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Weed biocontrol: Extended abstracts from the 1997 Interagency Noxious-Weed Symposium

DENNIS ISAACSON and MARTHA H. BROOKES, technical coordinators

Dennis Isaacson is special projects coordinator, Oregon Department of Agriculture, 635 Capitol Street SE, Salem, Oregon 97310-110. Martha H. Brookes is a science editor, Pacific Northwest Research Station, USDA Forest Service, Corvallis, OR 97331-8440.

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[1] Additional copies of this publication can be ordered from Dennis Isaacson, 503-986-4633, disaacso@oda.state.or.us or from Richard Reardon, 304-285-1563, rreardon/na_mo@fs.fed.us.

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Forest Health
Technology Enterprise Team

TECHNOLOGY TRANSFER

Biological Control

Weed biocontrol: Extended abstracts from the 1997 Interagency Noxious-Weed Symposium

DENNIS ISAACSON and MARTHA H. BROOKES

Forest Health Technology Enterprise Team — Morgantown, West Virginia

Oregon Department of Agriculture — Salem, Oregon

USDA United States Department of Agriculture

Forest Service

FHTET-98-12
June 1999

Abstract:

The Oregon Interagency Noxious-Weed Symposium, held in odd-numbered years, addresses themes of current interest to federal, state, and county weed-management specialists, as well as representatives of the general public. The fourth in the series of symposiums was held in Corvallis, Oregon, on December 2-4, 1997. The theme was biological control of weeds. Safety of weed biocontrol and the need for monitoring the effects of biocontrol agents were emphasized. The current regulatory system was described, as were techniques for testing candidate weed-biocontrol agents. Strategies for monitoring and managing weeds were also discussed, and the status of various weed-biocontrol projects throughout the West were updated. Along with extended abstracts of the presented papers, directed principally to practitioners in the field, this document provides a comprehensive list of related readings; provides addresses, phone numbers, and e-mail addresses of resource people; lists Worldwide Web sites for weed-biocontrol information; and contains a brief glossary of useful terms.

Keywords:

Biological control of weeds, integrated pest management, vegetation management, insect-plant interactions, safety testing for biocontrol agents, implementing biocontrol, monitoring biocontrol.

Cover photo:

A noxious wetland weed, purple loosestrife, with and without attacks by two leaf-feeding beetles.

Acknowledgments

Many of the tasks of organizing a symposium such as this – and there are many – are not obvious, and, if they are handled well, the effort that goes into them can easily be overlooked. Sherry Kudna of the Oregon Department of Agriculture Weed Control staff managed most of the arrangements and took care of many, many details, which helped the symposium run smoothly. We truly appreciate her many contributions.

We also acknowledge the contributions of the presenters. They not only organized their own presentations and manuscripts, but also assisted with reviewing drafts of each other's papers in the proceedings. Several of the presenters also covered their own expenses. Such dedication speaks well of their commitment to improving the practice of weed biocontrol.

Both the Oregon State Office of the Bureau of Land Management and the USDA Forest Service made major contributions to supporting the symposium. Although several individuals from both organizations provided assistance, we especially note the encouragement and advice of Bob Bolton, Oregon Bureau of Land Management Weed Control Coordinator, and the willingness to help and financial support for publishing this document from Richard C. Reardon, Biocontrol/Biopesticides Program Manager, USDA Forest Service's Forest Health Technology Enterprise Team, Morgantown, WV. We thank Tinathan Coger for layout and design and Patricia Dougherty for printing advice and coordination of the manuscript

We also thank Barbra Mullin, Montana State Department of Agriculture, who delivered the keynote address; Tami Lowry, Pacific Northwest Research Station, Corvallis, who helped format the document; and Eric Coombs, who provided the photographs of weeds and agents that convey the concepts of weed biocontrol.

Contents

1. Introduction

The Oregon interagency noxious-weed symposium

Dennis Isaacson

The most frequent question to weed-biocontrol specialists is, "What will the agents eat after they finish off the weed?" We also hear, "Does it really work?" The answers to these two questions were the core of our symposium, and we hope participants gained a thorough understanding of two concepts central to the practice of weed biocontrol:

- Some insects and diseases survive and reproduce only on a very limited number of plant species; and
- Insect and disease organisms can affect the distribution and abundance of the plant species they attack.

