segmented body divided into three regions (head, thorax, and abdomen, Figure 3-1b). 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.

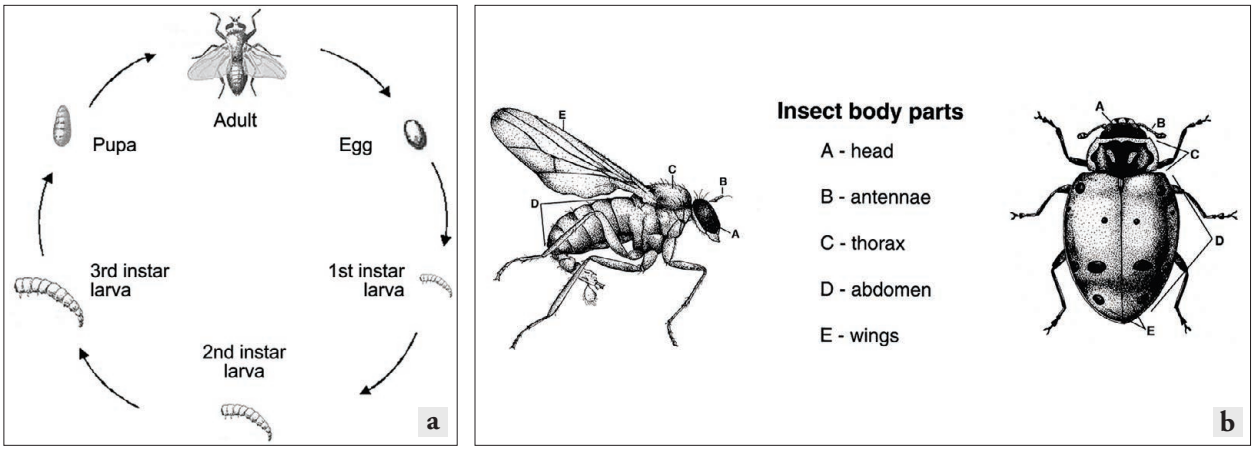


Figure 3-1. Line drawings of a. fly life cycle showing complete metamorphosis; b. fly and beetle anatomy: A. head, B. antenna, C. thorax, D. abdomen, E. wing (Credits: a L. Wilson, University of Idaho; b adapted from Biological Control of Weeds in the West, Rees et al. 1996)

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 3-1b). 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. All beetles have chewing mouth parts.

Flies (Order Diptera)

Many insects have the word "fly" in their name, though they may not be true flies. In the common names of true flies, "fly" is written as a separate word (e.g., house fly) to distinguish them from other orders of insects that use "fly" in their name (e.g., butterfly in the order Lepidoptera and mayfly in the order Ephemeroptera). Adult true flies are easily distinguished from other orders of insects by their single pair of membranous wings and typically soft bodies (Figure 3-1a,b). Larvae of most true flies, called maggots, are legless and worm-like.

Differentiating Beetles and Flies

An important part of any successful biocontrol program is to be able to identify the biocontrol agents in the field. As adults, the insects are relatively easy to identify, with their variable size, form, color, and habits. The larvae are more challenging to identify than the adults, and yet are probably more important to recognize as this is the stage that 1) does the damage, 2) is monitored in the field, and 3) provides the best evidence that the insects are established in the field.

As illustrated in Figure 3-2a, the simplest method to determine if a larva found in yellow starthistle is a beetle or a fly is to look for a head capsule. Beetle larvae are as variable as adult beetles are, but all have an obvious head capsule (Figure 3-2b). Fly larvae have no obvious head capsule. Fly larvae are sometimes confused with other larvae because they appear to have a broad, dark head (Figure 3-2c); however, this is actually a dark, hardened anal plate that is used to anchor the larva to its host.

Figure 3-3a illustrates the differences between beetles and flies in the pupal stage. Beetle pupae have

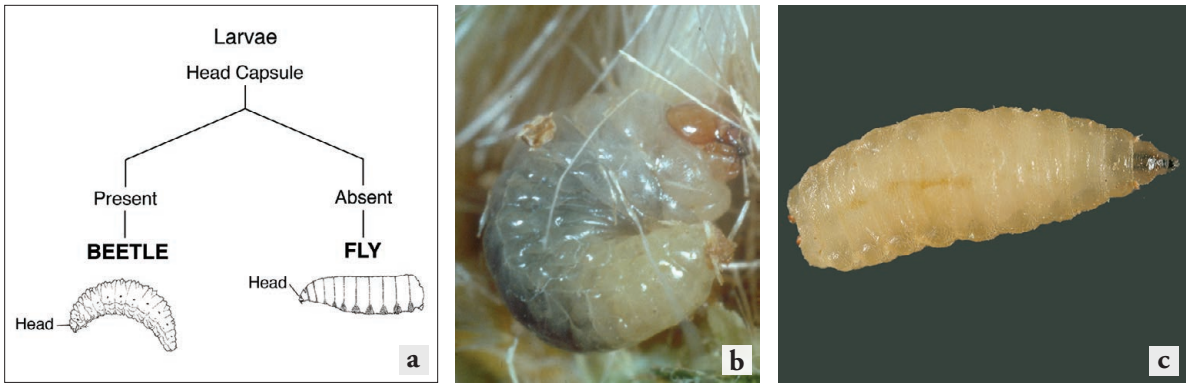


Figure 3-2. Differentiating beetle and fly larvae, a. line drawing key; b. beetle larva with an obvious head capsule; c. fly larva without an obvious head capsule (Credits: a L. Wilson, University of Idaho; b Charles Turner, USDA ARS, bugwood.org; c © Malcolm Storey, www.bioimages.org.uk)

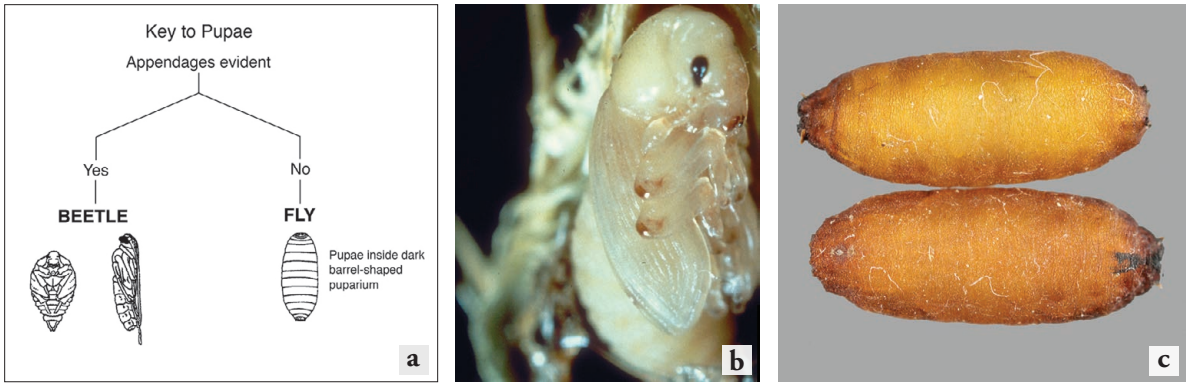


Figure 3-3. Differentiating beetle and fly pupae, a. line drawing key; b. beetle pupa with appendages; c. fly pupae contained in puparia (Credits: a L. Wilson, University of Idaho; b USDA ARS European Biological Control Laboratory, bugwood.org; c © Malcolm Storey, www.bioimages.org.uk)

well-developed appendages that are obviously not fused to the body (Figure 3-3b). Fly pupae are contained inside a puparium (Figure 3-3c).

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 aide in the 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, producing pustules on infected plant leaves and stems, and overwintering.

Yellow Starthistle Weevils

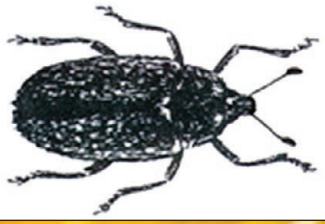
All three yellow starthistle beetles are weevils, which are plant-feeding beetles with long snouts bearing chewing mouth parts at the tip. They use the snout to chew and feed on plant tissues, or to notch out holes in which to lay their eggs. Antennae are elbowed and attached to the snout approximately halfway along its length.

Starthistle weevils complete one generation per year. The adults overwinter in protected areas on the ground and become active the following spring. Thus, the first weevils seen in spring are from the overwintering generation, and the new weevils that emerge in late summer are from the new generation.

As adults, weevils generally cause little damage to the plant. They may do some feeding of the foliage, but the amount is usually negligible. The exception is the hairy weevil (*Eustenopus villosus*) which feeds on starthistle buds, often killing the buds. For the other starthistle weevils, however, it is primarily the internally-feeding larval stage that causes damage. Larvae develop through three or four instars inside starthistle seed heads. Weevil larvae are distinctly white, C-shaped, and have a brown head capsule.

Table 3-1 provides details on the three weevils available for starthistle biocontrol as of 2016. Table 3-2 compares life cycles of each of the weevils.

Table 3-1. Comparison of adult yellow starthistle weevils

Bangasternus orientalis	***Eustenopus villosus***	***Larinus curtus***
		
		
Emerges 1st (bolting)	Emerges 2nd (BU-I)	Emerges 3rd (BU-1)
Cylindrical body shape	Cylindrical-oblong body shape	Oblong body shape
4-6 mm	4-6 mm	5-6 mm
Brown with yellow/white hairs	Brown with gray/white hairs	Brown
Mottled appearance	Striped	Yellow-spotted
Non-hairy looking	Hairy-looking	Pollen-covered
Short snout	Long, slender snout	Medium-sized snout
Release at BU-1 to BU-3 stages	Release at BU-2 to BU-4 stages	Release at flowering stage

Credits: Weevil line drawings (J. Johnson, University of Idaho); Photos (Laura Parsons & Mark Schwarzländer, University of Idaho)

Table 3-2. Comparison of weevil life cycles by yellow starthistle growth stages. BU 1-4 represent the four different bud stages (refer to Figure 2-7 to see pictures of each bud stage).

YST Stage	*Bangasternus orientalis*	*Eustenopus villosus*	*Larinus curtus*
Seedling	Adults overwinter in ground litter	Adults overwinter in ground litter	Adults overwinter in ground litter
Rosette			
Bolting	Adults emerge; visible on plants		
BU-1	Females oviposit; black egg cases visible	Adults emerge, feed on buds; visible on plant	Adults emerge; visible on plant
BU-2	Larvae develop; black egg cases visible		
BU-3			
BU-4	Larvae develop; find in seed head	Females oviposit. Feeding damage visible	Females oviposit
Flowering		Larvae develop; find in seed head	
Seed formation			Larvae develop; find in seed head
Mature	Larvae pupate	Larvae pupate	Larvae pupate
Dissemination	Adults emerge; visible on plant	Adults emerge; visible on plant	Adults emerge; visible on plant
Senescence	Adults overwinter in ground litter	Adults overwinter in ground litter	Adults overwinter in ground litter

Bangasternus orientalis (Capiomont)

Yellow starthistle bud weevil

Quick Facts	
Order	Coleoptera
Family	Curculionidae
Native Distribution	Eurasia, Mediterranean
Original Source	Greece
First Release	1985
Non-target Effects	None reported

Description

Eggs are tiny yellow spheres covered with dark egg caps (Figure 3-4a). Larvae are up to 6 mm long with white, C-shaped bodies and brown head capsules (Figure 3-4b). Adults are 4-6 mm long with somewhat flattened, cylinder-shaped bodies and short snouts (Figure 3-4c). Adult bodies are brown with yellow-white hairs that give them a mottled appearance.

Figure 3-4. *Bangasternus orientalis*, a. egg on plant stem (red arrow); b. larva in seed head; c. adult (Credits: a University of Idaho Archives; b California Department of Agriculture; c Laura Parsons & Mark Schwarzländer, University of Idaho)

Life Cycle

Overwintering adults resume activity in spring when yellow starthistle is bolting. Females lay eggs singly just below buds. They may lay up to 470 eggs in a lifetime. Eggs are covered with a dark, protective substance. Larvae hatch in late spring and tunnel through the stem to reach the developing flower head where they feed on bracts, receptacle tissue, and developing seeds. Larvae grow through four instars; the first instar mines the stem and bracts of the flower head while instars 2-4 occur inside the head and feed on the developing seeds. Pupation occurs within seed heads in chambers made of damaged seed and receptacle tissue. Adults emerge in late summer and overwinter in soil litter. There is one generation per year (Figure 3-5).

Habitat Preference

This weevil initially established throughout most yellow starthistle infestations in the western United States, indicating it is well-adapted to a variety of conditions. It appears to do better at mid-elevation sites where the weevil *Eustenopus villosus* is not already established or abundant than at hotter and drier locations.

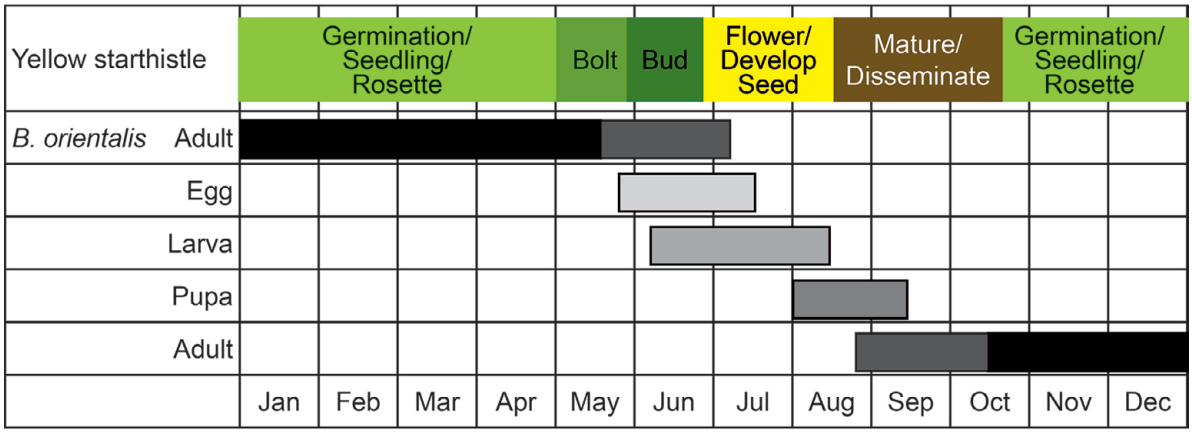


Figure 3-5. Schematic life cycles of *Bangasternus orientalis* and yellow starthistle in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. Black bars represent the inactive overwintering period.

Damage

Though adults may feed on yellow starthistle stem wings and leaves, the feeding is superficial and does not significantly damage the plant. Larvae feed on seed head tissue and developing seeds. Seed consumption does not kill existing plants, but reduces seed production which may help decrease the rate of spread of yellow starthistle populations and may reduce infestations in some habitats.

Current Status and Availability

In the western United States (Figure 3-6), larval feeding typically destroys 60% of seeds within attacked seed heads. It was initially the most widespread of established biocontrol agents. However, densities of the weevil have been declining since their peak a few years after their original release. The current attack rate is only 1% of available capitula. Predation, parasitism, and displacement by other established biocontrol agents limit populations in many areas.

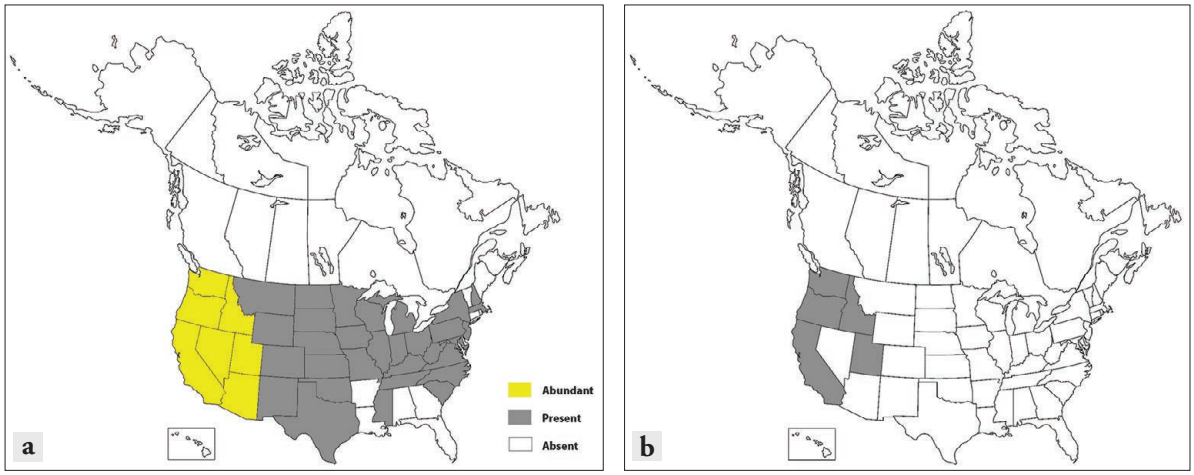


Figure 3-6. North American establishment of a. yellow starthistle; b. *Bangasternus orientalis* (Credits: a USDA PLANTS Database, EDDMapS; b Winston et al. 2014a)

Eustenopus villosus (Boheman)

Yellow starthistle hairy weevil

Quick Facts	
Order	Coleoptera
Family	Curculionidae
Native Distribution	Europe, Mediterranean
Original Source	Greece
First Release	1990
Non-target Effects	None reported

Description

Eggs are translucent, oval-shaped, and tiny (Figure 3-7a). Larvae are up to 6 mm long with white, C-shaped bodies and brown head capsules (Figure 3-7b). Adults are 4-6 mm long with oblong, cylindrical bodies and long, slender snouts (Figure 3-7d). Adult bodies are brown with lighter-colored longitudinal stripes and are covered with long hairs.

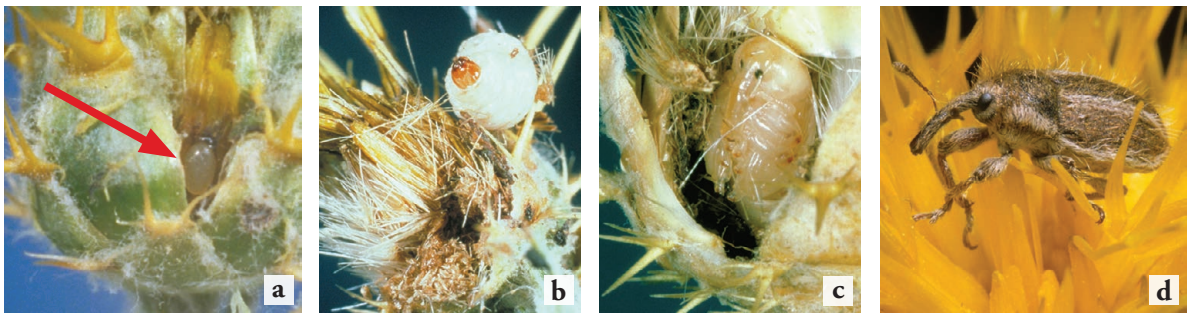


Figure 3-7. *Eustenopus villosus*, a. egg between starthistle bracts (red arrow); b. larva and seed head damage; c. pupa; d. adult (Credits: a John Connett, University of Idaho; b,c J. Johnson, University of Idaho; d Laura Parsons & Mark Schwarzländer, University of Idaho)

Life Cycle

Overwintering adults emerge in spring when yellow starthistle is entering the spiny bud stage. They feed heavily on early immature starthistle buds. Females chew holes in the sides of mature, closed buds (pre-flower) in early to midsummer, lay eggs inside, and cap holes with a dark substance (Figure 3-8a). Larvae hatch throughout summer and feed on developing seeds through three instars. Pupation occurs in seed heads in chambers made of damaged seed and receptacle tissue (Figure 3-7c, 3-8c). Adults emerge in late summer and overwinter in soil litter. There is one generation per year (Figure 3-9).

Habitat Preference

This weevil does well throughout the majority of conditions yellow starthistle has invaded in the USA. In California, it is most common in the foothills and less common in the Great Central Valley.

Damage

Larvae feed on receptacle tissue and developing seeds. Adult feeding can lead to a high percentage of mortality of young flower buds (Figure 3-8b). Both forms of feeding do not kill existing plants, but

Figure 3-8. *Eustenopus villosus* damage, a. oviposition hole; b. buds aborted from adult feeding; c. pupal chamber and chewed up florets, seeds, and receptacle tissue (Credits: a John Connett, University of Idaho; b Mark Schwarzländer, University of Idaho; c Charles Turner, USDA ARS)

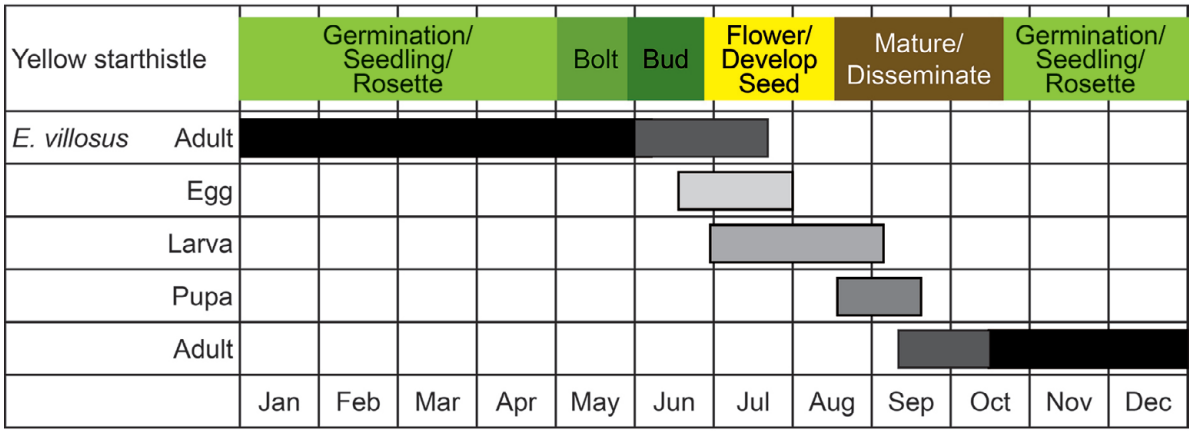


Figure 3-9. Schematic life cycles of *Eustenopus villosus* and yellow starthistle in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. Black bars represent the inactive overwintering period.

reduce seed production which may help decrease the rate of spread of yellow starthistle populations and may reduce infestations in some habitats.

Current Status and Availability

Eustenopus villosus is abundant and widespread in the western USA (Figure 3-10) where larval feeding destroys up to 100% of seeds within attacked seed heads. Adult feeding also delays production of mature flowers by 2-3 weeks and often causes abortion of attacked young flower buds. The combined effect of larval and adult feeding has the largest total impact on yellow starthistle's reproductive output compared with the other biological control insects. However, delayed flower production and mortality of the early flower buds reduces the plant's synchronicity with and attractiveness to other ovipositing seed predators.

Eustenopus villosus consumes a slightly higher proportion of seeds in yellow starthistle seed heads not infected with the rust *Puccinia jacea* var. *solstitialis*. However, this difference is not significant when comparing overall seed production per plant; seed production for plants attacked by seed biocontrol agents is similar whether or not plants are infected with the rust.

In conjunction with the fly, *Chaetorellia succinea*, *E. villosus* can reduce seed production by >70% overall. This is believed to have contributed to significant declines of yellow starthistle populations at some sites that have no disturbance and have competition from grasses and other forbs. No declines in yellow starthistle have been observed at several other areas, especially those with high disturbance such as along roadsides. At many sites, yellow starthistle plants compensate for any decreases in density by growing larger and producing more seed heads. Parasitism and predation may negate the impact of this weevil at some sites.