These questions are not likely to confront and puzzle us in our everyday activities; they often surface only with news of impending or ongoing releases of biocontrol agents. They are simple questions – with complicated answers – that push biocontrol practitioners to trivialize their responses. With this symposium, we intended to create an environment where practitioners and other attendees could explore these questions in depth and systematically, without the press of limited time that so often beleaguers them.

We asked some biocontrol practitioners who specialize in the different steps by which weed-biocontrol agents are selected and used, to explain their responsibilities and activities. We invited some scientists who search in the country of origin for natural enemies of introduced weeds, manage quarantine facilities where safety and efficacy are tested, and analyze agent performance after release. We invited regulators who oversee procedures for review of petitions to import and release biocontrol agents. And we included weed managers who use biocontrol agents along with other approaches to control target weed species. Our goal was to describe the system in place in the United States to ensure the safety and effectiveness of weed biocontrol.

The system has its critics. In 1997, Louda *et al*. published a report in *Science* of a biological agent attacking native thistle species in the Midwest and apparently affecting populations of native insects that use these thistles. In 1987, the same agent was reported to attack native thistles in California (Turner *et al*. 1987). These disturbing findings have generated calls for reconsidering the way decisions are reached to approve importing and releasing biocontrol agents. Proposals range from outright bans against using exotic species as control agents to calls for extensive research on risk analysis. Many practitioners think the current system is adequate and has evolved in response to changes in public interest. Our symposium provided a context for informed discussion of the many facets of weed biocontrol.

Monitoring is a recognized need in weed biocontrol: the efficacy and safety of biocontrol agents can be determined only by systematic and objective observations from the field. Information presented in the session on monitoring supports incorporating it into management plans, to ensure that weed-biocontrol projects are monitored and evaluated.

Symposium speakers have written these extended abstracts to summarize their talks and respond to issues raised in the discussions. Brief though these summaries are, we believe they collectively characterize the current scope, practices, and issues in weed biocontrol. For further information, browse the extensive list of weed-biocontrol literature provided or consult with the authors and other resource people – for whom we provide addresses – or check the list of relevant web sites.

2. History

Developing safe weed biocontrol in the United States

Jack R. Coulson

Origins of classical biocontrol

Introducing exotic natural enemies to reduce populations of an introduced pest is the definition of **classical biocontrol**. Its history is fairly long: the first such agent intentionally introduced into the United States was an insect parasitoid in 1883. But biocontrol really began in earnest after the famous Vedalia beetle was introduced in 1888-89. The first introductions for weed control began in 1902 in Hawaii. Few precautions were followed during the earliest introductions, and no one studied host specificity with the weed insects back then. Successful weed biocontrol in other countries, however, sparked interest in biocontrol of weeds in North America. Importations of exotic weed-control agents into the continental United States began in the 1940s and into Canada in 1950. These early introductions were before today's detailed testing protocols and safety precautions were developed, and before proposed introductions were formally reviewed – beyond the review by the scientists conducting the studies.

Early development of safety precautions

In the early years, three laws were passed that had direct bearing on classical biocontrol – the Plant Quarantine Act of 1912; the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) of 1947; and the Federal Plant Pest Act (FPPA) of 1957 – though these laws were intended for other purposes. Under the Plant Quarantine Act and the Federal Plant Pest Act, federal permits from the Department of Agriculture (USDA) are required for importing plant pests and for moving them – or articles that may contain them – across state lines; this requirement was interpreted until recently to cover all biocontrol agents, including those attacking insect pests as "indirect plant pests." Under FIFRA, biocontrol agents are classified as "pesticides" and thus can be regulated by the Environmental Protection Agency (EPA). In 1980, macroorganisms (invertebrate parasites, predators, and weed-control agents) were exempted because these groups were deemed to be adequately regulated by another agency (the USDA), but microbial biocontrol organisms remained regulated by the EPA. Also during this early period, biocontrol quarantine facilities were established in the United States; imported material was initially received and examined under quarantine to ensure against accidentally introducing unwanted organisms.

In December 1957, the joint Weed Committees of the USDA and U.S. Department of the Interior (USDI) established a subcommittee on biocontrol of weeds, at the request of weed-biocontrol researchers, who recognized a need for wide disciplinary participation in decisions about introducing exotic weed-biocontrol agents. The group's name was changed from subcommittee to working group in 1971. Initial members included representatives from seven USDA and USDI agencies. By 1978, membership had expanded to eleven, and included members from EPA and the U.S. Army Corps of Engineers. In 1962, the practice of reciprocal reviews of proposed introductions of weed-biocontrol agents by Canadian and U.S. review groups began, and in 1971, Mexican plant-protection officials were included as reviewers. The rationale was, of course, that when an agent is introduced by any of the countries, it is introduced into North America, and thus it deserves review by each actual and potential host country.