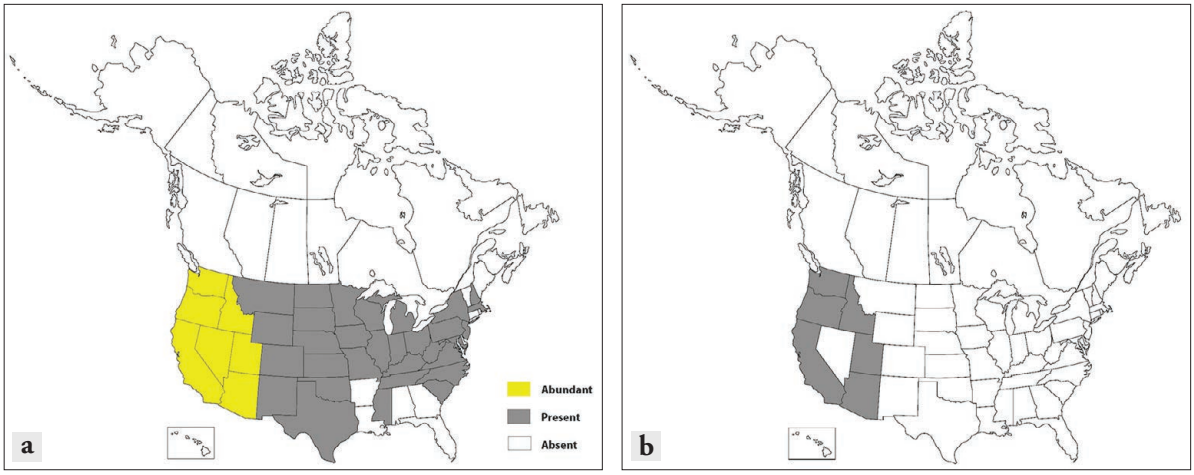


Figure 3-10. North American establishment of a. yellow starthistle; b. *Eustenopus villosus* (Credits: a USDA PLANTS Database, EDDMapS; b Winston et al. 2014a)

Larinus curtus Hochhut

Yellow starthistle flower weevil

Quick Facts	
Order	Coleoptera
Family	Curculionidae
Native Distribution	Eurasia, Mediterranean
Original Source	Greece
First Release	1992
Non-target Effects	None reported

Description

Eggs are tiny, yellow, and elongate. Larvae are up to 6 mm long with white, C-shaped bodies and brown head capsules (Figure 3-11a). Adults are 5-6 mm long with oval-shaped bodies and medium-length snouts (Figure 3-11b). Adult bodies are brown with white hairs that give them a mottled appearance. The body hairs are often yellowish from yellow starthistle pollen.

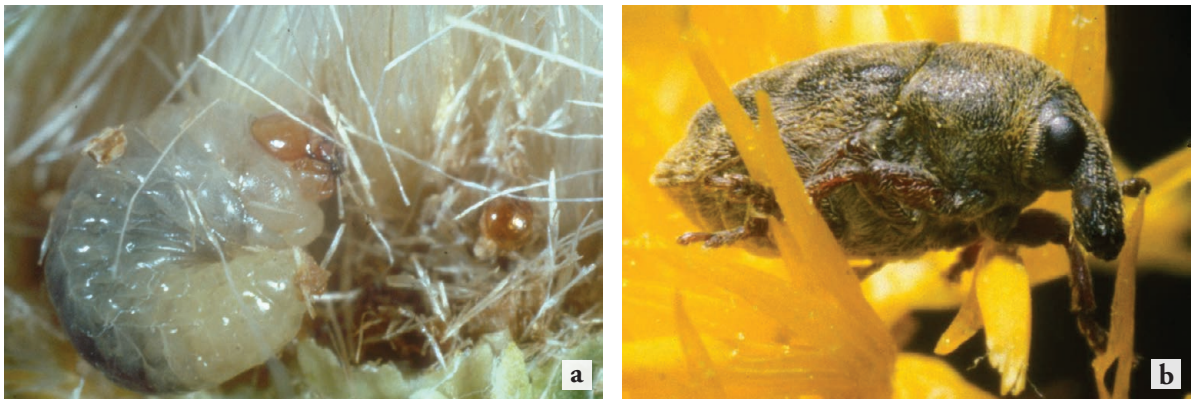


Figure 3-11. *Larinus curtus*, a. larvae; b. adult (Credits: a Charles Turner, USDA ARS, bugwood.org; b Laura Parsons & Mark Schwarzländer, University of Idaho)

Life Cycle

Overwintering adults emerge in summer when yellow starthistle is in bud and flowering and feed on florets and pollen. Females lay eggs singly in open flower heads at the base of florets. Larvae hatch in late summer and feed on developing seeds through three instars. Pupation occurs in seed heads in chambers made of damaged seed and receptacle tissue. Adults emerge in late summer and overwinter in the soil litter. There is one generation per year (Figure 3-12).

Habitat Preference

This weevil does well throughout the majority of conditions yellow starthistle has invaded in the USA.

Damage

Adults feed on pollen and florets, though the impact is typically minor. Larvae feed on flower head tissue and developing seeds. Seed consumption does not kill existing plants, but reduces seed production which may help decrease the rate of spread of yellow starthistle populations and may reduce infestations in some habitats.

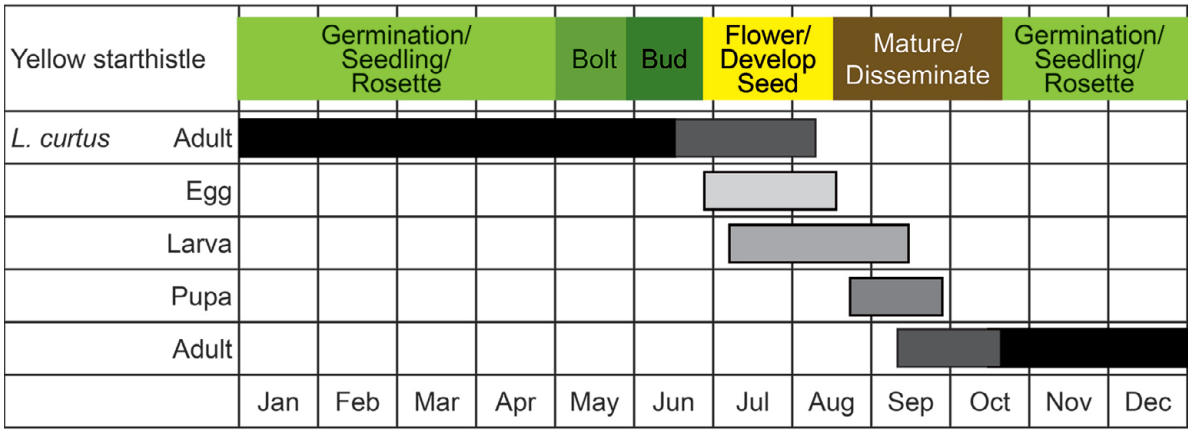


Figure 3-12. Schematic life cycles of *Larinus curtus* and yellow starthistle in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. Black bars represent the inactive overwintering period.

Current Status and Availability

In the western United States (Figure 3-13), larval feeding destroys up to 100% of seeds within attacked seed heads; however, attack rates are typically low. Abundance of this weevil plateaued within a few years of its introduction, and its current abundance varies from high in portions of Oregon, to moderate in Washington, to becoming more limited in Idaho and California. It is less abundant than the other seed-feeding biocontrol agents which have been unable to impact yellow starthistle population trajectories at many sites. Impact is highest at sites with significant competition from other plant species. Some *L. curtus* populations have been found to be infected with microsporidia (*Nosema* sp.), which are internal parasites of the digestive tract. It has been suggested that microsporidia may reduce survivorship and fecundity of infected adults; however, population-level impacts on *L. curtus* field populations are unknown.

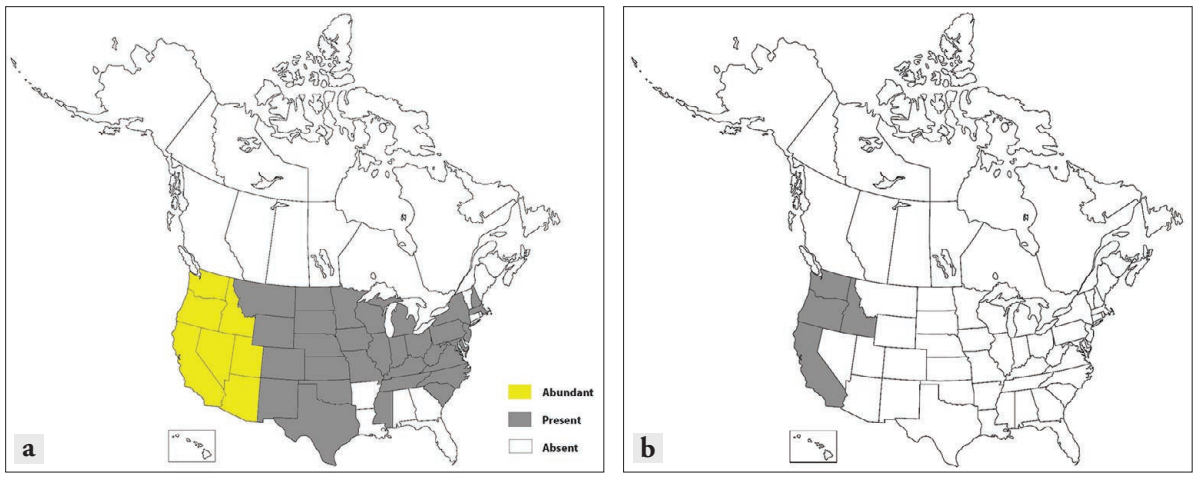


Figure 3-13. North American establishment of a. yellow starthistle; b. *Larinus curtus* (Credits: a USDA PLANTS Database, EDDMapS; b Winston et al. 2014a)

Non-target Effects

Adult *L. curtus* were found feeding on open flower heads of cultivated safflower (*Carthamus tinctorius*), but no egg laying or development occurred. Consequently, there has been no impact to safflower production.

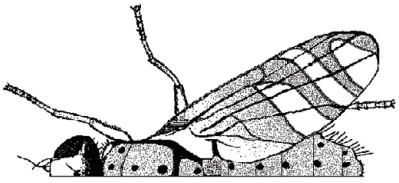
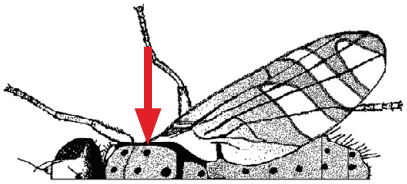
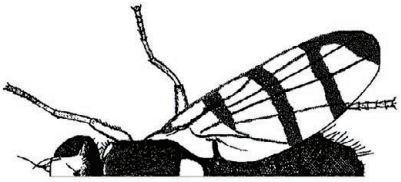
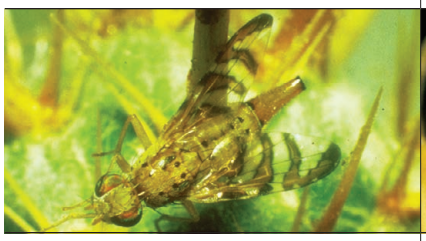
Yellow Starthistle Flies

Flies used for yellow starthistle biological control are fruit flies; larvae of the flies eat the developing yellow starthistle seeds (fruit). Adult flies are small with short antennae and patterned wings. They obtain nectar from yellow starthistle and other flowers, but adults do not damage yellow starthistle plants. It is the internally-feeding larval stage that causes damage. Larvae develop through three instars inside yellow starthistle seed heads. Fly larvae are white, turning yellowish with maturity. They are legless, without an obvious head capsule, and slightly thicker at one end.

All three yellow starthistle flies have two generations per year, although the *Chaetorellia* spp. may have three at sites with long growing seasons. Overwintering larvae pupate in old seed heads in the spring, and adults emerge to feed, mate, and lay eggs in newly-formed seed heads. The summer generation adults emerge during early to mid-summer to feed, mate, and oviposit eggs. Larvae from this generation typically overwinter in seed heads and finish development the following spring.

Table 3-3 provides a comparison of the three flies used for yellow starthistle biological control. Table 3-4 compares life cycles of each of the flies.

Table 3-3. Comparison of adult yellow starthistle flies.

Chaetorellia australis	*Chaetorellia succinea*	*Urophora sirunaseva*
		
		
4 black spots on thorax (2 per side)	6 spots on thorax (2 per side)	Yellow spot on thorax
Straw-colored body	Straw-colored body	Black body
Straw-colored wing bands	Straw-colored wing bands	Black wing bands
2-3 generations per year	2-3 generations per year	2 generations per year
Female oviposits inner side lateral bracts	Female oviposits inner side lateral bracts	Female oviposits on top of buds
Release at BU-3 stage	**Accidental, not approved for release**	Release at BU-2 to BU-3

Credits: Fly line drawings (J. Johnson, University of Idaho); Photos (*C. australis* Charles Turner USDA ARS; *C. succinea* and *U. sirunaseva* Laura Parsons & Mark Schwarzländer, University of Idaho)

Table 3-4. Comparison of fly life cycles by yellow starthistle growth stages. BU 1-4 represent the four different bud stages (refer to Figure 2-7 to see pictures of each bud stage).

YST Stage	*Chaetorellia australis*	*Chaetorellia succinea*	*Urophora sirunaseva*
Seedling	Larvae overwinter in old seed heads	Larvae overwinter in old seed heads	Larvae overwinter in woody galls in seed heads
Rosette			
Bolting	Adults emerge and are visible on plants; sometimes utilizing *Centaurea cyanus*	Adults emerge and are visible on plants; sometimes utilizing *Centaurea melitensis* and *C. cyanus*	
BU-1	Females oviposit between bracts of closed buds	Adults continue to emerge; females oviposit between bracts of closed buds	Adults emerge; visible on plant
BU-2	Larvae develop, feed on seeds; pupation begins	Larvae develop, feed on seeds; pupation begins	Females oviposit in closed buds
BU-3	New generation adults emerge; oviposit in buds	New generation adults emerge; oviposit in buds	Larvae tunnel in and feed within galls; pupation begins in galls
BU-4	Adults still present on plants; new larvae develop, feed on seeds	Adults still present on plants; new larvae develop, feed on seeds	New generation adults emerge; oviposit on buds
Flowering	Larvae continue to develop; feed on seeds	Larvae continue to develop; feed on seeds	Adults still present on plants; new larvae develop, feed within galls
Seed formation	Mature larvae found in seed heads; overwinter in seed heads	Mature larvae found in seed heads; overwinter in seed heads	Larvae continue to develop and feed within galls
Mature			Mature larvae overwinter in woody galls in seed heads
Dissemination			
Senescence			

Chaetorellia australis (Treitschke) & *C. succinea* (Costa)

Yellow starthistle peacock fly & False yellow starthistle peacock fly

Chaetorellia australis	
Order	Diptera
Family	Tephritidae
Native Distribution	Europe, Mediterranean
Original Source	Greece
First Release	1988
Non-target Effects	None reported

Chaetorellia succinea	
Order	Diptera
Family	Tephritidae
Native Distribution	Europe, Mediterranean
Original Source	Greece
First Release	1991, Accidental
Non-target Effects	*Carthamus tinctorius*

Description

Both species are very similar in appearance, with the exception of the spots on the thorax of adults. Eggs are elongated and white or pale yellow. Larvae are somewhat barrel-shaped (though slightly thicker at one end) and up to 4 mm long. They are white, turning yellowish with maturity, and lack an obvious head capsule (Figure 3-14a,d). Pupae are concealed in a barrel-shaped puparium up to 3.5 mm long and pale yellow with dark ends. Adults have tan bodies with black spots on the thorax; there are 8 spots on the thorax of *C. australis* while *C. succinea* has 10 (Figure 3-14b,e). Their eyes are multi-colored and metallic, and their wings are clear with thick brown bands (Figure 3-15c,f). Males are 3-4 mm long; females are 4-6 mm, including ovipositors.

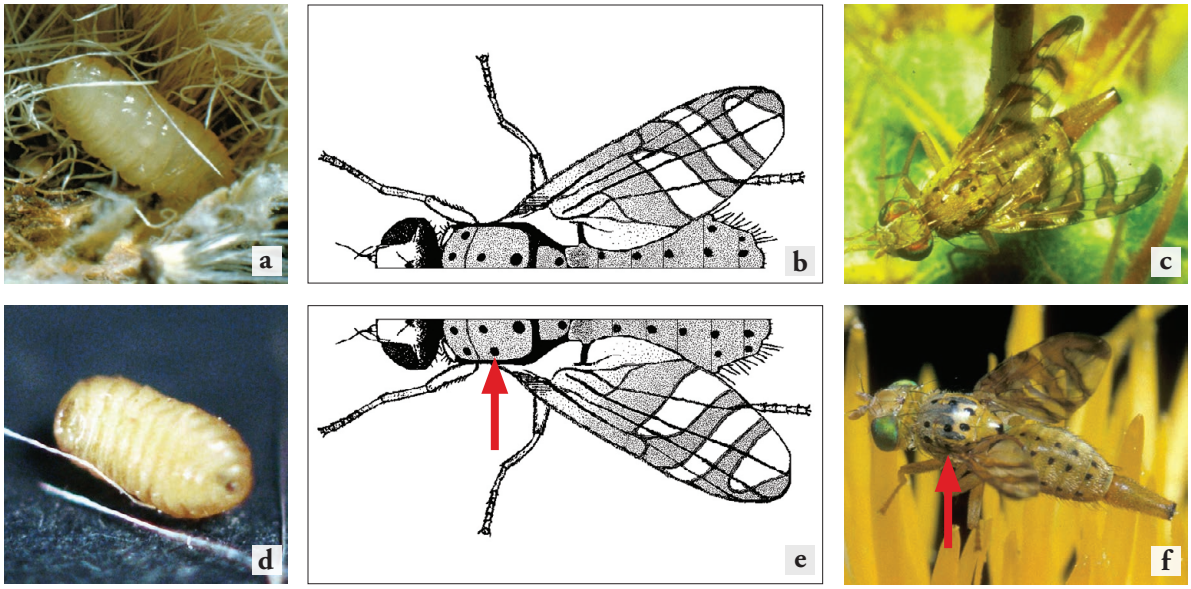


Figure 3-14. *Chaetorellia australis,* a. larva, b. line drawing, c. adult; *C. succinea* d. larva, e. line drawing with extra spot on thorax (red arrow), f. adult with extra spot on thorax (red arrow) (Credits; a Gary Piper, Washington State University; b,e J. Johnson, University of Idaho; c Charles Turner, USDA ARS; d Rachel Winston, MIA Consulting; f Laura Parsons & Mark Schwarzländer, University of Idaho)

Life Cycle

Adults of both species emerge in spring before yellow starthistle has begun to bolt. Adults often feed on nectar of vetch (*Vicia* spp.) or other plants with early-developing flowers while waiting for

their target plants to develop to the appropriate stage for oviposition. Adult females lay eggs singly beneath bracts of closed buds. After hatching, larvae tunnel into capitula and feed on receptacle tissue and developing seeds through three instars. Pupation occurs in puparia within flower heads inside chambers made of pappus and chewed seeds. Adults emerge in early to mid-summer, mate, and lay eggs in more starthistle buds. Larvae of the summer generation overwinter as mature larvae within starthistle seed heads. There are usually two generations, though three generations are possible where the growing season is sufficiently long (Figure 3-15, 3-16).

Both *C. australis* and *C. succinea* adults often emerge too early to utilize yellow starthistle. *Chaetorellia australis* will frequently oviposit in buds of the earlier-flowering invasive weed bachelor's button (*Centaurea cyanus*); adults emerging as part of the next generation will then utilize yellow starthistle. Likewise, *C. succinea* females will often oviposit in seed heads of *C. cyanus* and the invasive Maltese starthistle (*C. melitensis*) in spring, then move to yellow starthistle in the subsequent generation.

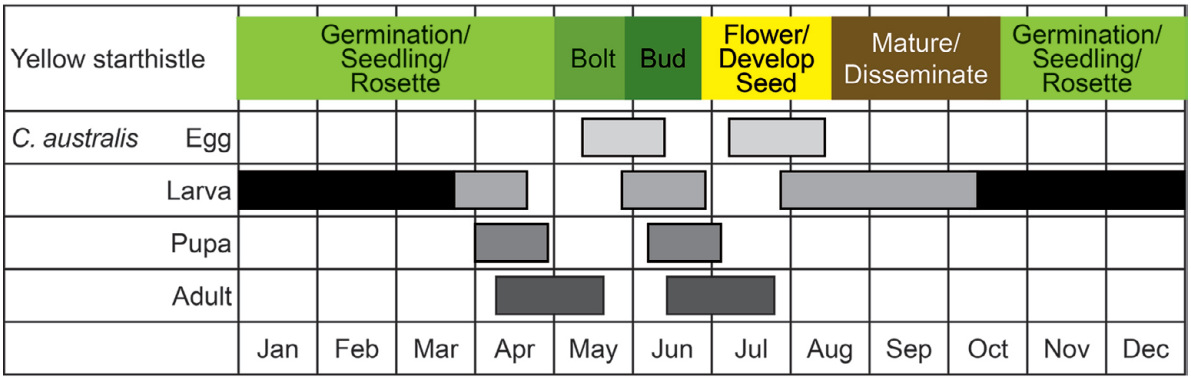


Figure 3-15. Schematic life cycles of *Chaetorellia australis* and yellow starthistle in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. Black bars represent the inactive overwintering period. There are typically two generations per year, sometimes three where growing seasons are long.

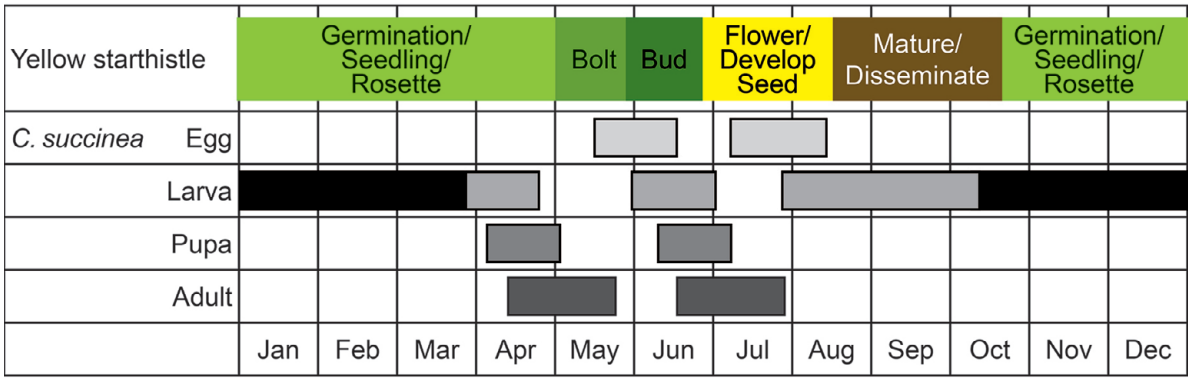


Figure 3-16. Schematic life cycles of *Chaetorellia succinea* and yellow starthistle in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. Black bars represent the inactive overwintering period. There are typically two generations per year, sometimes three where growing seasons are long.