Evolving safety considerations in classical weed biocontrol

The original subcommittee identified two initial safety concerns: **Conflicts of interest** that is, whether the targeted plant is universally regarded as a weed – and recommending plants against which potential biocontrol agents should be tested, to assure the **safety of plants important to agriculture, horticulture, forestry, or wildlife**. The working group gradually broadened its responsibilities to include not only responding to these points, but also evaluating the adequacy of research data showing the safety of – and the need for – releasing an exotic organism to control a weed. The group continued to make comments and recommendations for the benefit of researchers, but the advice was also of value to the USDA's Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ), in reaching decisions on whether to permit release of an agent.

In response to growing environmental concerns by the U.S. public, two other laws were passed that have changed classical biocontrol procedures greatly: The National Environmental Policy Act of 1969 (NEPA), and the Endangered Species Act of 1973 (ESA). NEPA requires that all federal agencies must consider the environmental effects of proposed major actions that may significantly affect the human environment in the United States. In response, USDA agencies now require an environmental assessment (EA) for the initial field release of exotic biocontrol agents in the United States, approvals from the affected state or states, and USDA permits for agent release. ESA requires all federal agencies to ensure that any action they carry out or fund is not likely to jeopardize the continued existence of any listed or proposed endangered or threatened species, including the more than 650 plants currently listed by the USDI's Fish and Wildlife Service (FWS), or destroy or adversely modify designated or proposed critical habitat. The provisions of these new laws point out the problems in developing a classical weed-biocontrol program, and in reviewing proposed introductions. No longer can we consider only the "plants of importance to agriculture, horticulture, forestry, or wildlife;" researchers and reviewers must now consider not only the plants related to endangered and threatened species, but also other related, nonlisted native plants, and the effects of proposed introductions on native habitats.

In response to these new rules, the USDA's Agricultural Research Service (ARS) began developing detailed guidelines in the 1970s for its scientists to follow in introducing the many different types of exotic organisms that can be used in classical biocontrol pro-

grams. The ARS guidelines were published in draft in 1991 for introducing six types of organisms, including weed-biocontrol agents. The guidelines remain in draft today, awaiting final action on several pertinent regulatory proposals made in recent years by APHIS. Also, in partial response to changed regulations, the old working group was abolished and replaced in January 1987 by the Technical Advisory Group on Introduction of Biological Control Agents for Weeds (called TAG), under APHIS-PPQ. The initial charge to the 13-member advisory group remained about the same as for the previous review group, except that the new Group became a more specific adjunct of APHIS-PPQ's permit process for weed-biocontrol agents, rather than specifically for the benefit of researchers (although that benefit has actually been maintained through distribution of copies of the Group's correspondence).

Note that rules and regulations remain most stringent for introducing exotic weed-biocontrol agents, both invertebrates and microbials. APHIS-PPQ and EPA have recently discussed the use of microbials in classical biocontrol, which has been regulated by PPQ, even though FIFRA places microbials under EPA jurisdiction. The rules for biocontrol agents for arthropods (including invertebrate and microbial natural enemies) are currently confused because APHIS-PPQ's recent advance notice of proposed regulations states that these organisms are no longer to be considered potential "plant pests." The PPQ will therefore no longer issue permits for releasing these agents, leaving to the releasing agency the responsibility for meeting all legal requirements, including environmental assessments and endangered species considerations. A major USDA workshop was held in October 1996 in Maryland – attended by about 80 people from the USDA's APHIS, ARS, Forest Service, and Cooperative State Research, Education, and Extension Service, and from state departments of agriculture and land-grant universities. The main topics of the meeting were changes in regulations affecting classical biocontrol and the proposal put forth by APHIS's National Biological Control Institute for implementing procedures in the United States. As yet, the regulatory proposals made at that workshop have not been acted upon, so the regulatory situation is still murky.

History of weed biocontrol in North America

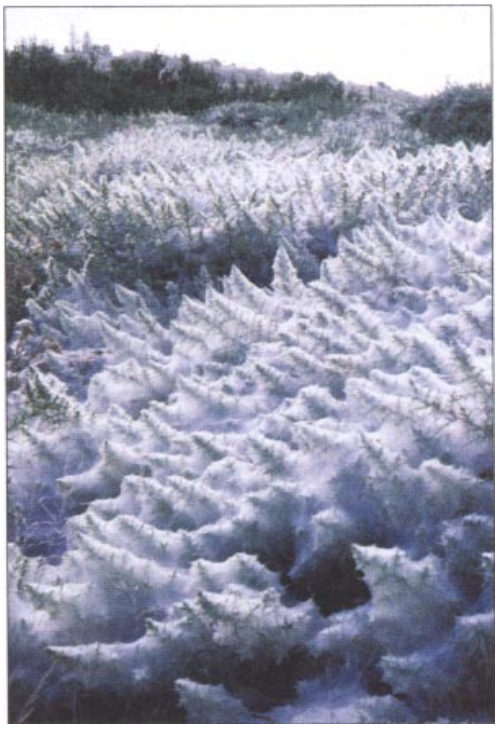
Lloyd A. Andres

The first decade – The Klamath weed project

The release by two entomologists of two species of beetles to control Klamath weed in northern California in the mid 1940s marked the real beginning of weed biocontrol in the continental United States. As sometimes happens, one of the species readily established; spread quickly, with the aid of ranchers and researchers; and controlled the weed over an increasing area. This remarkable control not only fired the enthusiasm of the two entomologists – Harry Smith, a professor at the University of California, and Jim Holloway, USDA – but also research administrators of the University and the USDA and the ranchers and farmers who benefited from the control. Thus, the first decade, 1946-1955, of what has now become over a half century of weed biocontrol in North America, was truly the decade of the Klamath weed project. From this point until 1988, weed-

biocontrol efforts throughout much of the United States were centered at the USDA's Albany, California, laboratory.

The second decade – Early growth



Gorse mites on gorse.

The second decade, 1956-1965, which I call the "early growth period," saw a five-fold increase in the number of researchers hired by the USDA, the building of a new quarantine laboratory at Albany, and the initiation of a handful of new projects. In 1956, two entomologists were hired and sent to the Middle East to seek natural enemies of halogeton, a poisonous range weed in areas of the Great Basin. A third entomologist was hired in 1958 to establish a laboratory in the Mediterranean region, and three more entomologists were hired by the Albany laboratory. New projects included puncture vine, Scotch broom, gorse, Mediterranean sage, Dalmatian toadflax, yellow starthistle, and tansy ragwort. In 1961, another entomologist was temporarily reassigned from the USDA Insect Identification Branch to survey South America for biocontrol agents of alligator weed, a pest in the southeastern United States. By 1961, the first of a series of insects began to be cleared and imported for release.

This period also saw the reestablishment of a weed-biocontrol program in Canada. Because many of Canada's major weeds also grow in the northern United States, as frequently as and sometimes more abundantly than in Canada, the insects cleared by their program often proved of benefit to the United States and visa versa. This cooperative exchange of biocontrol agents between researchers is one of the discipline's greatest strengths and extends worldwide. For such "transfer projects" to achieve greater success elsewhere than in the originating country is not unusual.

The third decade – The ripple effect

The third decade, 1966-1975, I call the "ripple-effect period." As new agents were cleared by the Albany laboratory and sent to the several states, we requested that a contact person responsible for the weed program be designated for each state. New researchers were hired in many of the states, especially in the West. With early indications that alligator weed was succumbing to the attack of the alligator weed beetle in some areas, a new USDA quarantine facility was established at Gainesville, Florida. Indications were also that the tansy ragwort flea beetle was reducing tansy ragwort populations at release sites in California.

In 1972, the research units of the USDA Agricultural Research Service were reshaped, including the disbanding of the Entomology Research Division and the Insect Identification and Parasite Introduction Research Branch, which had directly coordinated the biocontrol programs of the Department. Thereafter, program funds were directed to each of several area offices under whose jurisdiction a biological laboratory existed; program technical direction came from one of several advisors and was funneled through a staff person at Beltsville, Maryland. The programs continued but gradually became fragmented.