Habitat Preference

In the western United States, *C. succinea* occurs wherever yellow starthistle grows (Figure 3-17c). *Chaetorellia australis* (Figure 3-17b) does best where bachelor's button (*Centaurea cyanus*) co-occurs with yellow starthistle. Both fly species prefer warm sites. *Chaetorellia australis* appears to do best at low-elevation sites, while elevation does not limit *C. succinea* populations.

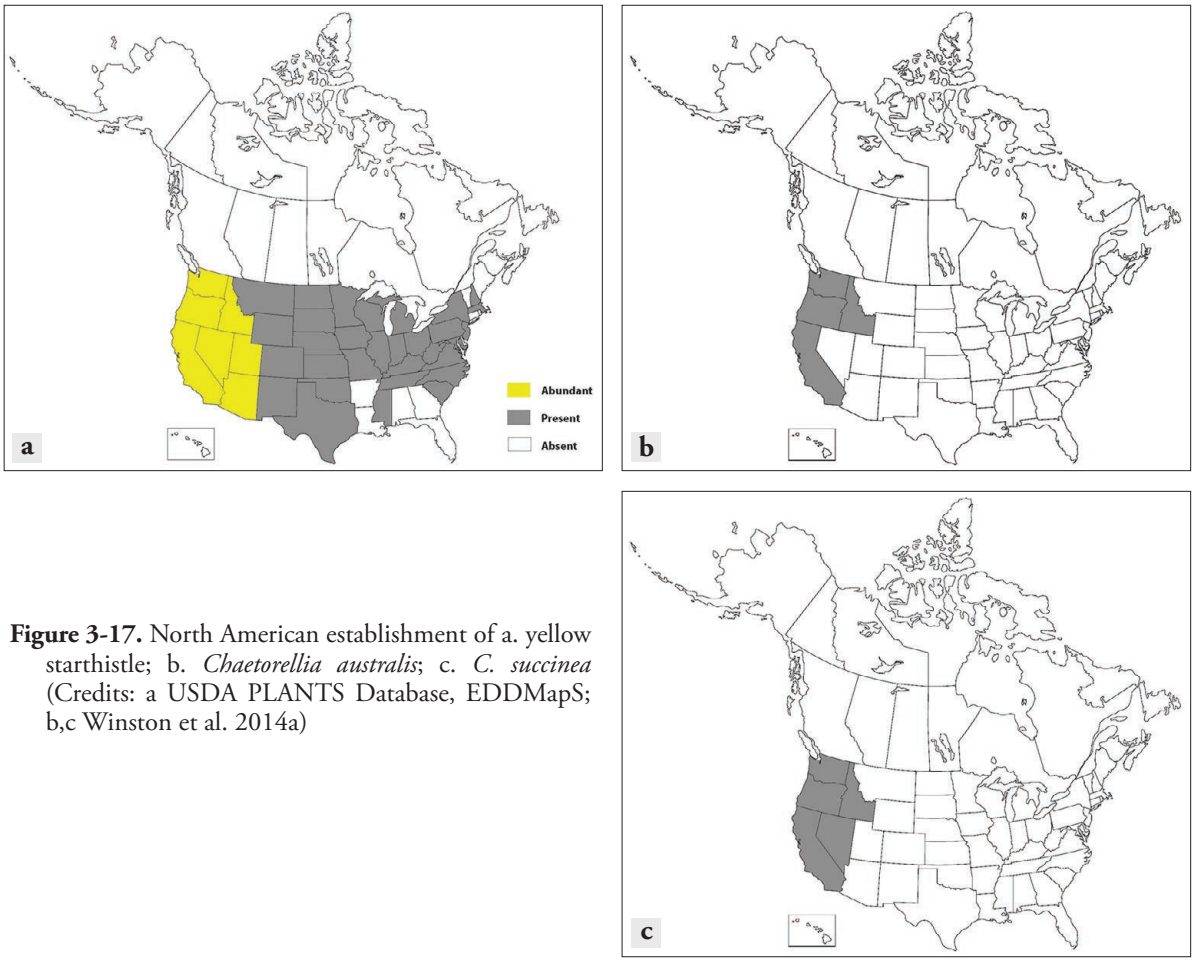


Figure 3-17. North American establishment of a. yellow starthistle; b. *Chaetorellia australis*; c. *C. succinea* (Credits: a USDA PLANTS Database, EDDMapS; b,c Winston et al. 2014a)

Damage

Larvae feed on developing seeds. Seed consumption does not kill existing plants, but reduces seed production which may help decrease the rate of spread of yellow starthistle populations and may reduce infestations in some habitats.

Current Status and Availability

Chaetorellia australis initially established only at sites where bachelor's button, *Centaurea cyanus,* was present. At one successful release site where bachelor's button was not established, it was determined the release inadvertently contained a mix of *C. australis* and the closely related *C. succinea*. *Chaetorellia succinea* subsequently spread rapidly throughout western USA.

Chaetorellia australis is currently established on both bachelor's button and yellow starthistle. Its abundance varies, often in relation to bachelor's button presence. Attack rates are often higher on

bachelor's button, on which it can reduce seed production by up to 70% in Washington. It can destroy up to 90% of seeds in attacked yellow starthistle capitula; however, attack rates have typically not exceeded 10% of available capitula, likely due to poor synchrony in spring.

Of the two species, *C. succinea* is considered the more effective biocontrol agent for yellow starthistle because it is widespread and often builds up high populations locally. Larval feeding destroys up to 80% of seeds within attacked yellow starthistle seed heads and decreases pollinator visitation. *Chaetorellia succinea* consumes a slightly higher proportion of seeds in yellow starthistle seed heads not infected with the rust *Puccinia jacea* var. *solstitialis*. However, this difference is not significant when comparing overall seed production per plant; seed production for plants attacked by seed biocontrol agents is similar whether or not plants are infected with the rust. *Eustenopus villosus* populations are associated with lower populations of *C. succinea* (and the other seed head insects), due to *E. villosus* causing delayed flower production and mortality of early flower buds, and also possibly due to *E. villosus* larvae killing larvae of other insects co-habiting the seed head. Further studies of these interactions and their outcomes are warranted. Despite this, *C. succinea* and *E. villosus* in combination can reduce yellow starthistle seed production by >70% overall. Whether this level of seed destruction results in a decline of yellow starthistle abundance depends on many factors. At many infestations, yellow starthistle plants compensate for any decreases in density by growing larger and producing more seed heads. Impact is highest at sites with significant competition from other plant species.

Non-target Effects

Chaetorellia succinea larvae were found feeding in the heads of commercial safflower (*Carthamus tinctorius*) in California, though damage was minimal. Field and laboratory trials documented *C. succinea* ovipositing and developing in the flower heads of *Plectocephalus americana*, a related genus indigenous to the central and southwestern United States. An application and permit (USDA-APHIS-PPQ 526 permit) to move *C. succinea* has not been submitted, and **this species remains unauthorized for release or redistribution**. It is likely that this fly will attack *P. americana* and its relative *P. rothrockii* in the field if the fly should reach their geographic range (Arizona to Missouri) through its own natural dispersal.

Field and laboratory trials also found *C. succinea* to oviposit and develop on the weedy and exotic Maltese starthistle (*Centaurea melitensis*) and Sicilian starthistle (*C. sulphurea*).

Urophora sirunaseva (Héring)

Yellow starthistle gall fly

Quick Facts	
Order	Diptera
Family	Tephritidae
Native Distribution	Europe, Mediterranean
Original Source	Greece
First Release	1984
Non-target Effects	None reported

Description

Eggs are elongated and white or pale yellow. Larvae are somewhat barrel-shaped (though slightly thicker at one end) and up to 4 mm long. They are white, turning yellowish with maturity, and lack an obvious head capsule but have a dark anal plate (Figure 3-18a). Pupae are concealed in a barrel-shaped puparium up to 3.5 mm long and pale yellow with dark ends. Puparia are contained in woody galls (Figure 3-18a,b). Adults have black bodies with a yellow spot on the rear part of the thorax. Their eyes are multi-colored and metallic, and their wings are clear with dark crossbands (Figure 3-18c). Males are 3-4 mm long; females are 4-6 mm, including ovipositors.

Figure 3-18. *Urophora sirunaseva*, a. larva in gall; b. multiple woody galls in capitulum; c. adult (Credits: a,b Charles Turner, USDA ARS; c Laura Parsons & Mark Schwarzländer, University of Idaho)

Life Cycle

Adults emerge in spring as yellow starthistle is bolting and starting to form buds. Females lay eggs in immature, closed buds amongst the developing florets. After hatching, the larva follows a floret tube down to the ovule at the base of the floret. The larva enters the ovule (young achene) and the plant responds by beginning formation of a gall. Multiple galls will occur in one flower head. There are three larval instars, prior to pupation within galls. Adults emerge in early to mid-summer, mate, and lay eggs in more yellow starthistle buds. Larvae of the summer generation overwinter within galls inside the seed heads. There are two generations per year (Figure 3-19).

Habitat Preference

Specific habitat requirements are unknown for *Urophora sirunaseva,* but this fly does not seem to do well at overly windy locations. In California, *U. sirunaseva* is more common in the coastal mountains and less common in the interior of the state.

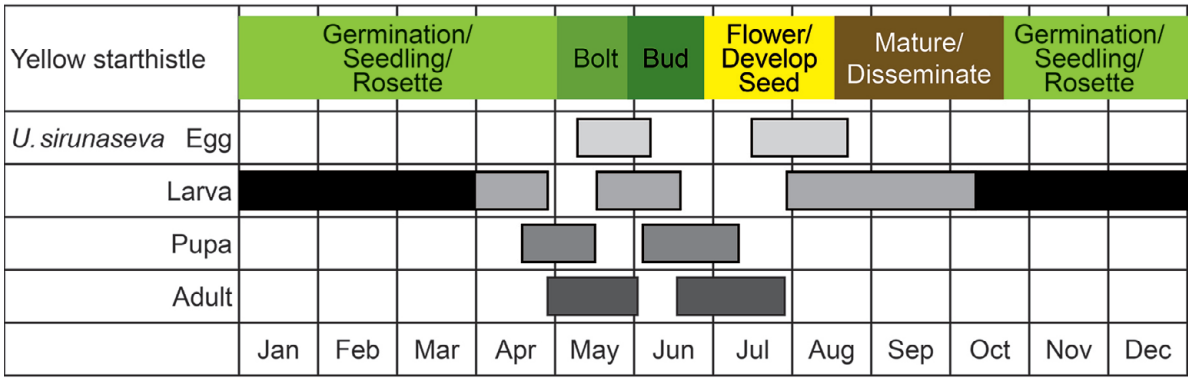


Figure 3-19. Schematic life cycles of *Urophora sirunaseva* and yellow starthistle in North America. Bars indicate the approximate length of activity for each life stage; dates will vary depending on local conditions. Black bars represent the inactive overwintering period. There are typically two generations per year, sometimes three where growing seasons are long.

Damage

Floret feeding and gall formation reduce seed production. Galls are believed to act as nutrient sinks, diverting plant resources away from regular plant function and seed formation.

Current Status and Availability

The first introductions occurred on yellow starthistle in California beginning in 1969, utilizing flies collected in Italy. After multiple releases failed to establish, it was determined the species introduced was in fact *Urophora jaculata,* which is specific to yellow starthistle biotypes growing only in Italy. The true *U. sirunaseva* was subsequently released in the USA beginning in 1984.

In the western United States (Figure 3-20), gall formation decreases yellow starthistle seed production, though multiple galls are required per seed head before seed reduction is significant, and high gall density per capitulum is not common. While this species is widely distributed, abundance is low. Attack rates peaked at approximately 50% a few years following their successful establishment. More recently, attack rates are closer to 10% of yellow starthistle seed heads. Consequently, its overall impact is now limited. Populations at some sites are hindered by competition with other seed head agents.

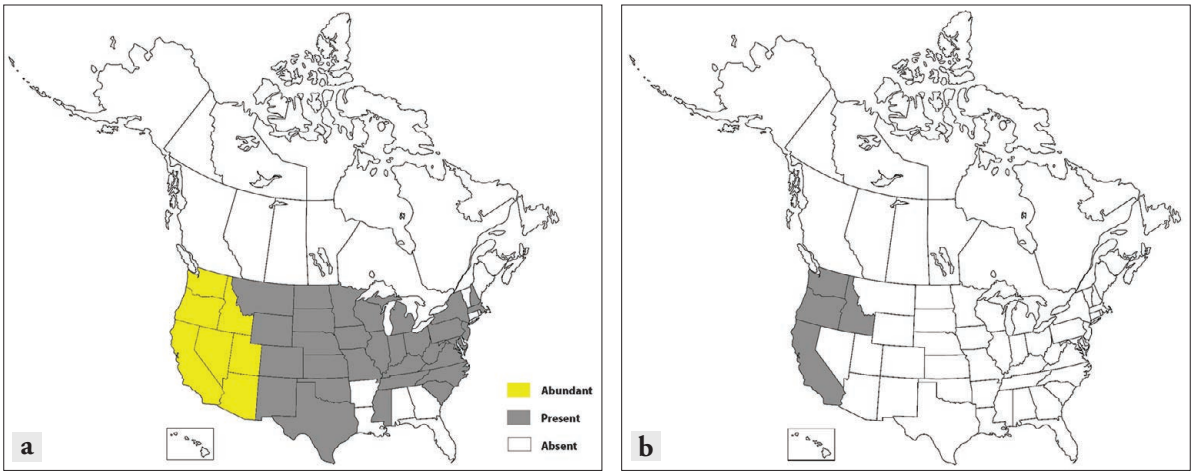


Figure 3-20. North American establishment of a. yellow starthistle; b. *Urophora sirunaseva* (Credits: a USDA PLANTS Database, EDDMapS; b Winston et al. 2014a)

Puccinia jaceae var. *solstitialis* (Savile)

Yellow starthistle rust fungus

Quick Facts	
Class	Pucciniomycetes
Order	Pucciniales
Native Distribution	Eurasia, Mediterranean
Original Source	Turkey
First Release	2003
Non-target Effects	None reported

Description and Life Cycle

The fungus produces up to five spore stages throughout the growing season. In the spring, overwintering spores germinate and infest yellow starthistle rosette leaves, forming yellowish chlorotic lesions with raised centers. These turn into orangish-brown pustules that produce large amounts of dry, powdery, round, spores that are rusty or dark brown in coloration (Figure 3-21). These spread rapidly from plant to plant; they are easily dispersed by both wind and rain. The entire process can take two weeks to complete, and multiple cycles may be produced throughout the year.

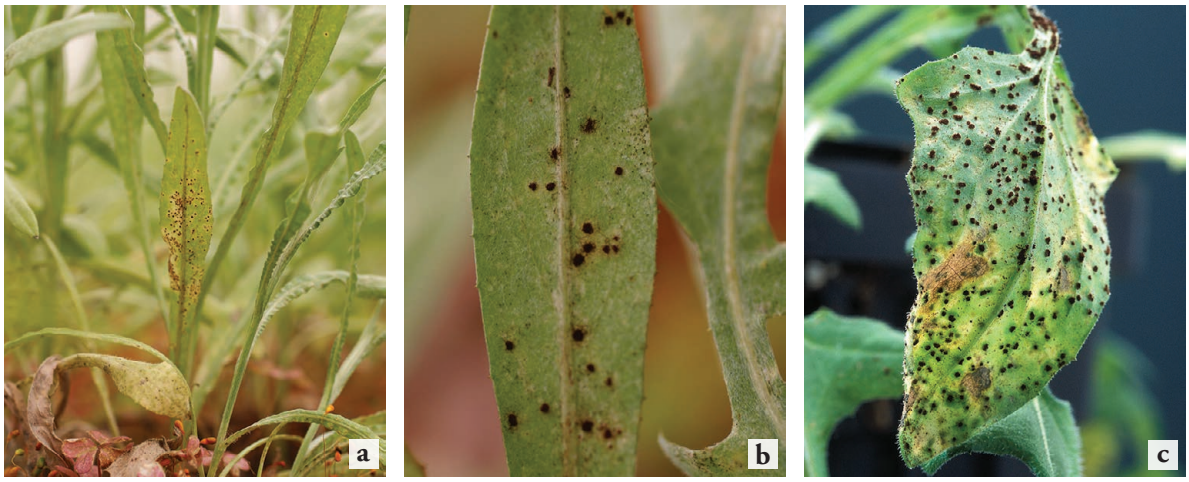


Figure 3-21. *Puccinia jaceae* var. *solstitialis* infecting yellow starthistle (Credits: a,b Eric Coombs, Oregon Department of Agriculture, bugwood.org; c Stephen Ausmus, USDA ARS, bugwood.org)

Habitat Preference

The yellow starthistle rust fungus requires climates with dew periods that result in moisture forming or collecting on starthistle foliage.

Damage

Infected plants can experience stunted growth, reduced seed production, and a higher susceptibility both to competition from other plants and attack from additional biocontrol agents.

Current Status and Availability

The yellow starthistle rust fungus is established only in California and Oregon (Figure 3-22). Under

optimal conditions (moist, mild temperatures) the rust can reduce yellow starthistle biomass and the number of capitula, especially in conjunction with high plant competition. At drier sites, impact is decreased and likely to be of only minor biological significance. Across much of yellow starthistle's range, suboptimal climatic conditions prevent the rust's persistence and/or significant impact.

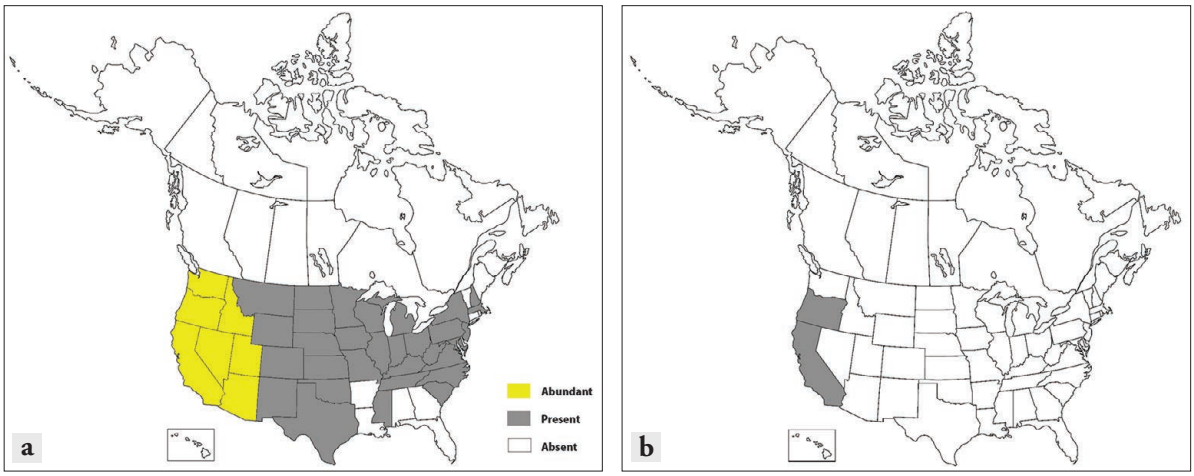


Figure 3-22. North American establishment of a. yellow starthistle; b. *Puccinia jaceae* var. *solstitialis* (Credits: a USDA PLANTS Database, EDDMapS; b Winston et al. 2014a)

CHAPTER 4: ELEMENTS OF A YELLOW STARTHISTLE 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 yellow starthistle is not present or where a small number of localized populations occur. Biological control as a control method is best suited to yellow starthistle populations in the later phases of the invasion curve, where yellow starthistle populations are experiencing a rapid increase in distribution and abundance (containment), or where yellow starthistle is widespread and abundant throughout its potential range (asset based protection, Figure 1-3 repeated here in Figure 4-1).

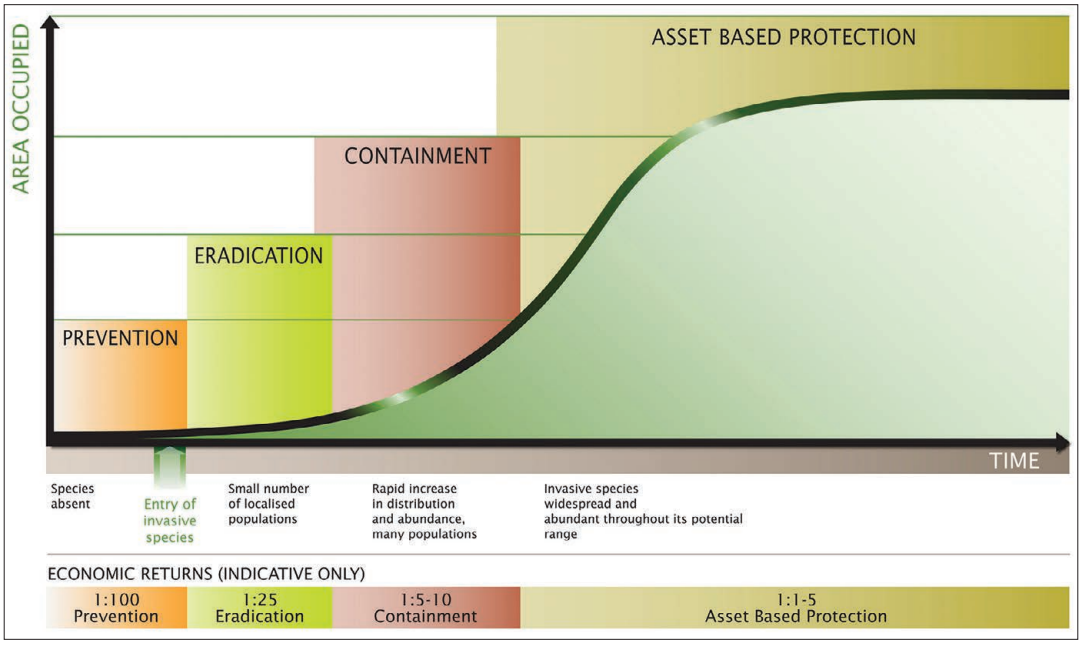


Figure 4-1. Generalized invasion curve showing actions appropriate to each stage (Credit: © State of Victoria, Department of Economic Development, Jobs, Transport and Resources, Reproduced with permission)

The results of using biological control to treat yellow starthistle 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 yellow starthistle problem, defining overall goals for the yellow starthistle 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 yellow starthistle 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 yellow starthistle infestations and limited resources, aerial mapping of large patches of yellow starthistle may be sufficient to identify priority areas for additional survey, mapping, and weed management activities. In other management areas with smaller, more discrete yellow starthistle 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).