The fourth decade – Reassessment and resolution of project conflicts

The fourth decade, 1976-1985, continued as a period of ongoing introductions, but it could be called the decade of "reassessment and the resolution of project conflicts." As new weeds were targeted and the usefulness of weed biocontrol with plant pathogens and nematodes was demonstrated, additional USDA researchers were assigned full or part-time responsibilities at USDA laboratories in Fayetteville, Arkansas; Ft. Lauderdale, Florida; Beltsville and Frederick, Maryland; Stoneville, Mississippi; Columbia, Missouri; Bozeman, Montana; Lincoln, Nebraska; and Lubbock and Temple, Texas.

In mid-1975, the Klamath weed beetle, which had so successfully controlled Klamath weed, was beginning to feed more or less consistently on a related (in the same genus, *Hypericum*) ornamental planted along the highways of northern California and had been found on gold-wire, a native plant also in the same genus. The thistlehead weevil, introduced in the 1960s for controlling musk, milk, and Italian thistles, was beginning to appear on several native *Cirsium* species. The stem weevil used to control puncture vine continued to attack the native and closely related Arizona poppy. Several researchers hired during this decade focused on evaluating these nontarget effects and how to minimize future attacks on native plants.

Also at this time, we were working on controlling leafy spurge, a major pest on the pastures and ranges of the north-central plains. Leafy spurge has more than 100 North American native relatives, including some rare and endangered species, which posed a potential problem. Because including all of the native spurges in host-specificity studies was impractical, researchers chose test plant species based on subgeneric taxonomic classifications in the genus *Euphorbia,* their geographic distribution in North America, their proximity to leafy spurge populations, and other relevant characteristics. Only the safest of the potential biocontrol insects, those that were host specific below the subgenus, were selected for release; those insects of broader feeding range were held in abeyance. Reports of reduced leafy spurge abundance in areas where the biocontrol agents were released suggest that this testing and release strategy merits further attention when attack on related native plants is of concern.

This reassessment of introduction standards often sparked heated discussion between all elements in the biocontrol community, including the ranchers and other weed-control beneficiaries, the USDA research administrators, state legislators, persons dedicated to protecting native plants and animals, and even the researchers themselves. These questions still have not been fully resolved, and ongoing discussion and studies offer an excellent opportunity for increased understanding of insect behavior and the dynamics of plant and animal populations.

The fifth decade – Increasing regulation

The fifth decade, 1986-1995 and on to the present, has been one of continuing introductions and increased prerelease and regulatory evaluation. The concept of introducing biotic agents to control their coevolved naturalized weed hosts remains simple and straightforward. The process of clearing these biocontrol agents has become increasingly complex, difficult, and time consuming, however. As we move ahead with new projects and releases, we must keep in mind that biocontrol remains the only tool suited for use against many of our widespread weeds, especially those on low-value land. And it's a tool we must be careful not to lose.

3. Regulation

Biocontrol and the national environmental policy act

Robert E. Pizel

NEPA defined

The National Environmental Policy Act of 1969 requires every federal agency to consider the environmental consequences of its actions and may require preparing an environmental assessment (EA) or an environmental impact statement (EIS) for a proposed Agency action. The Act reflects an environmental philosophy, and its process must be integrated with Agency planning and decisions. The Act is an analytical tool that requires the interdisciplinary use of the natural and social sciences in federal planning and decisions that could affect the human environment.

NEPA is a procedural, not a substantive act. As long as the Agency complies with the Act's procedures, NEPA cannot be used to overturn a decision based on the evidence presented in the EA or EIS, even if the decision results in environmental damage.

The NEPA Process

The components of the NEPA process include

- Integrating NEPA with other planning and analysis as early as possible to ensure that planning and decisions reflect environmental values; the analysis is narrowed to the most important issues; all reasonable alternatives to the proposed action are explored and evaluated; and the alternatives selected (including no action) will avoid or reduce adverse environmental effects;
- Ensuring public participation in planning, to uphold the democratic principles of public direction and promote acceptance (public notices are required);
- Making sure that every stakeholder understands, accepts, and promotes environmental considerations, or the process will not work;
- Documenting the environmental analysis in an EIS or an EA, or categorically excluding the action from documentation; and

- Monitoring implementation for management oversight and to ensure that plans are followed and that mitigation is effective, as required by the President's Council on Environmental Quality (CEQ).

Environmental analysis and documentation are another cost of doing business. The official responsible for the decision:

- Oversees the analysis;
- Reviews and accepts responsibility for the resulting documents;
- Selects the course of action from the range of alternatives;
- Notifies the public of the decision;
- Implements the decision; and
- Monitors the results.