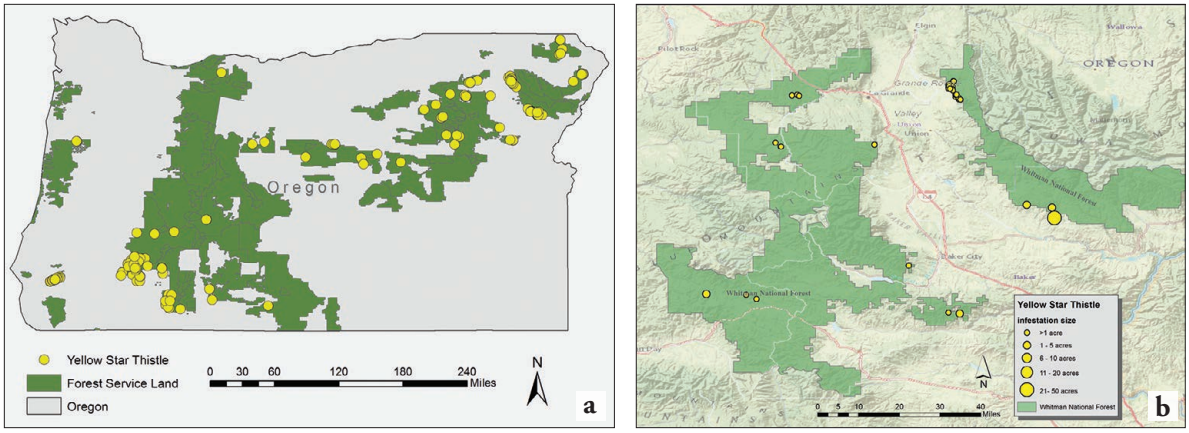


Figure 4-2. Yellow starthistle data for a. USDA Forest Service land with yellow starthistle infestations in the state of Oregon; b. infestations in Oregon's Whitman National Forest (Credits: a,b Becca VanKampen, MIA Consulting, EDDMapS)

In many cases, it may prove useful to check for existing yellow starthistle distribution data before collecting your own. Several agencies and organizations maintain weed distribution databases, including state agricultural 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 yellow starthistle distribution maps for their area. By visiting www.eddmaps.org and creating a free account, users can view existing distribution maps for yellow starthistle or other weeds at the state, county, or point level. By selecting the GIS view option, users can view yellow starthistle data on various backgrounds and zoomed 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 yellow starthistle data from user shapefiles, edit the management status of various infestations, and print finished maps (see page 68 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 yellow starthistle management program. For example, the objective of ". . . a noticeable reduction in yellow starthistle 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% reduction in yellow starthistle stems over the next three years . . ." is objectively measurable (and therefore SMART). If your goal is to reduce the abundance of yellow starthistle or slow its rate of spread, then biological control might be an appropriate weed management tool; however, by itself biological control will not completely and permanently remove yellow starthistle from the landscape. If your goal is to eradicate yellow starthistle, 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 Yellow Starthistle Management Options

Once you determine the scope of your yellow starthistle infestations and define your overall program goals, review all 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 yellow starthistle management activities (herbicide use, grazing, 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 yellow starthistle management program.

With a map of yellow starthistle 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 Yellow Starthistle Biological Control Program

When biological control is deemed suitable for treating your yellow starthistle infestations, there are several important factors to consider. These include selecting appropriate release sites, obtaining and releasing biocontrol agents, and monitoring the success of the program. Familiarity with all aspects of a biocontrol

program before beginning will greatly facilitate its implementation and increase its chances of success. These items are discussed in their own sections below. If problems are encountered following the initiation of a biological control program, refer to the troubleshooting guide in Appendix I for potential solutions.

Selecting Biological Control Agent Release Sites

Establish Goals for Your Release Site

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

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

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

Determine Site Characteristics

For practical purposes, no yellow starthistle infestation is too large for biocontrol releases; however, it might not be large enough (Figure 4-3a). Very small, isolated patches of yellow starthistle 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 (0.4 ha) of yellow starthistle 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 yellow starthistle 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 yellow starthistle 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 yellow starthistle 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, rangelands that are subjected to grasshopper control, or

Figure 4-3. Yellow starthistle infestations, a. too small for biological control (single plant); b. appropriate for biological control (Credits: a John M. Randall, The Nature Conservancy, bugwood.org; b Charles Turner, USDA ARS, bugwood.org)

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

Survey for Presence of Biological Control Agents

Always examine your prospective release sites to determine if yellow starthistle biological control agents are already present. 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 biocontrol agent 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 biocontrol agent harvesting or data collection. General releases of biological control agents to control yellow starthistle 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
- 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).

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

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 (Table 4-1).

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) more effective given local site characteristics and management scenarios.

Biocontrol Agent Availability

All six of the USA-approved biological control agents described in this manual are established in the continental USA; however, availability varies greatly between species and sites (Table 4-1). The unapproved *Chaetorellia succinea* is the most widespread of all yellow starthistle biocontrol agents, and care should be taken when collecting any other species to ensure *C. succinea* is not collected along with approved biocontrol agents. The hairy weevil *Eustenopus villosus* is also very widespread and effective on yellow starthistle in the USA and is available for collection in Arizona, California, Idaho,

Table 4-1. Summary of general characteristics and site preferences of yellow starthistle biological control agents released in North America

Biocontrol Agent Characteristics				Site Characteristics	
Species	**Part Attacked**	**Efficacy**	**Availability**	**Favorable Conditions**	**Unfavorable Conditions**
Bangasternus orientalis Yellow starthistle bud weevil	Receptacle tissue and seeds	Destroys 60% seeds in attacked seed heads, but attacks only 1% of seed heads; hindered by predation, parasitism, and competition with other established biocontrol agents	Initially widespread, but now limited in abundance in CA, ID, OR, WA and UT	Mesic climates; sites where *Eustenopus villosus* is absent or limited	Cold or hot/dry climates; sites with high predator, parasite, and/or *Eustenopus villosus* populations
Chaetorellia australis Yellow starthistle peacock fly	Receptacle tissue and seeds	Destroys up to 90% seeds in attacked seed heads, but usually attacks ≤10% of seed heads; limited by poor synchrony with yellow starthistle in spring	Abundance in CA, ID, OR and WA varies in relation to bachelor's button presence	Sites with populations of bachelor's button; warm, low-elevation sites	Sites with no bachelor's button available in spring; cold, high-elevation sites
Chaetorellia succinea False yellow starthistle peacock fly	Receptacle tissue and seeds	Destroys up to 80% seeds in attacked seed heads and decreases pollinator visits; in conjunction with *E. villosus*, reduces seed produced by >70% overall; most effective at sites with high interspecific plant competition	Abundant in CA, ID, NV, OR and WA. **Not approved for release or redistribution**	Does well under conditions found at most yellow starthistle infestations in the USA	Sites with no alternative *Centaurea* species or other nectar-producing species available in spring; cold sites
Eustenopus villosus Yellow starthistle hairy weevil	Receptacle tissue and seeds	Destroys up to 100% seeds in attacked seed heads and causes bud abortion; in conjunction with *C. succinea*, reduces seed produced by >70% overall; most effective at sites with high interspecific plant competition	Abundant in AZ, CA, ID, OR, WA and UT	Does well under conditions found at most yellow starthistle infestations in the USA	Sites with high predator and/ or parasite populations
Larinus curtus Yellow starthistle flower weevil	Receptacle tissue and seeds	Destroys up to 100% seeds in attacked seed heads, but seed head attack rates are typically low; hindered by parasitism	Abundant in portions of OR, moderate in WA, becoming more limited in ID and CA	Does well under conditions found at most yellow starthistle infestations in the USA	Sites with *Nosema* sp. microsporidia present
Puccinia jaceae var. *solstitialis* Yellow starthistle rust	All above-ground growth	Reduces biomass and number of seed heads, but only under moist, mild conditions. At dry sites, impact is limited. Most effective at sites with high interspecific plant competition.	Abundance limited in CA and OR	Moist, mild temperatures	Hot, dry sites with limited dew periods
Urophora sirunaseva Yellow starthistle gall fly	Receptacle tissue and seeds	Gall formation decreases seed production; multiple galls per seed head are needed before seed reduction is significant; attacks typically only 10% of seed heads	Though widely distributed in CA, ID, OR and WA, abundance is low	Sites where other biocontrol agents are limited or absent	Windy locations; sites with high populations of other biocontrol agents

Oregon, Washington, and Utah. The weevils *Bangasternus orientalis* and *Larinus curtus* and the flies *Chaetorellia australis* and *Urophora sirunaseva* are all established in California, Idaho, Oregon, and Washington, but they vary in their abundance and impact. *Bangasternus orientalis* (also established in Utah) and *U. sirunaseva* were initially more widespread but are both now limited in abundance. *Chaetorellia australis* is most abundant at sites where bachelor's button (*Centaurea cyanus*) is also established. *Larinus curtus* abundance is high in portions of Oregon, moderate in Washington, and becoming more limited in Idaho and California. The rust *Puccinia jaceae* var. *solstitialis* is the least abundant biocontrol agent; it is sparsely established on yellow starthistle only in California and Oregon.

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 Yellow Starthistle Biological Control Agents, below). In the USA, 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 USA, interstate transport of biological control agents requires a USDA-APHIS-PPQ 526 Permit (see Regulations for the Transfer of Yellow Starthistle Biological Control Agents, page 66). 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 Table 4-1 to help land managers ensure that biocontrol agents are released at sites with suitable conditions.

Obtaining and Releasing Yellow Starthistle Biological Control Agents

You can obtain yellow starthistle 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 yellow starthistle biocontrol agents.

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 locations in adjacent counties/districts. Remember that in the USA, interstate transport of biological control agents requires a USDA-APHIS-PPQ 526 Permit (see Regulations Pertaining to the Transfer of Yellow starthistle Biological Control Agents, page 66). Get your permits early to avoid delays.

Some USA states, counties, and universities have "field days" at productive insectary sites (Figure 4-5). On these days, land managers and landowners are invited to collect or receive locally collected yellow starthistle biological control agents for quick release at other sites. These sessions are an easy

and often inexpensive way for you to acquire biological control agents. They are good educational opportunities as well, because you can often see first-hand any impacts the various biocontrol agents might be having on yellow starthistle plant communities.

Figure 4-5. Yellow starthistle field day including, a. indoor instruction; b. field tour; c. biocontrol agent collection (Credits: a-c Paul Brusven, Nez Perce BioControl Center)

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 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 Yellow Starthistle 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 yellow starthistle biological control agents are listed in the following sections and in Table 4-2.

For all yellow starthistle insects, collect only on a day with good weather. Do not collect in the rain; flying insects will not be active during rain, and crawling insects will hide and become difficult to find in rainy weather. In addition, excess moisture causes adverse effects, and biocontrol agents may drown in wet collection containers. The only exception to this rule is the rust fungus *Puccinia jaceae* var. *solstitialis*, for which overcast and rainy days are optimal for collection.

Table 4-2. Recommended timetable and methods for collecting yellow starthistle biological control agents in North America. Methods are listed in the order of ease of collection and efficacy. Refer to Chapter 2 for detailed descriptions of yellow starthistle stages. Plant and biocontrol agent stages will vary by location.

BIOCONTROL AGENT	BIOCONTROL AGENT STAGE	PLANT STAGE	TIMING	METHOD
Bangasternus orientalis Yellow starthistle bud weevil	Adult	BU-1 to BU-3	Late May to late June	Sweep or tap adults from foliage in afternoon and aspirate into collection container
Chaetorellia australis Yellow starthistle peacock fly	Larva; or Adult	Flowering to senescence; or bolting to BU-1 or BU-3 to BU-4	August to March; or sweep adults in April/May or June/July	Rear indoors; or sweep adults from foliage and aspirate into collection container
Chaetorellia succinea False yellow starthistle peacock fly	N/A	N/A	N/A	**This species is not approved for release or redistribution in the USA**
Eustenopus villosus Yellow starthistle hairy weevil	Adult	BU-2 to BU-4	June to July	Sweep or tap adults from foliage in afternoon and aspirate into collection container
Larinus curtus Yellow starthistle flower weevil	Larva, Pupa	BU-4 to mature	Late June to September	Rear indoors; only *Nosema*-free populations (lab-reared) are permitted for release in the USA
Puccinia jaceae var. *solstitialis* Yellow starthistle rust	All stages	Seedling to mature	Whenever green yellow starthistle plant material is present	Vacuum spores, suspend in water, and spray on uninfected leaves prior to dew period; or move infected plant stems to uninfected sites
Urophora sirunaseva Yellow starthistle gall fly	Larva; or Adult	Seed formation to senescence; or bolting to BU-2 or BU-4 to flowering	August to March; or sweep adults in May or June/July	Rear indoors; or sweep adults from foliage and aspirate into collection container

Collection methods

Sweep netting: Using a sweep net is the best method for collecting the weevils *Bangasternus orientalis* and *Eustenopus villosus*. Though sweeping can be damaging to adult flies, it is also an alternative method for collecting *Chaetorellia australis* and *Urophora sirunaseva*. **Extreme caution should be used when sweeping for adult *C. australis*, however, to ensure that the very similar but unapproved fly *C. succinea* is not collected and redistributed.**

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 4-6a,b). They can be purchased from entomological, forestry, and biological supply companies, or you can construct them yourself. As their name implies, these are heavy duty nets used to "sweep" insects off yellow starthistle. A sweep is made by swinging the net through the plant canopy and collecting insects off the foliage. It is best to use no more than 25 sweeps (10 sweeps for delicate biocontrol agents such as adult flies) before removing the biocontrol agents from the net. Removing insects at regular intervals

reduces the potential harm that could result from knocking biocontrol agents around with debris, and reduces the opportunity for predator insects and spiders swept up with the biocontrol agents from incapacitating or devouring the biocontrol agents.

Figure 4-6. Sweep net, a. closeup; b. being used to collect yellow starthistle biocontrol agents (Credits: a Laura Parsons, University of Idaho; b Rachel Winston, MIA Consulting)

Tapping: If a sturdy sweep net is not available (see above), adult *Bangasternus orientalis* and *Eustenopus villosus* can be collected using a tool such as a racket to tap the biocontrol agents off of their host plant foliage and into a tray placed strategically beneath the stem being tapped. Biocontrol agents thus tapped off the foliage can then be gathered directly using an aspirator (see below). Avoid disturbing the yellow starthistle before tapping because this will often cause beetles to drop to the ground or fly away. This method is effective for yellow starthistle beetles but is not appropriate for collecting the yellow starthistle flies.

Aspirating: An aspirator is a device used to suck insects from a surface into a collection vial (Figure 4-7a). An aspirator is used to collect insects out of a sweep net (described above), though it can also be used to remove adult *Bangasternus orientalis* and *Eustenopus villosus* directly from yellow starthistle plants. A variety of aspirators can be purchased from entomological, forestry, and biological supply companies, or you can construct them yourself. For the latter, inline filters (e.g., HEPA filters) are commercially available to prevent unintentional inhalation or swallowing of particles or debris during mouth aspiration. At the very least, make sure that tubing reaching your mouth is covered by fine-mesh screening, so that insects and small particles are not inhaled (Figure 4-7b).

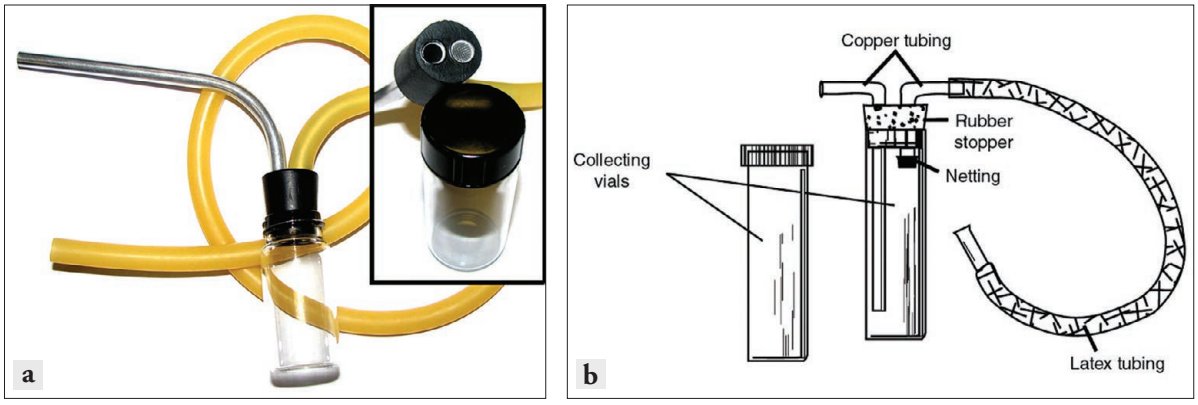


Figure 4-7. Aspirator, a. components; b. diagram (Credits: a wiki.bugwood.org; b Karen Loeffelman, University of Idaho, bugwood.org)

Rearing out biocontrol agents: The preferred collection method for delicate insects such as moths or flies is to rear adults out indoors. This method is also useful for biocontrol agents plagued by parasitoids or microorganisms/diseases, such as the *Nosema*-affected weevil *Larinus curtus.* Yellow starthistle seed heads infested with larvae or pupae of *L. curtus, C. australis,* and *U. sirunaseva* can be collected in the fall or winter and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time, bring them to room temperature in rearing cages or breathable, clear containers. Any parasitoids that emerge should be separated and destroyed. Emerging biocontrol agents can be transferred to new yellow starthistle patches during the appropriate plant stage. Care should be taken to ensure that all emerging *Chaetorellia* flies are indeed *C. australis* and not the very similar but unapproved *C. succinea.*

Suspending rust spores: Rust fungus spores can be vacuumed from infected yellow starthistle leaves throughout the growing season (Figure 4-8), suspended in a carrier (typically distilled water and a surfactant and sprayed on new, uninfected yellow starthistle foliage prior to a dew period. Because the methods for spore collection, suspension, and application are varied and more consistent with a bioherbicide, we do not attempt to describe them in depth in this manual. For more information, contact your local biocontrol specialist.

Transferring infected stems: An alternative method for collecting the rust fungus is to transfer infected stems to uninfected sites. Infected stems can be cut, bundled in groups of 20-50, and moved to new sites where the rust is not yet established. See the section "*Release as many biocontrol agents as possible*" on page 65 for detailed instructions on the proper way to utilize bundled plants at new yellow starthistle sites. Care should be taken not to spread yellow starthistle seeds to new sites as this may exacerbate the yellow starthistle problem. 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. Vacuuming yellow starthistle spores (Credit: Stephen Ausmus, USDA ARS)

Methods by species

Bangasternus orientalis: Collect adult beetles by sweeping yellow starthistle foliage or tapping stems over trays with tools such as rackets to dislodge the insects. Adult *B. orientalis* should then be aspirated from the net or tray. Collect the bud weevils during the heat of the day. The optimal time to collect is in spring when yellow starthistle is in the bud stage (BU-1 to BU-3) and when adult *B. orientalis* are currently or have recently finished mating. Depending on location, the collecting period is generally from late May to late June. Because this beetle has been decreasing in abundance and efficacy in the USA, it is not a high priority for redistribution.

Chaetorellia australis: The preferred method for obtaining *C. australis* is to rear the fly out indoors. Yellow starthistle seed heads infested with larvae can be collected in the fall or winter and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time (April/May), bring them to room temperature in rearing cages or breathable, clear containers. Any parasitoids that emerge should be separated and destroyed. Emerging *C. australis* adults can be transferred to new yellow starthistle

patches during the bolting to BUI-1 stages. **Care should be taken to ensure that all emerging flies are indeed *C. australis* and not the very similar but unapproved *C. succinea*.** Refer to Chapter 3 for tips on differentiating the two species.

Alternatively, *C. australis* adults can be collected from yellow starthistle (they are present during the late bolting or late bud stages of yellow starthistle). Depending on location, the two adult collection periods are generally April/May or June/July. Sweeping can be very damaging to the delicate adult flies, so this method is less desirable than rearing adults out indoors. In addition, differentiating between *C. australis* and the unapproved *C. succinea* can be very difficult in the field, making this collection method even less desirable. Any adult *Chaetorellia* collected in the field should be properly identified in a laboratory setting before redistributions occur. Because *C. australis* has an overall lower efficacy and is often limited to sites where bachelor's button (*Centaurea cyanus*) is also present, it is a low priority for redistribution.

Eustenopus villosus: Collect adult beetles by sweeping yellow starthistle foliage or tapping stems over trays with tools such as rackets to dislodge the insects. Adult *E. villosus* should then be aspirated from the net or tray. Collect the hairy weevils during the heat of the day. The optimal time to collect is in spring and early summer when yellow starthistle is in the bud stage (BU-2 to BU-4) and when adult *E. villosus* are currently or have recently finished mating. Depending on location, the collecting period is generally from June to July. This weevil is already widespread throughout much of western North America, but it should be redistributed to yellow starthistle sites where it is not already established.

Larinus curtus: Many populations of this species are plagued by *Nosema* microsporidia that likely reduce its reproductive output and life span. Only *Nosema*-free (lab reared) individuals are approved for redistribution. In most cases, it will be necessary to obtain the beetles from research or professional rearing operations.

Rearing healthy beetles out indoors is also possible with assistance from biocontrol experts that have experience with *Nosema*. Yellow starthistle seed heads infested with larvae can be collected in the fall or winter and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time (June/July), bring them to room temperature in rearing cages or breathable, clear containers. Any parasitoids that emerge should be separated and destroyed. Emerging *L. curtus* adults can be transferred to new yellow starthistle patches during the bud to early flowering stages. Because this beetle has been decreasing in abundance and efficacy in the USA, it is not a high priority for redistribution.

***Puccinia jaceae* var. *solstitialis*:** Spores of this rust fungus can be vacuumed from infected yellow starthistle leaves throughout the growing season, suspended in a carrier (typically distilled water and a surfactant) and sprayed on new, uninfected yellow starthistle foliage prior to a dew period. Because the methods for spore collection, suspension, and application are varied and more consistent with a bioherbicide, we do not attempt to describe them in this manual. For more information, contact your local biocontrol specialist.

Alternatively, the rust fungus can be transferred to new sites via infected stems. Infected stems can be cut, bundled in groups of 20-50, and moved to new sites where the rust is not yet established. See the section "Release as many biocontrol agents as possible" on page 65 for detailed instructions on the proper way to utilize bundled plants at new yellow starthistle sites. Care should be taken not to spread yellow starthistle seeds to new sites as this may exacerbate the yellow starthistle problem. Care should also be taken to avoid spreading other plant or insect species to new sites as this may inadvertently create future problems. Because establishment and efficacy of this rust are limited by

climatic conditions, it is only a high priority for redistribution at sites with moist, mild climates with significant periods of dew and/or fog.

Urophora sirunaseva: The preferred method for obtaining *U. sirunaseva* is to rear the fly out indoors. Yellow starthistle seed heads infested with larvae can be collected in the fall or winter and stored at 39-46°F (4-8°C). Two to three weeks prior to their normal emergence time (May), bring them to room temperature in rearing cages or breathable, clear containers. Any parasitoids that emerge should be separated and destroyed. Emerging *U. sirunaseva* adults can be transferred to new yellow starthistle patches during the BUI-1 to BU-2 stages.

Alternatively, *U. sirunaseva* adults can be collected from yellow starthistle (they are present during bolting to early bud stage and the late bud/early flowering stages of yellow starthistle). Depending on location, the two adult collection periods are generally May and June/July. Sweeping can be very damaging to the delicate adult flies, so this method is less desirable than rearing adults out indoors. Because this fly has been decreasing in abundance and efficacy in the USA, it is not a high priority for redistribution.

Release Containers for Yellow Starthistle 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 them from escaping en route). When large sections of infected stems are transferred between sites to redistribute *Puccinia jaceae* var. *solstitialis*, the stems should be stored in large paper bags (minus all flowers and seeds). Paper bags provide sufficient ventilation while plastic bags may cause moist plant material to rot. Though paper bags are appropriate for rust-infected stems, they are less ideal for transferring yellow starthistle weevils and flies because they 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.

When transferring lab-reared or field-collected adult *B. orientalis, E. villosus, L. curtus, C. australis* or *U. sirunaseva*, 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 4-9) 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. **Do not use glass or metal release containers**; they are breakable and make it difficult to regulate temperature, airflow, and humidity.

Figure 4-9. Cardboard release containers for transporting yellow starthistle biocontrol agents (Credit: Martin Moses, University of Idaho, bugwood.org)

Fill release containers half full with crumpled paper towels or tissue paper to provide a substrate for biocontrol agents to rest on and hide in, and to help regulate humidity. Fill the other half with yellow starthistle sprigs. All 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.