Environmental jurisdiction

A jurisdictional determination is not an action subject to NEPA or other environmental laws. A determination that an organism is not a plant pest (or does not represent a plant-pest risk) and may therefore be released into the environment does not require a supporting NEPA document. A plant-pest risk assessment, which uses a public process, may be all that is required to document a jurisdictional finding. A subsequent NEPA document could refer to or use the analysis in the risk assessment and eliminate any duplication of effort. Other laws (for example, FIFRA) could be found to apply to situations in which an agency has no jurisdiction.

States, universities, and other nonfederal entities are not subject to NEPA and other environmental review laws unless they are undertaking an action over which a federal agency exercises control. Federal funding alone does not establish "control" for NEPA purposes; however, this "exclusion" theory has not been applied to consultations under section 7 of the Endangered Species Act. Case law defining federal action emphasizes authority to exercise discretion over the outcome, but the federal agency must have actual power to control the nonfederal activity. If the federal agency does exercise control, it could require the nonfederal actor to prepare an environmental assessment under NEPA and consult preliminarily with the United States Fish and Wildlife Service under section 7 of the ESA before deciding whether to approve the activity.

***Agapeta zoegana* on spotted knapweed.**

***Cyphocleonus achates* on spotted knapweed.**

Given these NEPA requirements, anyone in the biocontrol community should determine where jurisdiction, if any, resides before undertaking research or other work on any organism.

APHIS's process to implement NEPA

Nearly all of the projects you would propose for APHIS permits will require only an EA and result in either a finding of no significant impact (FONSI) and therefore a decision to issue the permit, or in a finding of significant impact, which will require a notice of intent to prepare an EIS. The two classifications under the CEQ regulations and APHIS implementation are

- Environmental assessments. Relevant actions in this class are approvals and issuance of permits for proposals that include genetically engineered or nonindigenous species, except actions that are categorically excluded, and research or testing that will be conducted outside a laboratory or other containment area (for example, field trials).
- Categorical exclusions. Categorically excluded actions are those in which the methods for avoiding or reducing adverse effects have been built into the action and established through testing and monitoring. Relevant actions in this class are routine measures and research activities.

  Routine measures – such as surveys, testing, quarantine, inoculations, control, and monitoring – are those that are used by agency programs to pursue their missions and functions. Such measures may include the use of chemicals, pesticides, or other potentially hazardous or harmful substances, materials, and target-specific devices or remedies, if such use:

  - Is localized or contained in areas where people are unlikely to be exposed and limited in quantity, that is, in dosages and remedies;
  - Will not cause contaminants to enter water bodies, including wetlands;
  - Does not adversely affect any federally protected species or a critical habitat; and

  Does not bioaccumulate.

  Research and development activities excluded are those:

  - Being conducted in laboratories or other areas designed to eliminate potential harmful environmental effects – internal or external – and to provide for lawful waste disposal;
  - Permitting or acknowledging notifications for confined field releases of genetically engineered organisms and products, and
  - Permitting importation of nonindigenous species into containment facilities, interstate movement of a nonindigenous species between containment facilities, or releases into a state's environment of pure cultures of organisms that are either native or established introductions.

The National Environmental Policy Act is a mandate from Congress, so you need to do the NEPA analysis along with research planning and analysis, which will benefit both

processes. Doing the analyses at this time and predicting the likely outcome before the fact is a great benefit. The same is true for doing ESA Section 7 consultation early. A memorandum of understanding with the Fish and Wildlife Service is being considered as an approach to the unknown consequences of releasing nonindigenous species.

The NEPA documents are not decision documents, but they do provide the analysis that supports the decisions. NEPA does not require taking sides on the controversy about introducing nonindigenous species. We need only provide facts so the decision comes from a position of knowledge.

As Louda *et al*. (1997) remind us:

"The responsibility for demonstration that a release will have no unacceptable ecological consequences must reside with the advocate of introduction."

USDA APHIS and its technical advisory group

George P. Markin

Because biological agents for controlling noxious weeds attack plants, they are considered potential pests of agricultural crops; they are therefore technically listed as plant pests by the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS), the agency responsible for controlling introductions of plant pests into the United States and their movement within its borders. For routine permission to bring plant pests into the country for study – or to move them between states – APHIS depends on its own staff to review proposals and issue permits. For new biocontrol agents proposed for release, however, APHIS depends on the advice of technical experts, known as the Technical Advisory Group.