Transporting Yellow Starthistle 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 or 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 biocontrol agents to their release sites within three hours of 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. 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 4-10). 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 yellow starthistle stems infected with the rust. **Please note that for safety reasons, dry ice cannot be used for transporting biocontrol agents.**

Figure 4-10. Commercially made shipping container suitable for biocontrol agent transport (Credit: University of Idaho, bugwood.org)

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.

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.
- Provide the receiver with a tracking number and verify someone will be there to accept the shipment.
- Releases should be made immediately upon receipt. If that is not possible, biocontrol agents should be checked for food depletion, excess moisture, and overcrowding and then be refrigerated.
- Have the receiver provide feedback to the shipper on the overall condition of the shipment. This can provide important guidance on packing/shipping methods.

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- Seal release containers securely with rubber bands or easily removable/resealable tape (e.g., masking tape) to prevent mobile 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 Yellow Starthistle Biological Control Agents

A number of commercial suppliers provide yellow starthistle biological control agents. In the USA, 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 yellow starthistle biological control agents by commercial suppliers also require a USDA PPQ 526 Permit (see page 66), 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 Yellow Starthistle Biological Control Agents

Establish permanent location marker

Place a steel fence post or plastic/fiberglass pole as a marker at the release point (Figure 4-11a). 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 52). 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 4-11b). 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.

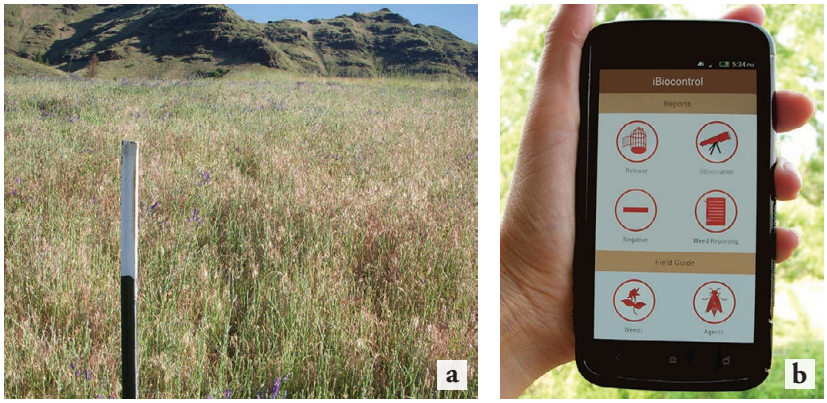


Figure 4-11. Biocontrol agent release site tools, a. permanent marker; b. smartphone with free weed and biocontrol agent mapping app iBioControl (Credits: a,b Rachel Winston, MIA Consulting)

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 68 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 yellow starthistle 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.

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 yellow starthistle infestation than it is to spread those individuals too thinly over multiple yellow starthistle 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 200 adult yellow starthistle biocontrol insects (or more) are encouraged.

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 releases may be necessary if initial releases fail to establish. For species or locations where establishment is likely to be slow (e.g., due to high levels of overwintering mortality), planning to make releases on the same site for two or three 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 releases is wiped out by flooding, fire, herbicide application or other catastrophic disturbance, then biocontrol agents from adjoining releases 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 yellow starthistle weevils and flies, gently shake out all biocontrol agents in one small area, taking care to dislodge any insects hiding in or clinging to the paper towels in the release containers (Figure 4-12a). **Do not scatter biocontrol agents throughout the infestation. Do not walk back over the area where you just made a release.**

When *Puccinia jaceae* var. *solstitialis* spores have been vacuum-collected from yellow starthistle foliage, a suspension can be made by combining spores with a carrier (typically distilled water and a surfactant) and sprayed on new (uninfected) yellow starthistle foliage prior to a dew period (Figure 4-12b). Temporary "tents" can be used to maintain humidity after the inoculation, aiding in the establishment of the rust (Figure 4-12c).

When using the alternative method of transferring large yellow starthistle stems infected with the rust, first ensure collected stems have no flowers or seeds or other insects or plant species. 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

Figure 4-12. Releasing yellow starthistle biocontrol agents, a. releasing adult weevils; b. inoculating yellow starthistle plants with a suspension of the rust fungus; c. tent used to increase humidity following yellow starthistle rust inoculation (Credits: a Rachel Winston, MIA Consulting; b,c Eric Coombs, Oregon Department of Agriculture, bugwood.org)

Regulations for the Transfer of Yellow Starthistle 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.

end, providing a supportive base. Place the fanned bundles upright within dense stands of uninfected yellow starthistle. In less dense yellow starthistle infestations or at windy locations, tying the fanned bundle against uninfected yellow starthistle plants may aid in successful establishment. Four to five rust-infected bundles should be used per site, though more or fewer may be required, depending on the yellow starthistle infestation size. The transfer should take place in the evening, and uninfected starthistle plants should be sprayed with water to increase inoculation success.

Caged releases confine biocontrol agents for a period of time so they adjust to the site and easily find one another for mating. Cages 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 yellow starthistle plant or a small area containing multiple plants. Release the adult weevils or flies inside the cage, and secure the bottom of the cage to either the yellow starthistle stem or the ground. Cages should be removed within a few days (for plants) or weeks (for areas).

Releases of adult weevils or flies 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 insects when they are dumped out of release containers; appropriately timed releases can significantly enhance the probability of establishment. Milder temperatures are also more conducive to successful rust establishment. Avoid making releases/transfers on rainy days, unless dealing with the rust, which is aided by moist conditions. If you encounter an extended period of poor weather, it is better to release the biological control 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.

Documenting, Monitoring, and Evaluating a Biological Control Program

The Need for Documentation

The purpose of monitoring is to evaluate the success of your yellow starthistle 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 yellow starthistle problem. (See the Code of Best Practices for Classical Biological Control of Weeds on page 7).

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

- if the biological control agents have become established at the release site
- if biological control agent populations are increasing or decreasing and how far they have spread from the initial release point
- if the biological control agents are having an impact on yellow starthistle
- 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).

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 (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.

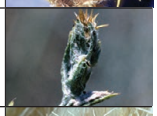
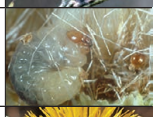
Monitoring Methods

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

Assessing biological control agent populations

If you wish to determine whether yellow starthistle biocontrol agents have established after initial release, you simply need to find the biocontrol agents in one or more of their life stages, or evidence of their presence (Table 4-3). Begin looking for biocontrol agents where they were first released, and then expand to the area around the release site.

Table 4-3. Life stages/damage to look for to determine establishment of yellow starthistle biological control agents. a. *Bangasternus orientalis* egg on plant stem; b. *B. orientalis* larva in seed head; c. *Chaetorellia australis* larva in seed head; d. *C. australis* adult; e. *C. succinea* larva; f. *C. succinea* adult; g. *Eustenopus villosus* pupal chamber and larval-chewed florets, seeds, and receptacle tissue; h. seed heads aborted from *E. villosus* feeding; i. *Larinus curtus* larvae in a seed head; j. *L. curtus* adult face down in starthistle florets; k. leaf infected by *Puccinia jaceae* var. *solstitialis*; l. *Urophora sirunaseva* larva in gall; m. *U. sirunaseva* adult

Biocontrol Agent	Life Stage	Where to Look	When to Look	Most Frequently Observed Damage	Appearance
Bangasternus orientalis Yellow starthistle bud weevil	Larva	In seed heads	June to August	Larva feeding in seed head within chamber made of plant tissue and frass; C-shaped body with brown head capsule, indistinguishable from other seedhead weevil biocontrol agent larvae	
	Adult	Mating or ovipositing females around buds	Late May to late June	Adults do not cause any direct damage to yellow starthistle; females oviposit black-covered eggs beneath seed heads	
Chaetorellia australis Yellow starthistle peacock fly	Larva	In seed heads	May to mid-June; August to April	Larva feeding in seed head within chamber made of plant tissue and frass; barrel-shaped body with no true head capsule, indistinguishable from larva of *C. succinea*	
	Adult	Mating or ovipositing females around buds	Mid-April to mid-May; June to mid-July	Adults do not cause any direct damage to yellow starthistle; females oviposit beneath the bracts of closed buds	
Chaetorellia succinea False yellow starthistle peacock fly	Larva	In seed heads	May to mid-June; August to April	Larva feeding in seed head within chamber made of plant tissue and frass; barrel-shaped body with no true head capsule, indistinguishable from larva of *C. australia*	
	Adult	Mating or ovipositing females around buds	May; Mid-June to July	Adults do not cause any direct damage to yellow starthistle; females oviposit beneath the bracts of closed buds	
Eustenopus villosus Yellow starthistle hairy weevil	Larva	In seed heads	Late June to early September	Larva feeding in seed head within chamber made of plant tissue and frass; C-shaped body with brown head capsule, indistinguishable from other seedhead weevil biocontrol agent larvae	
	Adult	Mating, feeding, or ovipositing females on buds	June to July	Adult feeding causes buds to abort (some aborted buds tip sideways); oviposition and feeding holes in seed head bracts are dark-colored	
Larinus curtus Yellow starthistle flower weevil	Larva	In seed heads	July to September	Larva feeding in seed head within chamber made of plant tissue and frass; C-shaped body with brown head capsule, indistinguishable from other seedhead weevil biocontrol agent larvae	
	Adult	Mating, feeding, or ovipositing females among florets	Late June to July	Adults feeding on florets (often face down); females oviposit among florets	
Puccinia jaceae var. *solstitialis* Yellow starthistle rust	All	All above-ground growth	Year-round (there can be multiple cycles per year; symptoms and stages will vary)	Foliage covered with yellowish chlorotic lesions with raised centers, becoming orangish-brown pustules that produce powdery, round, and dark brown/rust-colored spores; infected plants stunted	
Urophora sirunaseva Yellow starthistle gall fly	Larva	In woody galls in seed heads	Mid-May to mid-June; August to April	Larva feeding in seed head within woody galls; barrel-shaped body with no true head capsule but with a dark anal plate	
	Adult	Mating or ovipositing females around buds	May; June to July	Adults do not cause any direct damage to yellow starthistle; females oviposit on top of closed buds	

Credits from top to bottom: University of Idaho Archives; California Department of Agriculture; Gary Piper, Washington State University; Charles Turner, USDA ARS; Rachel Winston, MIA Consulting; Laura Parsons & Mark Schwarzländer, University of Idaho; Charles Turner, USDA ARS; Laura Parsons & Mark Schwarzländer, University of Idaho; Charles Turner, USDA ARS; Rachel Winston, MIA Consulting; Stephen Ausmus, USDA ARS; Charles Turner, USDA ARS; Laura Parsons & Mark Schwarzländer, University of Idaho

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. The Standardized Impact Monitoring Protocol (SIMP) is one such approach to monitoring biocontrol agent populations, weed populations, and the surrounding plant community over time (Appendix III). This protocol was developed through cooperation among the Bureau of Land Management, the University of Idaho, U.S. Forest Service Forest Health Protection, the Nez Perce Biocontrol Center, and the Idaho State Department of Agriculture. SIMP was designed to be simple, efficient, and sufficiently versatile to allow for the collection of information from the same sites over multiple years. The yellow starthistle SIMP system is designed to monitor yellow starthistle seed-feeding insects. An alternative general biological control agent monitoring form can be found in Appendix IV. In addition to measuring seed-feeding insect populations, Appendix IV is useful for estimating the presence and/or extent of yellow starthistle rust infection. Existing data sheets may be modified to meet the needs of each land manager by adding extra columns, descriptive classes, etc..

Assessing the status of yellow starthistle and co-occurring plants

The ultimate goal of a yellow starthistle biological control program is to permanently reduce the abundance and vigor of yellow starthistle 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.

Qualitative (descriptive) vegetation monitoring: Qualitative monitoring uses subjective measurements to describe the yellow starthistle 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 (Figure 4-13a-c).

Qualitative monitoring provides insight into the status or change of yellow starthistle populations; however, its descriptive nature does not generally allow for detailed statistical analyses. Data obtained

Figure 4-13. Yellow starthistle biocontrol release site in a. 1997; b. 2009; c. 2012 (Credits: a Leonard L. Lake, USDA Forest Service; b,c Rachel Winston, MIA Consulting)

in qualitative monitoring may trigger more quantitative monitoring later. See Appendix V for a sample data form useful for recording qualitative yellow starthistle monitoring data along with information on associated vegetation.

Quantitative vegetation monitoring: Quantitative monitoring measures changes in the yellow starthistle 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 yellow starthistle plants in a small sample area, or as complex as measuring yellow starthistle plant height, flower and seed production, biomass, species diversity, and species cover (Figure 4-14). Quantitative sampling data can be more readily analyzed using statistical methods to 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 4-14. Quantitatively monitoring new yellow starthistle rosettes in a $1m^2$ quadrat (Credit: Mark Schwarzländer, University of Idaho)

See Appendix VI for a sample data form useful for recording quantitative yellow starthistle monitoring data along with information on associated vegetation. The SIMP approach described earlier and found in Appendix III is a combination of qualitative and quantitative elements as well as counts for biological control agents.

Assessing impacts on non-target plants: To address possible non-target attacks on species related to or just growing adjacent to yellow starthistle, you must become familiar with the plant communities present at and around your release sites and be aware of species related to yellow starthistle. Start by compiling a list of other species in the Asteraceae family and the genus *Centaurea* that are present at the site (see Chapter 2 for more information). You may need to consult with local, state, or regional botanical experts, or review local herbarium records for guidance on areas where related non-target plants might be growing and additional information on how you can identify them. Care should be taken in the management of your yellow starthistle biocontrol program to ensure that all closely-related native or desirable species are identified and monitored along with yellow starthistle.

Please be aware that there are many "look-alike" native insects that feed on related native plants. Correct identification by insect specialists is needed to confirm such records. If you observe approved biological control agents feeding on and/or developing on native 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 non-target impacts. Be sure not to ascribe any damage you observe on native species to any specific species and thus bias the confirmation of attack and the identification of the species causing the attack.

If you observe approved biocontrol agents feeding on and/or developing on non-target plant species, the vegetation sampling procedures described above can be easily modified to monitor changes in density and/or cover of the non-target species. Concurrently, you may wish to collect additional data, such as the number of biocontrol agents observed on non-target plants, the amount of foliar

attack observed, or the presence of characteristic biocontrol agent damage. Collecting this data over subsequent years can help determine if there is a population level impact or if the non-target feeding is temporary or of minor consequence to the non-target species.

CHAPTER 5: AN INTEGRATED YELLOW STARTHISTLE MANAGEMENT PROGRAM

Introduction

The invasion curve (Figure 1-3, repeated here in Figure 5-1) shows that eradication of an invasive species such as yellow starthistle 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 yellow starthistle is on the invasion curve in a particular area is the first step to taking management action. Inventorying and mapping current yellow starthistle populations coupled with research efforts to predict where yellow starthistle is 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 yellow starthistle before it is too late to remove them.

Classical biological control has been applied to many invasive plant species, but biological control is generally 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 yellow starthistle 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]).

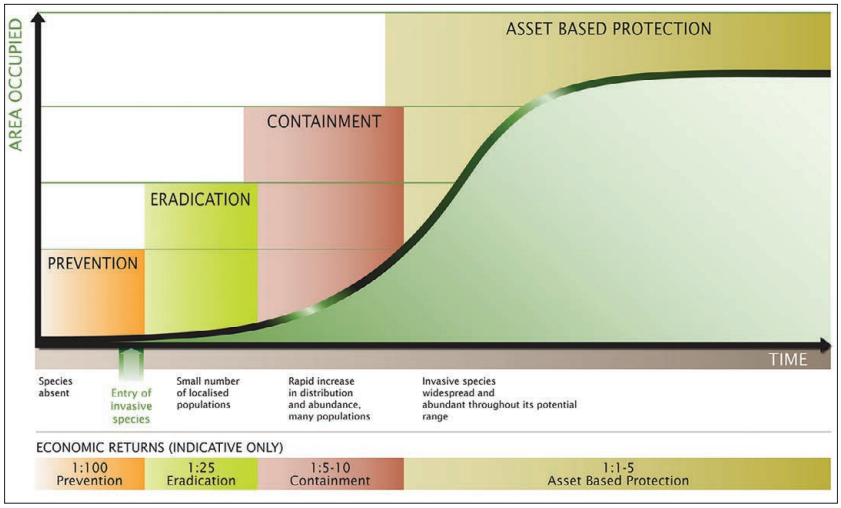


Figure 5-1. Generalized invasion curve showing actions appropriate to each stage (Credit: © State of Victoria, Department of Economic Development, Jobs, Transport and Resources, Reproduced with permission)

There are several examples in which both single- and multiple-biocontrol agent introductions have successfully controlled the targeted weeds. Where ideally suited, biological control can help maintain yellow starthistle densities below economically or ecologically significant levels, enabling land managers to live with the weed; however, it may take three to five years or more for biological control to help reduce weed populations to such manageable levels. Furthermore, yellow starthistle occurs across a wide range of conditions. Some habitats are unsuitable to biocontrol agents, so biological control is not going to work on yellow starthistle every time at every site. Depending on the infestation, integration with other weed control methods or resorting to other control measures entirely may be required to attain yellow starthistle management objectives.

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

- Education and Outreach
- Inventory and Monitoring
- Prevention
- Weed Control Activities: A variety of yellow starthistle 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 it 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 combine and coordinate 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 yellow starthistle. Sharing successes and failures in yellow starthistle management saves time and funding and reduces the incidence of both failure and

negative impacts from management efforts, such as destruction of wildlife habitat and damage to non-target species. Numerous CWMAs exist throughout the western states of the USA and are excellent sources of information, experience, and resources for treating yellow starthistle infestations using an IPM approach.

Components of Successful Integrated Pest Management Programs to Manage Yellow Starthistle

Though each component of IPM is an important tool for managing yellow starthistle, 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 yellow starthistle infestations, while at the same time achieving land use objectives.

Education, inventorying/mapping, and prevention are important and applicable across all landscapes, whether or not yellow starthistle is already present. When yellow starthistle is 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 contain the existing infestation while preventing 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 a yellow starthistle IPM program are described individually below. Because the focus of this manual is the biological control of yellow starthistle, the potential to integrate biocontrol with other weed control methods is described at the end of each control method's section.

Education & 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.


Nevada Project WEEDS
Fact Sheet 98-60

WANTED—Dead, Not Alive!

This outlaw weed is hiding out! Find it. Eradicate it.

Yellow Starthistle

Alias: *Centaurea solstitialis*

Yellow starthistle is a Mediterranean weed that dominates rangelands, roadsides, and fields primarily in Oregon, Washington, California, and Idaho. It is found scattered throughout the rest of the U.S. In Nevada, it can dominate rangeland that receives less than 15 inches of annual precipitation. It completely changes the natural habitat it invades. The injurious nature of its vicious spines negatively impacts recreationists, livestock, and wildlife. It is poisonous to horses, causing a nervous disorder called "chewing disease" when they are forced to eat it. Yellow starthistle is listed as a noxious weed by Nevada Administrative Code.

In Nevada, this weed dominates rangeland that receives less than 15 inches of annual precipitation. It completely changes the natural habitat it invades.

Distinguishing features:
- Grows up to 3 feet tall as a multi-branched plant.
- First leaves form a rosette of deeply lobed leaves up to 8 inches long. These form close to the ground in the fall or spring after germination.
- Second year leaves grow low on the plant, are deeply lobed, and 2 to 4 inches long. Upper leaves are narrower, pointed and smaller, forming fringe-like extensions along the stems. Both stem and leaves of the mature plant have a wooly appearance.
- Flower heads are yellow and located singly at the tips of branched stems with outward pointing, inch long, stiff spines.

Take action:
- Report its location to the land owner, gardener, manager or park ranger.
- Remove all weed seeds from clothing, pets, vehicle, and tire treads before moving out of an area.
- Monitor dry waste areas. Carefully remove any seeds, dig up the plant and dispose in a sealed garbage bag through the trash. Herbicides may be available to kill this plant.

Your reward:
A cleaner, healthier environment and the satisfaction that you have helped make the difference!

For more information about controlling this and other invasive weeds, contact:
Nevada Cooperative Extension 775-784-1334;
Nevada Division of Agriculture Bureau of Plant Industry, 775-688-1180; or
Your local Weed District manager or Conservation District:

University of Nevada, Reno Cooperative Extension
A County-State-Federal Partnership

Figure 5-2. Yellow starthistle education poster (Credit: University of Nevada Cooperative Extension)

Yellow starthistle education and outreach should focus on conveying to the public:

- the threat yellow starthistle poses
- how to identify yellow starthistle in different life stages (seedling – senescence)
- ways in which they can help in yellow starthistle management

By educating land managers, landowners, recreationalists and the public about the threat of yellow starthistle, 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 & Mapping

Inventory and mapping are key elements of a successful pest 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 threat yellow starthistle poses to their land, they are often more willing to participate to ensure that their land is inventoried and accurate maps of yellow starthistle are developed so the best control activities can be implemented.

Yellow starthistle infestations are often mapped by foot, vehicle, horse, or airplane using a global positioning system (GPS) unit and a geographical information system (GIS), though hard copy maps made by hand are suitable for some locations. Different infestations are best monitored by different means. Small infestations can be very difficult to spot, given the morphology of starthistle stems which make the plant difficult to distinguish from neighboring vegetation (Figure 5-3a). These infestations are often best spotted with small-scale search operations such as those done by foot or on horseback. Larger infestations are often more easily spotted by their gray-green appearance, monotypic tendencies and (during mid- to late summer) the presence of numerous scattered yellow flower heads. Many large infestations can be seen from hovering aircraft and helicopters; however, surrounding vegetation still determines the ease with which yellow starthistle can be distinguished. Some large infestations can be especially cryptic during early growth stages (Figure 5-3b) or as plants senesce and all vegetation begins to look similar (5-3c). For very large infestations, GoogleEarth can be a useful tool for providing birds-eye-view imagery that allows for visual delineation of yellow starthistle 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 68 for more information). Inventory efforts should document the following for each infestation: location coordinates, boundaries, estimated density (number of stems of target weed per area, e.g., square meter or square yard), land usage, treatment history, disturbance history (e.g., fire, flooding), habitat type (desert, upland, shrubland, grassland), 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 yellow starthistle 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 to monitor infestations.

Figure 5-3. Yellow starthistle infestations difficult to see, a. scattered starthistle plants in middle of image, infestations in foreground and background are different species; b. dense infestation of yellow starthistle rosettes in foreground obscured by previous-year stems and two other yellow-flowering species that are not yellow starthistle; c. yellow starthistle infestation interspersed with few other species though all look similar in the senescent stage (Credits: a-c Rachel Winston, MIA Consulting)

Prevention

Prevention activities focus on areas not currently infested by yellow starthistle with the goal of keeping these areas weed-free. Though yellow starthistle is already present throughout much of western North America, there are many sites where it is absent or remains at low densities, and entire counties/states/provinces where yellow starthistle has not yet invaded. Inventory and mapping efforts help identify the precise borders of existing yellow starthistle infestations as well as identify weed-free areas. Preventing introduction and spread of yellow starthistle to uninfested areas is more environmentally desirable and cost-effective than treating large-scale infestations.

Yellow starthistle is spread by the movement of seed in/on hay, motorized equipment, livestock, wildlife, or humans. Preventing the spread of yellow starthistle requires cooperation among all landowners and land managers. In areas where yellow starthistle is not yet present, it is important to ensure that possible invasion avenues are identified and management actions taken to reduce the risk of spread. This includes minimizing soil disturbances and regularly monitoring uninfested sites to confirm that they have remained uninfested.

Cultivation, soil erosion (especially following flooding events and prescribed burns or wildfire), 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. These conditions favor yellow starthistle establishment and persistence (Figure 5-4). Because such activities are also potential ways of spreading yellow starthistle seeds, they should either be avoided or closely monitored in starthistle-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 yellow starthistle. If possible, livestock should be kept off weed-infested land when they are most likely to spread viable

Figure 5-4. Overgrazing and erosion (Credit: Paul Bolstad, University of Minnesota, bugwood.org)

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 yellow starthistle infestations, it is crucial that a thorough cleaning take place before equipment leaves the contaminated area.

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 yellow starthistle may spread. It consists of three complementary activities: 1) educating land managers and the public on weed identification and mapping techniques, 2) enlisting their aid in immediate and thorough detection of the weed, and 3) initiating rapid response eradication efforts at all verified locations of the weed.

The most cost-effective strategies for dealing with yellow starthistle are prevention and EDRR. Because yellow starthistle is difficult to control once established, it is imperative that every effort be made to inventory regularly and immediately eliminate all early invaders.

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 yellow starthistle management is the most economical and suitable for larger infestations (tens to thousands of acres). For small patches (less than 4 acres or 1.6 ha) of new satellite infestations (those growing outside of well-established yellow starthistle populations), 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 yellow starthistle and Chapter 4 for how to implement a yellow starthistle biological control program in your area.

Physical Treatment

Physical treatment utilizes hand pulling, hoes or other hand-held equipment, mowing, or tillage to remove or disrupt the growth of weeds and is the oldest method of weed control. Physical methods have shown some success in controlling yellow starthistle when properly timed and applied repeatedly, but they are labor-intensive and often not suitable for the more rugged and inaccessible sites where starthistle has invaded. Regardless of the physical method employed, it is imperative that all equipment be thoroughly cleaned following use to prevent the spread of yellow starthistle seeds.

Hand pulling

Hand pulling can be useful in steep or uneven terrain where other forms of mechanical control (e.g., mowing, tillage) are not feasible. It is most appropriate in the EDRR stage of a yellow starthistle infestation or on satellite populations occurring outside larger containment areas. While hand pulling is most often used to control small yellow starthistle infestations (under 1 acre or 0.4 ha), larger populations (up to 40 acres or 16 ha) can also be controlled by starting at the outward edge of the population and moving inwards. Successful use of hand pulling requires repeated sessions to account for new yellow starthistle individuals sprouting throughout the growing season.

Hand pulling is especially effective on young plants; as plants age, or for plants growing in compacted soils, well-developed root systems anchor plants in the soil and can lead to stem breakage during pulling. Leaving even two inches (5 cm) of rooted stems with leaves attached can result in plant recovery. It is important to remove as much of the yellow starthistle root system as possible, while minimizing soil disturbance. The most appropriate and easiest time to pull plants is before they go to seed and before they produce the spiny flower heads. This is often the time when the soil is moist and plants are easy to pull. Because plants are not in flower, they can be left at the site with no threat of recovery as long as the roots are not contacting the soil. When yellow starthistle plants are in flower or seed, cut off and bag all flower stalks prior to pulling. Otherwise, the jarring action of pulling may dislodge and distribute seeds at the site. **All stems, flowers, and seeds should be securely bagged and taken to the trash or a transfer site to prevent possible yellow starthistle seed dispersal from pulled material (Figure 5-5a)**. Re-seeding the open space resulting from yellow starthistle removal with seeds of desirable vegetation can provide competition to decrease yellow starthistle seedling germination and persistence.

Because hand pulling removes the biocontrol agent's host from the site, this control method is not compatible with biological control. Hand pulling is most appropriate for small infestations where immediate eradication is feasible, while biological control is more appropriate for much larger, established infestations where the management goal is containment or asset-based protection. One way to successfully combine these two methods is to release biological control agents in a large, main infestation while employing hand pulling to remove individual plants and to control small, satellite patches arising outside of the main yellow starthistle infestation.

Mowing

Mowing yellow starthistle has proven effective for infestations along roadsides and rights-of-way (Figure 5-5b) when timed correctly and repeated. The most appropriate time to mow is when yellow starthistle plants are in the spiny bud (BU-3 to BU-4) to very early flowering stages. Mowing post-flowering can exacerbate the problem by spreading viable starthistle seeds. Mowing too early, when plants are at the bolting stage, can stimulate starthistle re-growth (and subsequent flowering) and suppress competing vegetation. Repeated mowing is often necessary. The lower the mowing blade is set, the more effective the treatment; plants should be cut below the height of the lowest branches. However, low mowing is typically not feasible in rough, rocky, or remote terrain where yellow starthistle is so problematic in the western USA. Alternatively, mowing can be used to reduce non-target plant cover and litter prior to fall herbicide applications, as this will improve coverage of the chemical on fall yellow starthistle rosettes.

Figure 5-5. Physical weed treatments, a. hand pulling yellow starthistle; b. roadside mowing; c. tillage (Credits: a Michael G. Common, National Park Service; b Joost J. Bakker, Ijmuiden; c Howard F. Schwartz, Colorado State University, bugwood.org)

Because the most effective time to mow is during the spiny bud and early flowering stages when seed-feeding biocontrol agents are active in the seed heads, mowing is not compatible with yellow starthistle biocontrol insects. Though it hasn't been explicitly studied because of the rust's limited current distribution, mowing may actually help distribute the yellow starthistle rust (*Puccinia jaceae* var. *solstitialis*), and the rust could theoretically re-establish on yellow starthistle plants recovering from mowing efforts.

Tillage

Cultivation (Figure 5-5c) can be used successfully for the control of yellow starthistle in an agricultural setting, if the timing and frequency are accurately applied. Tillage in early summer (when starthistle plants are in the bolting and bud stages) will control yellow starthistle plants provided the roots are removed from the shoots. Cultivation during the flowering and seed set stages will only help facilitate seed dispersal. Infestations should be tilled multiple times in a season if additional starthistle germination occurs between tillage events. Alternatively, a single tillage can be used if it is conducted during the early flowering stage of starthistle before the plant produces viable seed. At this timing, there is little chance of newly germinated seedlings surviving the dry summer months. In the extensive rangeland system yellow starthistle has invaded in western North America, frequent cultivation is not feasible.

Because cultivation destroys yellow starthistle plants, this form of weed control is destructive to all six approved yellow starthistle biocontrol agents. Repeated tillage is most applicable in a crop setting, where chronic disturbance and the need to attain immediate control make biological control fundamentally incompatible.

Cultural Practices

Cultural methods of weed control (including burning, grazing, and seeding with competitive species) are used to manipulate the environment by non-mechanical means and can enhance the growth of desired vegetation, which may slow the invasion of noxious weeds onto a site. Regardless of which method is used, all cultural control techniques are more successful when combined with other control methods, such as hand pulling prior to re-seeding or burning prior to applying herbicides.

Burning

Burning has yielded mixed results for controlling yellow starthistle. The most effective prescribed burns (Figure 5-6a) are applied during the early flowering stage of starthistle before the plant produces viable seed. This timing typically corresponds with other desirable species having already dispersed their seeds and senesced, contributing more fuel. When prescribed burns were applied during this stage at one study site and repeated for three years, the fires significantly reduced yellow starthistle by depleting its seed bank, while simultaneously increasing desirable perennial grasses. At the same study site four years after prescribed burns were no longer applied, the plant community transitioned back to a starthistle-dominated grassland. The general consensus is that burning is most effective when used as just one tool in an integrated approach over several years.

Fire can be used intentionally to burn off plant litter in order to stimulate germination and make new starthistle growth easier to see when applying herbicides. The bare soil following a fire is ideal for yellow starthistle germination. If new flushes of starthistle growth are treated rapidly with physical or chemical means, the starthistle seed bank can be depleted quickly. When prescribed fire kills off competing vegetation, it will only increase the starthistle problem, unless it is followed by a subsequent herbicide application. Revegetation with desired vegetation is recommended wherever fire is utilized

Figure 5-6. Yellow starthistle cultural management techniques, a. prescribed fire; b. grazing sheep (Credits: a David Cappaert, Michigan State University, bugwood.org; b Flying Mule Farm)

to aid in yellow starthistle herbicide control. Fire has deleterious effects on insects, small animals, and some native plant species, and it can increase soil erosion; caution should be applied when using this tool as part of an integrative pest management system.

Because the most effective time to burn is during the early flowering stages when seed-feeding biocontrol agents are active in the seed heads, burning is not compatible with yellow starthistle biocontrol insects. Burning also destroys the yellow starthistle rust.

Grazing

Most domestic livestock (including goats, sheep, and cattle) and some species of wildlife will graze yellow starthistle growing in the rosette and bolting stages prior to the production of the spiny seed heads. Yellow starthistle provides palatable, high-protein forage for cattle, sheep, and goats prior to the formation of the spiny bracts, though infested fields have less forage value than uninfested fields. Goats and sheep have also been observed feeding on the spiny seed heads (Figure 5-6b). Horses should not be exposed to yellow starthistle as this species contains compounds that are toxic to horses, leading to the fatal neurological disorder of nigropallidal encephalomalacia or "chewing disease".

Spring grazing reduces the growth, survivability, and reproductive ability of yellow starthistle. The best results have been found with continuous grazing rather than rotational grazing. When livestock are moved as part of rotational grazing, yellow starthistle quickly recovers and sets seeds. Continuous grazing keeps the plant from bolting when other green feed is scarce; however, this heavy feeding is considered by many to be overgrazing, which has been shown to exacerbate the starthistle problem by reducing competing species and promoting the germination of starthistle seeds. Although grazing can be effective for suppressing yellow starthistle under the right management circumstances, the difficulties and costs associated with proper livestock management often limit the implementation of this control method. Where it is feasible to utilize livestock to manage yellow starthistle, it is important the animals do not graze during seed set, as this can assist in the distribution of starthistle seeds.

The impact of grazing on the biological control of yellow starthistle is largely unknown. Feeding on yellow starthistle seed heads infested with the seed-feeding biocontrol agents would destroy those insects; however, most grazing animals prefer to feed on yellow starthistle prior to this stage, making grazing compatible with seed-feeding biological control agents.

Seeding competitive species

Where yellow starthistle is established and then suppressed by one or more control methods, reinvasion by yellow starthistle 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.

Yellow starthistle is sensitive to competition for light and resources during early growth stages. When cool season plants emerge before yellow starthistle, their dense shade restricts the growth of starthistle seedlings and rosettes. This can reduce yellow starthistle populations by as much as 90%. In addition to competition for light, certain species hinder the growth of yellow starthistle through other mechanisms. Deep-rooted perennials such as alfalfa (*Medicago sativa*, Figure 5-7a) or perennial grasses compete with yellow starthistle for much-needed soil moisture over the summer months. Alfalfa and other legumes such as sub-clover (*Trifolium subterraneum*, Figure 5-7b) also improve the soil nitrogen status by fixing their own nitrogen. This increases growth and competition from additional desirable pastoral species previously limited by nitrogen availability. The level of management required to maintain dense stands of shading and/or nitrogen-fixing species is often difficult to achieve, especially in the vast natural and rangeland habitat yellow starthistle has invaded in western North America.

Figure 5-7. Legume species that compete well with yellow starthistle in a pastoral setting, but are best used in combination with other weed control methods, a. alfalfa (*Medicago sativa*); b. sub-clover (*Trifolium subterraneum*) (Credits: a Olivier Pichard; b AnRo0002)

In more natural settings, the most suitable plant species to use for competition with yellow starthistle 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 yellow starthistle seedlings. Utilizing ecologically equivalent species (those with root and growth patterns similar to yellow starthistle) may provide the best competition. Inventorying nearby sites that are uninvaded by yellow starthistle may provide insight into the best replacement species. Consult your local county extension educator or Natural Resource Conservation Service 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 (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 yellow starthistle prior to seeding more desirable species is important because established starthistle plants are highly competitive. Seeding of competitors should take place immediately following exposure of soil to maximize their competitive advantage. For example, seeding should occur in bare soil following burning or after young starthistle plants have been hand pulled or killed with herbicides. 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. Drill seeding (rather than broadcast seeding) may also reduce predation by rodents. Besides exposing seeds to predation, broadcasted seeds are also more susceptible to decay and to desiccation following germination.

Incorporating biocontrol agents with re-seeding can 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 yellow starthistle stems and leaves to promote the growth of competitive species hinders the survival of all established starthistle biocontrol agents. Consequently, many successful revegetation programs establish competitive species first, using biological control agents after the seeded species have become established and yellow starthistle begins to reappear. Alternatively, revegetation projects can target only a small portion of the infestation annually, leaving a reservoir of yellow starthistle 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 yellow starthistle 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 yellow starthistle infestations. If utilized appropriately, herbicides are also useful on the leading edge of large, advancing yellow starthistle infestations.

Herbicides may be too costly to be of practical use in treating extensive infestations of yellow starthistle 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 yellow starthistle plants repeatedly germinate from the seed bank. It generally takes about three years of herbicide treatment to reduce the population to fairly low levels. Potential non-target damage to associated vegetation must also be considered when using herbicides. For these reasons, herbicides are best used as part of a larger, integrated pest management program that employs regular (annual) inventory and mapping, and incorporates 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 yellow starthistle plants or small patches (Figure 5-8a). In spot applications, an appropriate herbicide is applied to the foliage of target plants only, thus reducing non-target effects. Broadcast treatments are when herbicides are applied to an entire weed infestation rather than to single plants (Figure 5-8b). 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 should kill all plants in a treated area, the resulting bare soil may allow yellow starthistle to reinvade from the seedbank, creating a denser yellow starthistle infestation than was there originally.

Selective herbicides are those that target selected species (e.g., broad-leafed forbs vs. grasses) while leaving other species virtually unharmed. Utilizing selective herbicides and/or spot treatments helps

Figure 5-8. Yellow starthistle herbicide applications, a. spot-treating individual plants; b. broadcast treating infestations in rough terrain with a helicopter (Credits: a Mark Schwarzländer, University of Idaho; b Leon Slichter, Idaho County Weed Control)

reduce the non-target impacts of herbicide applications, and is the recommended approach for treating yellow starthistle infestations with chemical control. The herbicide label should always be referenced to help evaluate the risk of non-target species damage.

Both post-emergent (works on growing tissue) and pre-emergent (prevents seed germination) herbicides are registered for use against yellow starthistle. Some post-emergent herbicides are very effective on yellow starthistle seedlings and rosettes. Applying post-emergent herbicides later in the spring will control yellow starthistle plants which germinated in the fall, winter, or spring; however, yellow starthistle plants which germinated in the fall/winter will be larger plants that may require higher application rates to achieve desired control. Drought-stressed plants are also less susceptible to herbicides. Adding a surfactant when treating larger and/or drought-stressed plants may help increase post-emergent herbicide efficacy.

Pre-emergent herbicides with long residual periods in the soil tend to be more effective against yellow starthistle because they remain effective throughout yellow starthistle's long germination period. To achieve season-long control of yellow starthistle, the most successful programs utilize herbicides that have both post-emergence and pre-emergence activity.

Yellow starthistle is most prevalent in the state of California, and the California herbicide recommendations for yellow starthistle management include:

Broadleaf selective herbicides

- **Aminopyralid** is one of the most frequently used and effective herbicides for yellow starthistle. It can be applied from the seedling to bolting stages. Aminopyralid is very effective as a post-emergent and pre-emergent herbicide. It has a fairly long soil residual period and broadcast applications may reduce re-growth from remaining starthistle seedlings for 3-4 months following application. **Aminopyralid can damage other desirable forbs and trees, especially legumes, so its use should be carefully considered in relation to existing native species, or those that may be reintroduced to a site when used in conjunction with broadleaf revegetation efforts.** This herbicide can be applied near some tree species where dicamba and picloram cannot be used, but is not registered for use in forestry, and care should still be taken to verify whether a given species is tolerant of having aminopyralid applied within its dripline. Additional information regarding

the known tolerance of various tree species to aminopyralid is available on the manufacturer's website. This herbicide does not kill grasses, sedges, cattails, or other monocots when applied post-emergence at broadcast label rates, **but it demonstrates some pre-emergence control of medusahead and bromes dependent on application timing.**

- **Aminocyclopyrachlor** is a highly effective herbicide on yellow starthistle and can be applied to seedlings and rosettes in uncultivated non-agricultural land, industrial sites, and natural areas. Like aminopyralid, it is active both post- and pre-emergent and has a similar length of soil residual activity. **Low rates of aminocyclopyrachlor can kill non-target 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. It has a broader spectrum for control of broadleaf species compared to clopyralid or aminopyralid, but is still considered relatively selective for certain broadleaf plant families, particularly the sunflower and legume families. Its use should be carefully considered in relation to existing native species, or those that may be reintroduced to a site when used in conjunction with broadleaf revegetation efforts.**
- **Clopyralid** should be applied to yellow starthistle in the seedling to bolting stages. While it provides excellent control of starthistle foliar growth, its soil residual activity is about 2 to 3 months, which is slightly less than either aminopyralid or aminocyclopyrachlor. It is more selective than aminopyralid and aminocyclopyrachlor, and is not as damaging to woody plants. **Because it will kill desirable legume species and some other forbs, its use should be carefully considered in relation to existing native species, or those that may be reintroduced to a site when used in conjunction with broadleaf revegetation efforts.**
- **2,4-D** is only applied post-emergence to yellow starthistle and is often an option at later stages of growth, generally in the bolting or spiny stages. It is faster acting compared to the other products, so is a better choice when used late season. 2,4-D is a broadleaf herbicide and will not harm grasses, sedges, cattails, or other monocots, **but will damage most other broadleaf species**. Ester formulations are volatile and should not be applied when temperatures exceed 80°F (26.7°C).
- **Triclopyr** works much like 2,4-D and is also considered a late season control option. While it provides good control of yellow starthistle foliar growth, it has little to no soil activity. Like 2,4-D, it is a broadleaf herbicide that is largely safe on grasses, sedges, cattails, or other monocots, **but it will damage most other broadleaf species**.

Non-selective herbicides

- **Glyphosate** is active only as a post-emergence herbicide and is generally used for late season control of yellow starthistle when plants are at the bolting or spiny stage. **It is a non-selective herbicide and should only be used in spot treatments and in situations where all desirable species have already senesced or where loss of non-target vegetation is acceptable.** Glyphosate may temporarily result in bare ground if applied early in the season.

There are also registered herbicides labeled for the control of yellow starthistle not used in California, including:

Broadleaf selective herbicides

- **Picloram** may be used for the control of yellow starthistle. It should be applied from the rosette to bud formation stages. Picloram has a long soil residual period, which will reduce re-growth from starthistle seedlings for 2-3 years following application. **Picloram is mostly safe for**

use on grasses (young monocots may be affected, check the product label for additional information), but it will kill desirable legume species and other forbs so its use should be carefully considered in relation to existing native species, or those that may be reintroduced to a site when used in conjunction with broadleaf revegetation efforts. 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. One yellow starthistle population has shown resistance to picloram. Resistant individuals are less fit than susceptible plants, and the population has not spread since its discovery.

- **Dicamba** should be applied to yellow starthistle rosettes or bolting plants, prior to bud formation. Dicamba is less effective alone and is often mixed with other herbicides to increase weed control results. When mixed with diflufenzopyr, dicamba is accumulated in the plant and is more effective against yellow starthistle. It has limited to no soil residual activity, so repeated applications are necessary to treat late-germinating plants. **Dicamba will likely kill desirable broadleaf species, including legumes.** Alone, it does not kill grasses, sedges, cattails or other monocots (though increased effects may be observed when it is used in combination with diflufenzopyr). Ester formulations are highly volatile and so should not be applied when temperatures exceed 80°F (26.7°C).
- **Chlorsulfuron** is a pre-emergent herbicide that can be applied in fall (when used alone) or in spring (when in combination with other herbicides) to suppress the germination of yellow starthistle. It should not be applied to frozen ground. Chlorsulfuron has no post-emergent activity so must be combined with other herbicides to provide season-long control of yellow starthistle infestations. **Chlorsulfuron is damaging to most forb species**; while it is somewhat safe on grasses and other monocots, **some grasses may be damaged**. This herbicide in solution must be constantly shaken during application, and **it can leach when in the presence of excess water.**

Non-selective herbicides

- **Imazapyr** can be applied to yellow starthistle rosettes or bolting plants. It is soil-active with a long residual activity, so is effective in preventing seedling germination. Imazapyr's soil residual activity varies with the rate applied, and may still provide weed control or harm new plantings anywhere from 3 months to 2 years post application. **It is a non-selective herbicide and should only be used in spot treatments and in situations where loss of non-target vegetation is acceptable.** Even when used as a spot treatment, **imazapyr may harm other plants rooted in the general area or even downhill, depending on soil conditions and precipitation.** It is not highly effective against yellow starthistle. Because of its low efficacy and high non-target effects, its use should be carefully considered.

When herbicides are used for the control of yellow starthistle, it is important that the applicator adhere 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 yellow starthistle in all settings (including on or near water), or for use in each state of the USA and 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 treatments can vary widely depending upon geographic location, climatic conditions and rate of application. Please consult your local weed control authority, county agricultural extension educator, or forest invasive coordinator to learn which herbicides work best for yellow starthistle control and when to apply them in your area.

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.

If land usage of treated areas includes grazing practices, consult the herbicide label for any grazing restrictions that might be applicable.

Heavy herbicide use will kill starthistle growth and is not compatible with biological control. In order to guarantee that some biological control agent populations remain viable as the yellow starthistle infestations are reduced, plants should either be sprayed late in the growing season when the seed-feeding weevils are overwintering in the soil, 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 common yellow starthistle control methods are summarized in Table 5-1.

Table 5-1. Comparison of yellow starthistle management options

Control Method	Advantage	Disadvantage
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)
	Most economical option for large infestations	Some risk of undesirable effects on non-target plants
	Public acceptance is generally higher than with other weed control methods	Permanent; cannot be undone
	Selective	Not successful in all situations
Physical Control (Hand pulling)	Reduces seed production	Expensive and time intensive
	Useful for small infestations that must be quickly eradicated	Must be repeated regularly due to constant threat of re-establishment from seed bank
Physical Control (Mowing)	Repeated mowing may reduce seed production and populations if properly timed	May spread yellow starthistle if done during flowering or seeding; or lead to compensatory growth if done too early
	Removes plant litter, increasing coverage of herbicide applications	Expensive and time intensive; requires proper timing and equipment
		Impractical in rough or difficult to access areas; also, in rocky areas it can result in sparks that trigger wildfires
Physical Control (Tillage)	Kills yellow starthistle plants when done frequently and when stems are completely removed from roots	May lead to erosion in sloped areas
		Only applicable in limited crop settings; impractical in rocky soils
		May increase yellow starthistle infestation if done too early or improperly
		Expensive and time intensive; requires proper timing and equipment
Cultural Control (Burning)	Depletes yellow starthistle seed bank	Can decrease desirable competing vegetation
	Removes plant litter, increasing coverage of herbicide applications made on newly sprouting starthistle	Negative effects on animals, air, soil erosion, and water
	Can stimulate desirable legumes and perennial grasses.	Risk of fire escaping and damaging large areas
Cultural Control (Grazing)	With the proper timing, allows use of the land even with heavy yellow starthistle infestations	Cannot be used in many natural areas such as national parks and wilderness areas
		Non-selective; can exacerbate the problem
	Can be used (under the right conditions) in combination with biological or chemical control methods	Can be expensive
		Yellow starthistle can recover rapidly post-grazing
Cultural Control (Re-seeding)	Can be used to restore native or more desirable competitive species	Expensive for large areas
	Can be self-perpetuating	May be ineffective if existing yellow starthistle seed bank is extensive

Compatibility with Biological Control
Eustenopus villosus oviposition and bud herbivory deter oviposition by the other seed-feeding biocontrol insects. Damage by rust infection can be additive to seed herbivory at some sites, but under other conditions the effects of the rust are negated because *Chaetorellia succinea* and *E. villosus* both consume a higher proportion of seeds when plants are not infected with the rust.
Applicable only to very small infestations where biocontrol is not recommended. Hand pulling is not directly compatible with any biocontrol agent; however, biocontrol can be applied to large, main infestations while hand pulling can be used on surrounding small, satellite populations.
Not compatible with the seed-feeding species. Mowing may aid in the dispersal of *Puccinia jaceae* var. *solstitialis* where conditions suit the rust.
Not compatible with all six approved biocontrol agents. Tillage is only suitable in certain crop settings, where biocontrol is not recommended in general.
Not compatible with all six approved biocontrol agents. Can only be compatible if burning is done only on some sections of the infestation annually, leaving yellow starthistle "refuges" for the biocontrol agents.
Grazing seed heads infested with insect larvae would destroy the biocontrol agents; however, most grazing occurs earlier, making grazing and seed-feeding biocontrol agent compatible.
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 yellow starthistle "refuges" for the biocontrol agents. In some settings, it is biocontrol that may make re-seeding feasible.

GLOSSARY

Term	Definition
abdomen	The last of the three insect body regions; usually containing the digestive and reproductive organs
achene	A small, one-seeded fruit that does not split at maturity
adventive	A biocontrol species that arrived in the geographical area from elsewhere by any means, not through official biocontrol development processes
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
arthropod	An invertebrate animal having an exoskeleton, a segmented body, and jointed appendages. Arthropods form the phylum Arthropoda, which includes the insects, arachnids, myriapods, and crustaceans
basal	Located at the base of a plant or plant part
biennial	A plant that flowers and dies between its first and second years and does not flower in its first year
bioherbicide	A biologically based control agent for weeds, often using a fungus, bacteria, virus, or other pathogen.
biological control	The reduction in the abundance of a pest through intentional use of its natural enemies (predators, parasitoids, and pathogens)
bolting	Plant stage at which the flower stalk begins to grow
bract	A small, leaf-like structure below a flower
broadcast application	Application of a pesticide to a broad area, as opposed to small localized spots
capitulum (capitula pl.)	Seed head of a plant in the sunflower family
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 arthropods
coordinates	A set of numbers used to specify a location
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
dormancy	Period in an organism's life cycle when growth, development, and physical activity are temporarily stopped. This minimizes metabolic activity and helps an organism conserve energy
dripline	The outermost circumference of a tree's canopy, from which water drips onto the ground
emergence (insect)	Act of adult insect leaving the pupal exoskeleton, or leaving winter or summer dormancy
eradicate	To get rid of something completely
erect	Grows upright and vertical as opposed to prostrate (spreading on the ground)

Term	Definition
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
floret	One of the small, closely clustered flowers forming the head of a composite flower in the sunflower family
flower head	A special type of inflorescence consisting of numerous florets that actually look like one flower
forb	Herbaceous plant (does not have solid woody stems)
frass	Plant fragments, usually mixed with excrement, deposited by feeding insects
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-making 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
head	Insect segment with the mouth parts, antennae, and eyes
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
inflorescence	The flowering part of a plant
instar	The phase of an arthropod's nymphal or larval development between molts
invasive	Tending to spread prolifically and undesirably or harmfully
involucre	A circle of bracts under an inflorescence
larva (pl. larvae)	Immature stage of some animals, including insects and mites. In insects with complete metamorphosis, it is the stage between the egg and pupa (examples include grubs, caterpillars, and maggots)
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, orchids
monotypic	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
non-target effect	When control efforts affect a species other than the species they were enacted to control (can be positive or negative)

Term	Definition
Nosema	Small microsporidian parasites that live in the digestive tract of arthropods
noxious weed	A weed whose control is mandated, and whose movement is regulated by federal or state law
nymph	Immature form of invertebrates, including mites and insects, that undergoes gradual metamorphosis. Resembles adults
outcrossing	Introducing unrelated genetic material into a breeding line
oviposit	To lay or deposit eggs
pappus	A tuft of hairs, scales, or bristles at the base of an achene in flowers of the sunflower family
parasitoid	An insect (e.g., a wasp) whose larvae live as parasites, eventually killing their hosts (typically other insects)
perennial	A plant that lives for more than two years
plant cover	The portion of the vegetative canopy in a fixed area attributable to an individual or a single plant species
post-emergent herbicide	Herbicide that kills plants at any point during the growth cycle
pre-emergent herbicide	Herbicide that prevents the germination of seeds
pupa (pl. pupae; v. pupate)	Non-feeding, inactive stage between larva and adult for an insect with complete metamorphosis
puparium	A rigid outer shell formed from the last larval skin that covers the pupae of some insects, especially some fly species
qualitative	Measurement of descriptive elements (e.g., age class, distribution)
quantitative	Measurement of quantity; the number or amount (e.g., seeds per capitula)
receptacle	Part of the stem to which the flower is attached
rosette	A compact, circular, and normally basal cluster of leaves
self-incompatible	Mechanism in flowering plants that prevents self-fertilization (inbreeding) and promotes outcrossing
senescence	Final stage in a plant's life cycle
seed head	Mature flower head containing seeds
species	A fundamental category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding
spot spray application	Application of a pesticide to small localized spots or individuals, as opposed to a broad area
surfactant	A compound 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
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

SELECTED REFERENCES

Chapter 1: Introduction

Balciunas JK. 1999. Code of best practices for classical biocontrol of weeds. In: N.R. Spencer (ed.). Proceedings of the X International Symposium on Biological Control of Weeds. Montana State University, Bozeman, Montana, USA.

CFIA. 2014. Yellow starthistle – *Centaurea solstitialis* L. Canadian Food and Inspection Agency, Government of Canada.

Clinton, W.J. 1993. Executive Order 13122 Invasive Species, 3 February 1993. United States. Office of the Federal Register (http://www.gsa.gov/portal/content/101587, Accessed 20 March 2016).

Department of Primary Industries. 2010. Invasive Plants and Animals Policy Framework. State of Victoria, Australia (http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/protecting-victoria-from-pest-animals-and-weeds/invasive-plants-and-animals/invasive-plants-and-animals-policy-framework, Accessed 20 March 2016).

DiTomaso, J.M. 1998. Biology and impact of yellow starthistle. Pp. 82-84, M.S. Hoddle, ed. *In*, California Conference on Biological Control. Innovation in Biological Control Research.

DiTomaso, J.M. and J.D. Gerlach, Jr. 2000. *Centaurea solstitialis*. *In:* Bossard, C.C., J.M. Randall, and M.C. Hoshovsky, eds. Invasive plants of California's wildlands. Berkeley, CA: University of California Press: 101-106.

Duncan, C.L. 2001. Knapweed management: another decade of change. *In*: Smith, Lincoln, ed. Proceedings, 1st international knapweed symposium of the 21st century; 2001 March 15-16; Coeur d'Alene, ID. Albany, CA: U.S. Department of Agriculture, Agricultural Research Service: 1-7.

Eagle, A.J., M.E. Eiswerth, W.S. Johnson, S.E. Schoenig, and G.C. van Kooten. 2007. Costs and losses imposed on California ranchers by yellow starthistle. Rangeland Ecology and Management 60:369-377.

EDDMapS. 2016. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. (www.eddmaps.org, Accessed 26 June 2016).

Enloe, S.F., J.M. DiTomaso, S.B. Orloff, and D.J. Drake. 2004. Soil water dynamics differ among rangeland plant communities dominated by yellow starthistle (*Centaurea solstitialis*), annual grasses, or perennial grasses. Weed Science 52(6): 929–935.

Gerlach, J.D., Jr. 2004. The impacts of serial land-use changes and biological invasions on soil water resources in California, USA. Journal of Arid Environments 57(3): 365-379.

Juliá, R., D. W. Holland, and J. Guenthner. 2007. Assessing the economic impact of invasive species: the case of yellow starthistle (*Centaurea solstitialis* L.) in the rangelands of Idaho, USA. Journal of Environmental Management 85:876-882.

McFadyen, R.E.C. 1998. Biological control of weeds. Annual Review of Entomology 43:369-393.

NAPPO RSMP NO.7. 2008. North American Plant Protection Organization, Regional Standards for Phytosanitary Measures, Number 7. Guidelines for Petition for First Release of Non-indigenous Phytophagous Biological Control Agents. Ottawa, Ontario, Canada.

Scott, T. and N. Pratini. 1995. Habitat fragmentation: the sum of the pieces is less than the whole. California Agriculture. 49(6):56.

Susanna, A, M. Galbany-Casals, K. Romaschenko, L. Barres, J. Martin, and N. Garcia-Jacas. 2011. Lessons from *Plectocephalus* (Compositae, Cardueae-Centaureinae): ITS disorientation in annuals and Beringian dispersal as revealed by molecular analyses. Annals of Botany 108(2): 263-277.

USDA, APHIS. 2000. Reviewer's Manual for the Technical Advisory Group for Biological Control Agents of Weeds Guidelines for Evaluating the Safety of Candidate Biological Control Agents. Animal and Plant Health Inspection Service, Plant Protection and Quarantine. 02/2003.

USDA, NRCS. 2016. The PLANTS Database (http://plants.usda.gov, 26 July 2016). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

Wilson, L.M., C. Jette, J. Connett, and J. McCaffrey. 2003. Biology and Biological Control of Yellow Starthistle. 2nd ed. Fort Collins, CO: Forest Health Technology Enterprise Team, U.S. Department of Agriculture, Forest Service Publication FHTET-1998-17.

Zouhar, K. 2002. *Centaurea solstitialis. In*: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/plants/forb/censol/all.html [Accessed 26 July 2016].

Chapter 2: Getting to Know Yellow Starthistle

Benefield, C.B., J.M. DiTomaso, G.B. Kyser, and A. Tschohl. 2001. Reproductive biology of yellow starthistle: maximizing late-season control. Weed Science. 49(1): 83-90.

Callihan, R.H., T.S. Prather and F.E. Northam. 1993. Longevity of yellow starthistle (*Centaurea solstitialis*) achenes in soil. Weed Technology. 7:33-35.

Center for Invasive Species Management. 2016. State and Province Noxious Weed Lists. (http://www.weedcenter.org/resources/state.html, Accessed 15 August 2016).

CFIA. 2014. Yellow starthistle – *Centaurea solstitialis* L. Canadian Food and Inspection Agency, Government of Canada.

Coombs, E.M., J.K. Clark, G.L. Piper, and A.F. Cofrancesco, Jr. (eds.). 2004. Biological Control of Invasive Plants in the United States. Oregon State University Press, Corvallis. 467 pp.

DiTomaso, J.M., G.B. Kyser and C.B. Pirosko. 2003. Effect of light and density on yellow starthistle (*Centaurea solstitialis*) root growth and soil moisture use. Weed Science. 51:334-341.

DiTomaso, J.M, G. B. Kyser, and M. J. Pitcairn. 2006. Yellow starthistle management guide. Cal-IPC Publication 2006-03. California Invasive Plant Council: Berkeley, CA. 78 pp. Available: www.cal-ipc.org.

Hickman, J. [ed.]. 1993. The Jepson Manual: Higher plants of California. Berkeley, CA: University of California Press. 1400 pp.

Hierro, J.L., O. Eren, L. Khetsuriani, A. Diaconu, K. Torok, D. Montesinos, K. Andonian, D. Kikodze, L. Janoian, D. Villarreal, M.E. Estanga-Mollica, and R.M. Callaway. 2009. Germination responses of an invasive species in native and non-native ranges. Oikos 118: 529-538.

Joley, D.B., D.M. Maddox, D.M.supkoff and A. Mayfield. 1992. Dynamics of yellow starthistle (*Centaurea solstsitialis*) achenes in field and laboratory. Weed Science. 40:190-194.

Joley, D. B., D. M. Maddox, S. E. Schoenig, and B. E. Mackey. 2003. Parameters affecting germinability and seed bank dynamics in dimorphic achenes of *Centaurea solstitialis* in California. Canadian Journal of Botany 81: 993-1007.

Keil, D.J. 2016. *Centaurea*. *In*: Jepson Flora Project (eds.) *Jepson eFlora* (ucjeps.berkeley.edu/cgi-bin/get_IJM.pl?tid=367, Accessed 26 July 2016).

Keil, D.J. and J. Ochsmann. 2006. *Centaurea. In* Flora of North America Editorial Committee 1993+, Ed. Flora of North America North of Mexico. Vol. 19. Oxford University Press, New York. pp. 181-194.

Larson, L. and G. Kiemnec. 1997. Differential germination by dimorphic achenes of yellow starthistle (*Centaurea solstitialis* L.) under water stress. Journal of Arid Environments. 37(1): 107-114.

Maddox, D.M. 1981. Introduction, phenology, and density of yellow starthistle in coastal, intercoastal, and central valley situations in California. Agric. Res. Results No. ARR-W-20/July. U.S. Department of Agriculture, Agriculture Research Service, Washington D.C.

Maddox, D.M. and A. Mayfield. 1985. Yellow starthistle infestations are on the increase. California Agriculture. 39(11/12):10-12.

Roche, B.F., Jr. 1965. Ecologic studies of yellow star-thistle (*Centaurea solstitialis* L.). Moscow, ID. University of Idaho. 78 p. Dissertation.

Sheley, R.L., L.L. Larson and D.E. Johnson. 1993. Germination and root dynamics of range weeds and forage species. Weed Technology. 7(1):234-237.

Sun, M. 1997. Population genetic structure of yellow starthistle (*Centaurea solstitialis*), a colonizing weed in western United States. Can. J. Bot. 75:1470-1478.

Sun, M. and K. Ritland. 1998. Mating system of yellow starthistle (*Centaurea solstitialis*), a successful colonizer in North America. Heredity. 80:225-232.

USDA, ARS. 2016. National Genetic Resources Program. Germplasm Resources Information Network - (GRIN). Online Database. (https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearch.aspx; 26 July 2016). National Germplasm Resources Laboratory, Beltsville, Maryland, USA.

USDA, NRCS. 2016. The PLANTS Database (http://plants.usda.gov, 26 June 2016). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

Young, S.L., G.B. Kyser, J.N. Barney, V.P. Claassen, and J.M. DiTomaso. 2010. Spatio-temporal relationship between water depletion and root distribution patterns of *Centaurea solstitialis* and two native perennials. Restoration Ecology 18(2): 323–333.

Chapter 3: Biology of Yellow Starthistle Biological Control Agents

Andreas, J.E., J. Milan, C. Randall, and C. Park. 2017. Biological Control. *In* E. Peachey, Ed. Pacific Northwest Weed Management Handbook. Oregon State University, Corvallis, Oregon. pp. B1-B6. https://pnwhandbooks.org/weed/biological-control

Balciunas, J. and B. Villegas. 1999. Two new seed head flies attack yellow starthistle. California Agriculture 53(2): 8-11.

Balciunas, J.K. and B. Villegas. 2001. Unintentionally released Chaetorellia succinea (Diptera: Tephritidae): is this natural enemy of yellow starthistle a threat to safflower growers? Environmental Entomology 30(5): 953-963.

Balciunas, J.K. and B. Villegas. 2007. Laboratory and realized host ranges of Chaetorellia succinea (Diptera: Tephritidae), an unintentionally introduced natural enemy of yellow starthistle. Environmental Entomology 36(4): 849-857.

Bruckart, W.L. III, J.L. Michael, E.M. Coombs, and C.B. Pirosko. 2016. Rust pathogen *Puccinia jaceae* is established on yellow starthistle (*Centaurea solstitialis*) in Oregon. Plant Disease 100(5): 1009.

Coombs, E.M., J.K. Clark, G.L. Piper, and A.F. Cofrancesco, Jr. (eds.). 2004. Biological Control of Invasive Plants in the United States. Oregon State University Press, Corvallis. 467 pp.

Garren, J.M. and S.Y. Strauss. 2009. Population-level compensation by an invasive thistle thwarts biological control from seed predators. Ecological Applications 19(3): 709-721.

O'Brien, J.M., G.B. Kyser, D.M. Woods, and J.M. DiTomaso. 2010. Effects of the rust *Puccinia jaceae* var. *solstitialis* on *Centaurea solstitialis* (yellow starthistle) growth and competition. Biological Control 52: 174-181.

Pitcairn, M.J., B. Villegas, D.M. Woods, R. Yacoub, and D.B. Joley. 2008. Evaluating implementation success for seven seed head insects on *Centaurea solstitialis* in California, USA. *In* M.H. Julien, R. Sforza, M.C. Bon, H.C. Evans, P.E. Hatcher, H.L. Hinz, and B.G. Rector, Eds. Proceedings of the XII International Symposium on Biological Control of Weeds. 22-27 April 2007, La Grande Motte, France; CAB International. pp. 610-616.

Rees, N.E., P.C. Quimby, Jr., G.L. Piper, E.M. Coombs, C.E. Turner, N.R. Spencer, L.V. Knutson. 1996. Biological Control of Weeds in the West. Western Society of Weed Science, Bozeman, Montana.

Swope, S.M. and I.M. Parker. 2010. Trait-mediated interactions and lifetime fitness of the invasive plant *Centaurea solstitialis*. Ecology 918(8): 2284-2296.

Swope, S.M. and I.M. Parker. 2012. Complex interactions among biocontrol agents, pollinators, and an invasive weed: a structural equation modeling approach. Ecological Applications 22(8): 2122-2134.

Swope, S.M. and W. Satterthwaite. 2012. Variable effects of a generalist parasitoid on a biocontrol seed predator and its target weed. Ecological Applications 22(1): 20-34.

Swope, S.M. and I.R. Stein. 2012. Soil type mediates indirect interactions between *Centaurea solstitialis* and its biocontrol agents. Biological Invasions 14: 1697- 1710.

Turner, C.E., G.L. Piper, and E.M. Coombs. 1996. *Chaetorellia australis* (Diptera: Tephritidae) for biological control of yellow starthistle, *Centaurea solstitialis* (Compositae), in the western U.S.A.: establishment and seed destruction. Bulletin of Entomological Research 86: 177-182.

Winston, R.L. 2012. Idaho County Biological Control Monitoring. Annual Progress Report 2012. MIA Consulting, Shelley, ID, USA. 91 pp.

Winston, R.L., M. Schwarzländer, H.L. Hinz, M.D. Day, M.J.W. Cock and M.H. Julien, Eds. 2014a. Biological Control of Weeds: A World Catalogue of Agents and Their Target Weeds, 5th edition. USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia. FHTET-2014-04. 838 pp.

Winston, R.L., C.B. Randall, R. De Clerck-Floate, A. McClay, J. Andreas, and M. Schwarzländer. 2014b. Field Guide for the Biological Control of Weeds in the Northwest. USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia. FHTET-2014-08. http://www.ibiocontrol.org/westernweeds.pdf.

Woods, D.M., M.J. Pitcairn, D.B. Joley, and C.E. Turner. 2008. Seasonal phenology and impact of *Urophora sirunaseva* on yellow starthistle seed production in California. Biological Control 47: 172-179.

Chapter 4: Elements of a Yellow Starthistle Biocontrol Program

Andreas, J.E., E.M. Coombs, J. Milan, M. Schwarzländer, and C. Randall. 2016. Biological Control. *In* E. Peachey, Ed. Pacific Northwest Weed Management Handbook. Oregon State University, Corvallis, Oregon. pp. B1-B6.

Coombs, E.M., J.K. Clark, G.L. Piper, and A.F. Cofrancesco, Jr. (eds.). 2004. Biological Control of Invasive Plants in the United States. Oregon State University Press, Corvallis. 467 pp.

BLM: National Applied Resource Sciences Center, Ed. 1996. Sampling vegetation attributes. Cooperative Extension Service, USDA Forest Service, Natural Re- source Conservation Service, Grazing land Technology Institute and USDI Bureau of land Management. BlM/RS/ST-96/002+1730.

Garren, J.M. and S.Y. Strauss. 2009. Population-level compensation by an invasive thistle thwarts biological control from seed predators. Ecological Applications 19(3): 709-721.

Harley, K.L.S. and I.W. Forno, eds. 1992. Biological control of weeds: a handbook for practitioners and students. Inkata Press, Melbourne and Sydney.

Hironaka, M. 1985. Frequency approaches to monitor rangeland vegetation. Proceedings 38th Society Range Management Conference at Salt Lake City, Utah, February 11-15: 84-86.

McFadyen, R.E.C. 1998. Biological control of weeds. Annual Review of Entomology 43:369- 393.

Pitcairn, M.J., B. Villegas, D.M. Woods, R. Yacoub, and D.B. Joley. 2008. Evaluating implementation success for seven seed head insects on *Centaurea solstitialis* in California, USA. *In* M.H. Julien, R. Sforza, M.C. Bon, H.C. Evans, P.E. Hatcher, H.L. Hinz, and B.G. Rector, Eds. Proceedings of the XII International Symposium on Biological Control of Weeds. 22-27 April 2007, La Grande Motte, France; CAB International. pp. 610-616.

Swope, S.M. and I.M. Parker. 2012. Complex interactions among biocontrol agents, pollinators, and an invasive weed: a structural equation modeling approach. Ecological Applications 22(8): 2122-2134.

Winston, R.L., M. Schwarzländer, H.L. Hinz, M.D. Day, M.J.W. Cock and M.H. Julien, Eds. 2014. Biological Control of Weeds: A World Catalogue of Agents and Their Target Weeds, 5th edition. USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia. FHTET-2014-04. 838 pp.

Winston, R.L. 2012. Idaho County Biological Control Monitoring. Annual Progress Report 2012. MIA Consulting, Shelley, ID, USA. 91 pp.

Zamora, D.L. and D.C. Thill. 1999. Early detection and eradication of new weed infestations. pp. 73-84 In: R.L. Sheley and J.K. Petroff (eds.) Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis, OR.

Chapter 5: An Integrated Yellow Starthistle Management Program

Barry, S. 1995. Cattle fecal fax. University of California, Cooperative Extension. October Report, Nov. 7, 1995.

Benefield, C.B., J.M. DiTomaso, G.B. Kyser, S.B. Orloff, K.R. Churches, D.B. Marcum and G.A. Nader. 1999. Success of mowing to control yellow starthistle depends on timing and plant's branching form. California Agriculture 53(2):17-21.

Callaway, R.M., J. Kim and B.E. Mahall. 2006. Defoliation of *Centaurea solstitialis* stimulates compensatory growth and intensifies negative effects on neighbors. Biological Invasions. 8:1389-1397.

Cordy, D.R. 1978. *Centaurea* species and equine nigropallidal encephalomalacia. R.F. Keeler, K.R. Van Kampen and L.F. James, eds. Pages 327-336. In: Effects of Poisonous Plants on Livestock. Academic Press, New York.

DiTomaso, J.M. 1997. Risk analysis of various weed control methods. Proc. California Exotic Pest Plant Council Symposium 3:34-39.

DiTomaso, J.M., G.B. Kyser and M.S. Hastings. 1999. Prescribed burning for control of yellow starthistle (*Centaurea solstitialis*) and enhanced native plant diversity. Weed Science. 47:233-242.

DiTomaso, J.M, G. B. Kyser, and M. J. Pitcairn. 2006. Yellow starthistle management guide. Cal-IPC Publication 2006-03. California Invasive Plant Council: Berkeley, CA. 78 pp. Available: www.cal-ipc.org.

DiTomaso, J.M., G.B. Kyser et al. 2013. Weed Control in Natural Areas in the Western United States. Weed Research and Information Center, University of California. 544 pp.

Enloe, S.F., J.M. DiTomaso, S. Orloff, and D. Drake. 2005. Perennial grass establishment integrated with clopyralid treatment for yellow starthistle management on annual range. Weed Technology 19(1):94-101.

Jacobs, J.S., M.F. Carpinelli, and R.L. Sheley. 1999. Revegetating noxious weed-infested rangeland. pp. 133-141. In: R.L. Sheley and J.K. Petroff (eds.) Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis, OR.

Kyser, G.B. and J.M. DiTomaso. 2002. Instability in a grassland community after the control of yellow starthistle (*Centaurea solstitialis*) with prescribed burning. Weed Science. 50:648-657.

Miller, T.W., S.L. Shinn and D.C. Thill. 2001. Cross-resistance in chemical control of auxinic herbicide-resistant yellow starthistle (*Centaurea solstitialis*). Weed Technology. 15: 293-299.

Miller, T.W., S.L. Shinn, R.H. Callihan, L.W. Lass and D.C. Thill. 1998. Livestock trampling of grass seedlings for enhanced establishment on yellow starthistle-infested rangelands. Proc. Western Society of Weed Science 51: 114-116.

Native Seed Network. http://www.nativeseednetwork.org. Accessed 15 August 2016.

Peachey, E., editor. 2016. Pacific Northwest Weed Management Handbook [online]. Corvallis, OR: Oregon State University. https://pnwhandbooks.org/weed (accessed 31 July 2016).

Sterling, T.M., N.K. Lownds, and L. W. Murray. 2001. Picloram-resistant and -susceptible yellow starthistle accessions have similar competitive ability. Weed Science 49(1):42-47.

Thomas, F. 1996. Using annual legumes to manage weeds. Proc., California Weed Science Society 48:120-122.

Thomsen, C.D., M.P. Vayssieres and W.A. Williams. 1997. Mowing and subclover plantings suppress yellow starthistle. California Agriculture 51(6):15-20.

Thomsen, C.D., W.A. Williams, M. Vayssieres, F.L. Bell and M.R. George. 1993. Controlled grazing on annual grassland decreases yellow starthistle. California Agriculture. 47(6):36-40.

USDA, NRCS. 2016. The PLANTS Database (http://plants.usda.gov, 15 August 2016). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

VanBebber, R. 2003. CWMA Cookbook: A recipe for success. Idaho State Department of Agriculture, Boise, ID. 22 pp.

Whitson, T.D. and R. Costa. 1986. Evaluation of various herbicides for control of yellowstar thistle (Centaurea solstitialis L.). Research Progress Report, Western Society of Weed Science, p. 51.

Woo, I., L. Swiadon, T. Drlik and W. Quarles. 1999. Integrated management of yellow starthistle. IPM Practitioner 21(7):1-10.

Wrysinski, J., P. Robins, G. Veserat, and J.M. DiTomaso. 1999. Clopyralid demonstration trial Yolo County, California. Proc., California Weed Science Society 51:114-119.

APPENDIX

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 yellow starthistle foliage (no flowers or seeds) in containers
	Release delay	Transport or ship biocontrol agents immediately after collection
		Release biocontrol agents at new site immediately upon arrival or receipt of biocontrol agent
	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 yellow starthistle 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 Table 4-2 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 Yellow Starthistle Biological Control Agents" for guidelines on desirable weather conditions
	Population insufficient	Only collect from well-established populations
Biocontrol 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 as many biocontrol agents as is feasible to ensure survival and reproduction (preferably ≥ 200 individuals)
	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 yellow starthistle is 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 Table 4-2 for guidelines
	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)
Cannot locate release site	Location marker not obvious	Use a 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): Larvae 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 m^2):**_____ **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 (cont.): Sample Biological Control Agent Release Form

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: Standardized Impact Monitoring Protocol (SIMP)

Overview:

A critical part of successful weed biological control programs is a monitoring process to measure populations of biological control agents and the impact they are having on the target weed. Monitoring should be conducted on an annual basis for a number of years. The Idaho State Department of Agriculture, in conjunction with the University of Idaho, Nez Perce Biocontrol Center, and federal land management agencies, has developed the monitoring protocol below to enable land managers to take a more active role in monitoring the progress and weed control ability of the yellow starthistle seed-feeding insects. This monitoring protocol was designed to be implemented by land managers in a timely manner while providing data which will enable researchers to better quantify the impact of seed-feeding insects on yellow starthistle throughout the USA.

Yellow starthistle:

Yellow starthistle is an herbaceous winter annual typically growing 1-3 feet tall from a deep taproot. Rosettes have deeply lobed leaves up to 6 inches long. Plants produce one or more rigid, upright stems with multiple spreading branches. Stem leaves are typically narrow, unlobed, and attach directly to plant stems by wings that run down the sides of the stems. All stems, leaves, and wings are densely covered with cobwebby hairs later in the season, resulting in a characteristic gray-green color. Flower heads are 0.7 inches across and consist of 10-80 bright yellow florets. Flower heads appear in late summer through early fall at branch tips and sometimes at leaf or branch axils. The bracts are spiny and up to 1 inch long. Seeds are oblong and up to 1/8 inch long. Plumed seeds are tan to brown, located at the center of the seed head, and have a ring of pappus consisting of fine, white bristles. Plumeless seeds are dark brown to black, fewer in number, occur around the periphery of the seed head, and lack pappus. A large plant is capable of producing up to 100,000 seeds that can remain viable in the soil for up to ten years (the majority germinate within three). Yellow starthistle is common in rangelands, along roadsides, and in other disturbed habitats such as hayfields, orchards, vineyards and abandoned areas.

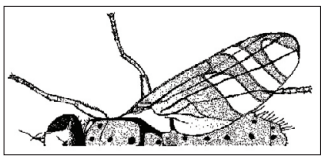
Yellow Starthistle Biological Control Agents:

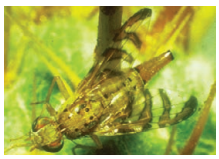
Bangasternus orientalis

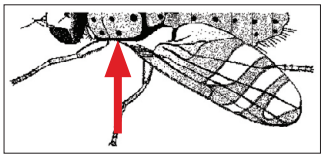
The adult weevils overwinter in soil litter and resume activity in spring when yellow starthistle is bolting. Adults are 4-6 mm long with somewhat flattened, cylinder-shaped bodies and short snouts. Adult bodies are brown with yellow-white hairs that give them a mottled appearance. Though adults may feed on starthistle stem wings and leaves, the feeding is superficial and does not significantly damage the plant. Females lay eggs singly just below flower heads and cover them with dark caps. Females may lay up to 470 eggs in a lifetime. Eggs are covered with a dark, protective substance. Hatching larvae tunnel through the stem to reach the flower head where they feed on bracts, receptacle tissue, and developing seeds. Seed consumption does not kill existing plants, but does help reduce the rate of spread of starthistle populations. Larvae are up to 6 mm long with white, C-shaped bodies and brown head capsules. Pupation occurs in chambers made of damaged seed and receptacle tissue. Adults emerge in late summer and overwinter in soil litter. There is one generation per year.

Chaetorellia australis/Chaetorellia succinea

***Chaetorellia succinea* is not approved for redistribution.**







Adults of both species emerge in early spring as yellow starthistle is beginning to bolt. Both species are very similar in appearance, with the exception of the spots on the thorax. Adults have tan bodies with black spots on the thorax; there are 8 spots on the thorax of *C. australis* while *C. succinea* has 10. Their eyes are multi-colored and metallic, and their wings are clear with thick brown bands. Males are 3-4 mm long; females are 4-6 mm, including ovipositors. Females lay eggs singly beneath bracts of closed buds. After hatching, larvae tunnel into capitula and feed on receptacle tissue and

Appendix III (cont.): Standardized Impact Monitoring Protocol (SIMP)

developing seeds through three instars. Seed consumption does not kill existing plants, but does help reduce the rate of spread of starthistle populations. Larvae are somewhat barrel-shaped (though slightly thicker at one end) and up to 4 mm long. They are white, turning yellowish with maturity, and lack a head capsule. Pupation occurs in barrel-shaped puparia within flower heads inside chambers made of pappus and chewed seeds. Adults emerge in early summer, mate, and lay eggs on more starthistle buds. Larvae of this generation overwinter within seed heads. There are usually two generations, though three generations are possible where the growing season is sufficiently long. First generation *C. australis* adults emerge one to a few weeks earlier than *C. succinea*, often too early to utilize starthistle. Consequently, they frequently use buds of the earlier-flowering invasive weed bachelor's button (*Centaurea cyanus*). The second generation of *C. australis* utilizes yellow starthistle.

Eustenopus villosus

Overwintering adults emerge in spring when yellow starthistle is bolting. They feed heavily on immature starthistle buds, leading to a high percentage of seed head abortion. Adults are 4-6 mm long with oblong, cylindrical bodies and long, slender snouts. Adult bodies are brown with lighter-colored longitudinal stripes and are covered with long hairs. Females chew holes in the sides of mature, closed buds in early to midsummer, lay eggs singly inside, and cap holes with a dark substance. Larvae hatch throughout summer and feed on developing seeds through three instars. Seed consumption does not kill existing plants, but does help reduce the rate of spread of starthistle populations. Larvae are up to 6 mm long with white, C-shaped bodies and brown head capsules. Pupation occurs in seed heads in chambers made of damaged seed and receptacle tissue. Adults emerge in late summer and overwinter in soil litter. There is one generation per year.

Larinus curtus

Overwintering adults emerge in summer when yellow starthistle is in bud and flowering and feed on florets and pollen. Adults are 5-6 mm long with oval-shaped bodies and medium-length snouts. Adult bodies are brown with white hairs that give them a mottled appearance. The body hairs are often yellowish from yellow starthistle pollen. Females lay eggs singly at the base of florets. Larvae hatch in late summer and feed on developing seeds through three instars. Seed consumption does not kill existing plants, but does help reduce the rate of spread of starthistle populations. Larvae are up to 6 mm long with white, C-shaped bodies and brown head capsules. Pupation occurs in seed heads in chambers made of damaged seed and receptacle tissue. Adults emerge in late summer and overwinter in the soil litter. There is one generation per year.

Urophora sirunaseva

Adults emerge in spring as yellow starthistle is bolting and starting to form buds. Adults have black bodies with a yellow spot on the bottom part of the thorax. Their eyes are multi-colored and metallic, and their wings are clear with dark crossbands. Males are 3-4 mm long; females are 4-6 mm, including ovipositors. Females lay eggs on top of immature, closed buds. After hatching, larvae tunnel into the bud and feed on florets through three instars. When they reach the receptacle, a woody gall is formed around each larva; multiple galls may occur in one flower head. Floret feeding and gall formation reduce seed production, helping reduce the rate of spread of starthistle populations. Galls are believed to act as nutrient sinks, diverting plant resources away from regular plant function. Larvae are somewhat barrel-shaped (though slightly thicker at one end) and up to 4 mm long. They are white, turning yellowish with maturity, and lack a head capsule but have a dark anal plate. Pupation occurs in barrel-shaped puparia within the woody galls. Adults emerge in summer, mate, and lay eggs on more starthistle buds. Larvae of this generation overwinter within galls inside the seed heads. There are two generations per year.

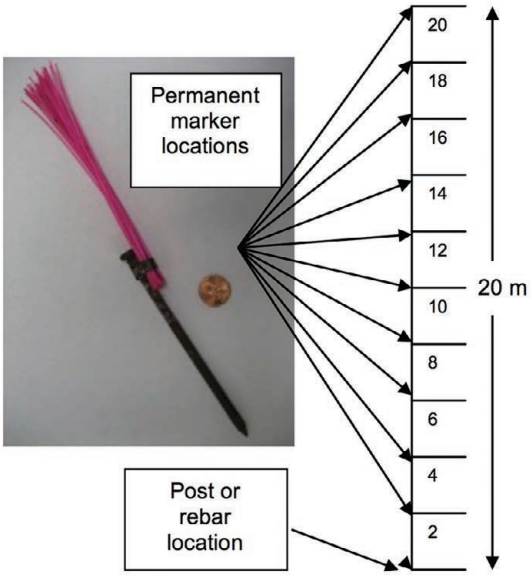
Appendix III (cont.): Standardized Impact Monitoring Protocol (SIMP)

Monitoring:

The standardized biological control impact monitoring protocol is based upon a permanent 20 meter vegetation sampling transect randomly placed in a suitable (at least 1 acre) infestation of yellow starthistle and sweep net samples of yellow starthistle seed head insects. Annual vegetation sampling will allow researchers to characterize the plant community and the abundance and vigor of yellow starthistle. Sweep net samples of yellow starthistle seed-feeding adults will provide researchers with an estimate of their annual population levels.

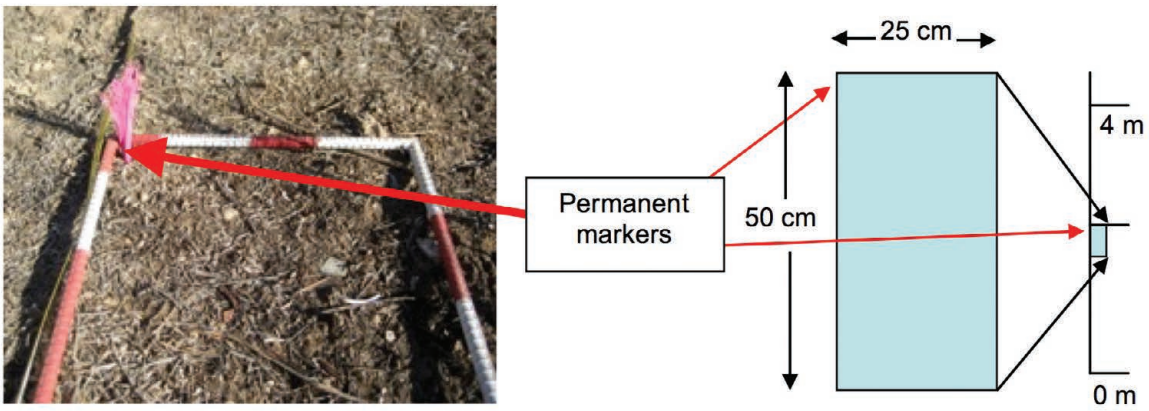
Permanent Site Set-up:

To set up the vegetation monitoring transect, you will need:
1) a 25 x 50 cm Daubenmire frame made from PVC (preferred) or rebar
2) a 20 m tape measure for the transect and plant height
3) 10 permanent markers (road whiskers and 16 penny nails – see picture at right)
4) a post (stake or piece of rebar) to monument the site (see pictures for examples of field equipment)
5) 30-45 minutes at the site during the appropriate time period for monitoring your desired seed head insect:



Bangasternus orientalis: Late May to late June
Chaetorellia australis: 1st gen: Mid-April to mid-May
2nd gen: June to mid-July
Chaetorellia succinea: 1st gen: May
2nd gen: Mid-June to July
Eustenopus villosus: June to July
Larinus curtus: Late June to July
Urophora sirunaseva: 1st gen: May
2nd gen: June to July

To set up the transect, place the 20 m tape randomly within the infestation. Mark the beginning of the transect with a post. Place permanent markers every 2 m (for a total of 10 markers) beginning at the 2 m mark and ending with the 20 m mark on the tape measure. Place the Daubenmire frame parallel to the tape on the 50 cm side with the permanent marker in the upper left corner starting at 2 m (see pictures). **Refer to the following monitoring form for how to conduct monitoring.** Repeat the frame placement at 2 m intervals for a total of 10 measurements (one at each permanent marker).



Appendix III (cont.): Standardized Impact Monitoring Protocol (SIMP)

Monitoring biological control agents is an essential component of a successful biological control program. Monitoring data can be used to accurately document the impact of this weed management practice. This monitoring form has been endorsed by the Nez Perce Biocontrol Center, University of Idaho, Forest Health Protection, Bureau of Land Management, and Idaho State Department of Agriculture. The monitoring information from this form will be used to document vegetation cover, target weed density, and biological control agent abundance. When conducted annually, this monitoring data will document changes that occur over time.

Standardized Impact Monitoring Protocol (SIMP) Biological Control Monitoring Form

General Information:

Observer(s):		Date:	Landowner:
Permanent site? Y N	Site name:		Weed:
Biological control agent:		Insect Stage:	
Lat/Long: N ° ‘	W ° ‘	UTM Datum:	UTM E:
		UTM Year :	UTM N:

Weed Infestation:

Size in acres:	Picture taken?	Yes No	If Y, picture direction:

Vegetation cover (all in %, rows add to 100%):

Frame	Target weed%	Other weed%	Forb/ shrub%	Perennial Grass%	Bare ground%	Litter%	Moss%	Total%
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Target weed size/density:

Frame	Number of Stems	Height of tallest stem (cm)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Biological control agent:

Count site	Insect count
10 sweeps repeated 6 times for (circle one):	
Bangasternus orientalis *Chaetorellia australis*	
Eustenopus villosus *Chaetorellia succinea*	
Larinus minutus *Urophora sirunaseva*	
1	
2	
3	
4	
5	
6	

Notes:

Appendix III (cont.): Standardized Impact Monitoring Protocol (SIMP)

A step-by-step guide for completing the SIMP biological control monitoring form:

General Information:

- Observer(s) – Who are you?
- Date – Today's date.
- Landowner – Who is the landowner/land manager?
- Permanent? – Is this a permanent monitoring site?
- Site name – Which site are you monitoring? This could have a specific name if it is a permanent site.
- Weed – Which target weed are you are monitoring?
- Biological control agent – Which biological control agent you are monitoring?
- Insect Stage – What is the developmental stage of the agent are you monitoring (egg, larva, nymph, pupa adult)?
- Lat/Long OR UTM – What are the GPS coordinates of the site you are monitoring? If UTM (preferred), what datum and year is your coordinate system?

Annual grass – note stems which are typically solitary or in a few stemmed tufts.

Vegetation Cover (all in %, rows add up to 100%) – All percentages are to be estimated to the nearest 5%. If there is a trace of any of the vegetation you monitoring in the frame, round up to 5%.

- Frame – Which frame number are you working on (1= 2m, 2= 4m, …,10 = 20m)?
- Target weed % – What is % cover of the target weed to the nearest 5%?
- Other weeds % – What is the % cover of any other weeds in the frame to the nearest 5%? Count undesirable annual grasses as weeds.
- Forb/Shrub % – What is the % cover of native forbs/shrubs in the frame to the nearest 5%?
- Grass % – What is the % cover of perennial grass to the nearest 5%?
- Bare Ground/Litter % – What is the % cover of bare ground/litter to the nearest 5%?

Perennial grass – note the multiple stem base with multiple year's growth.

Target Weed Size/Density

- Frame – Which frame number are you working on (1=2m, 2=4m,…,10=20m)?
- Number of stems – How many stems of the target weed are in the frame?
- Height of tallest stems (cm) – How tall is the tallest stem of the target weed in the frame (in cm)?

Biological Control Agent

- Sampling location – Identify 6 sites at least 5 paces away from the vegetation transect but within the same weed infestation.
- # of insects per 10 sweeps – How many insects are in your net after 10 sweeps of the surrounding vegetation? Take one step between each sweep. Repeat 5 more times (for a total of 6 sweep sites, 60 sweeps) moving at least 2 steps away from the last sweep location

Appendix IV: General Biological Control Agent Monitoring Form

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

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

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

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

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

1. Counting Biocontrol Agents

Perform a series of 25 sweeps, counting the adults of all six seed-feeding biocontrol insect species separately. Following each count, move to a new part of the infestation and repeat for a total of 5 counts. Record your counts in the table below, and then sum your measurements to determine the total number of adults observed.

Sample	*Bangasternus orientalis*	*Chaetorellia australis*	*Chaetorellia succinea*	*Eustenopus villosus*	*Larinus curtus*	*Urophora sirunaseva*
1						
2						
3						
4						
5						
TOTAL						

2. Estimating Visual Damage

Eustenopus villosus

Walk throughout the infestation and look closely at yellow starthistle seed heads to identify feeding damage by *Eustenopus villosus* (seed heads will have plugged holes between bracts; some seed heads will be aborted and "tipped"). Estimate the overall damage by circling the most appropriate choice in the list below.

- No *E. villosus* agent feeding observed
- Occasional, scattered feeding damage observed
- Conspicuous, widespread feeding damage observed

Puccinia jaceae var. *solstitialis*

Walk throughout the infestation and look closely at yellow starthistle foliage to identify rust infection (look for small yellow, orange, or rust-colored pustules or lesions). Estimate the overall infection level by circling the most appropriate choice in the list below.

- No *P. jaceae var. solstitialis* infection observed
- Occasional, scattered infection observed
- Conspicuous, widespread infection observed

Notes: _____

Appendix V: Yellow Starthistle 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:** _____

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%**
Yellow starthistle							
Annual grasses							
Perennial grasses							
Forbs							
Shrubs							
Trees							

Dominant Plant Species on Site:_____
_____
_____

Other Noxious Weeds:_____
_____

Estimate yellow starthistle density class (check one)			
Flowering plants/m²		Yellow starthistle distribution	
0		Isolated	
1-25		Scattered	
26-50		Scattered-Patchy	
50-75		Patchy	
>75		Continuous	

Yellow starthistle phenology class	
Starthistle stage	Estimated percent
Seedling	
Rosette	
Bolting	
Flowering	
Senescent	

Comments/Observations:

Appendix VI: Yellow Starthistle Quantitative 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:** _____

Chart A: Cover Class

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

Quad #	Yellow Starthistle Plants					Cover Class (use Chart A)						
	# Plants	Height (cm) of 4 tallest stems				Star-thistle	Annual Grass	Peren. Grass	Forbs	Shrubs	Litter	Bare ground
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

Notes: _____

Appendix VI (cont.): Yellow Starthistle Quantitative Monitoring Form

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

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

1) **Site information:** Fill out the site information at the top of the form.

2) Position the quadrat: Locate the transect using the GPS coordinates and the permanent markers. Position the quadrat frame along the transect, as close to the ground as possible, along that transect line. Gently arrange vegetation so that plant parts are either within or outside (rather than underneath) the frame, but be sure not to damage the plants. The quadrat should be in the same location as the previous year's quadrat.

4) Count stems: Count the number of yellow starthistle plants, beginning at one corner of the quadrat and working systematically across the quadrat.

5) Measure stems: Select the four tallest yellow starthistle plants in each quadrat (if there are fewer than four plants/quadrat, measure all that are present). Measure the stem height to the closest cm.

6) Estimate percent cover: Standing over the frame, estimate how much of the quadrat is covered by yellow starthistle. Then estimate the percent cover of annual grasses, perennial grasses, other forbs, shrubs, plant litter, and bare ground. Use cover estimates in Chart A to estimate the percent cover class.

7) Measure entire transect: Repeat steps 2-6 20 times at the 20 different quadrats.

8) Other observations: Record any general observations or useful information such as disturbances, grazing, fire, etc., for the sample quadrat or the site in general.