What is the Technical Advisory Group for Biological Control Agents of Weeds?

The Technical Advisory Group consists of representatives of 12 federal agencies responsible for enforcing policies or laws directly or indirectly affecting biocontrol activities, plus two scientific organizations:

- Department of Agriculture
  - APHIS, National Biological Control Institute
  - Agricultural Research Service (ARS)
  - Cooperative State Research, Education, and Extension Service
  - Forest Service
  - Natural Resource Conservation Service
- Department of the Interior
  - Bureau of Indian Affairs
  - Bureau of Land Management
  - Bureau of Reclamation
  - Fish and Wildlife Service
  - National Park Service
  - National Geological Survey

***Urophora cardui* on Canada thistle.**

• Environmental Protection Agency
• Department of Defense, Army Corps of Engineers
• National Plant Board
• Weed Society of America

Because biocontrol agents, once released, can stray across political boundaries, the advisory group encourages technical input from Canada and Mexico. In general, Canada and Mexico, although not official members of the group, participate in the reviews; their recommendations are considered the same as those of the other members.

I want to stress that the group is strictly **advisory**; it does not make final decisions on releasing biocontrol agents for weeds in North America. Group members are technical experts who represent their agencies in seeing that the laws and authorizations that are their agency's responsibility are recognized and adhered to. The group's two most important functions are to serve as technical experts to advise APHIS on whether an agent should be approved, and to serve as a source of expertise to help researchers design tests to study new agents, to select the plants that should be tested to show the safety of candidate agents, and to review petitions to determine the scientific accuracy and completeness of the data they wish to submit to APHIS.

What does the advisory group do?

When a new weed is targeted for biocontrol, the advisory group recommends that the researchers notify them and provide information about the scope of the problem and what is currently known about the weed. Most important, the researchers are asked to submit a research plan that outlines the safety tests they will use, along with a list of plants to be tested because they are related to or very similar in structure and function to the target weed and might thus be fed on by the candidate agent. Researchers are encouraged to give notice of their intent to study a new target weed as early as possible, to alert the advisory group and give the members a chance to deal with possible conflicts of interest, to suggest other tests that might be useful, and – most important – to identify other plants that ought to be tested.

When a study on a control agent is finished, a formal petition must be submitted to APHIS, with a request that the agent be considered for release in North America. Petitions are sent to advisory group members, who review them for compliance with their agency's regulations or legal responsibilities, conflicts of interest, scientific merit, and accuracy of the results. When questions arise, group members confer with the researchers for clarification and sometimes suggest additional tests or plants that should be evaluated. The reviews are compiled by the group's chairperson in a formal recommendation for approval or rejection; if the decision is to reject, the reasons are listed and sent to APHIS and forwarded to the researcher. The petitions are reviewed mostly on their scientific merit, and APHIS usually accepts the advisory group's recommendations, but sometimes for other reasons – either political or legal – APHIS may not accept them.

When the decision is to release an agent in this country, APHIS asks the researchers to submit a formal request for the release and to begin the NEPA process, preparing an environmental assessment. The EA, which describes how releasing the agent could affect the environment, is further reviewed. If no major objections are reported, a "finding of no

significant impact" is issued by APHIS and the researcher receives a permit to release the agent.

Even with a permit, release within each state requires an additional step. The person releasing the agent in the state **must first submit APHIS form PPQ-526, requesting permission to move an agent across state lines**. The form is sent to the state's agriculture department, which reviews it and decides whether it will allow the agent's release within the state's borders. If the state concurs, they sign the form and send it to APHIS, which issues a permit (PPQ-549) for the agent to enter that state.

Since 1983, the advisory group has reviewed more than 100 petitions; about half were returned to the researchers for additional work, but at least 90% were eventually approved and the agents released in North America.

A continually changing process

One of the biggest challenges in petition review by the Technical Advisory Group is the ever-changing standards, set by APHIS, by which potential control agents are screened. In the 1950s and 1960s, studies on introducing new agents concentrated on their possible effects on crops. With the rise of environmental awareness, researchers in the 1980s began to test insects against native plants that had no known economic value but were important components of the ecosystems in which the control agents would be released. Most recently, as the Fish and Wildlife Service has become more active in enforcing the Endangered Species Act, most control agents are now thoroughly screened against related species of threatened and endangered North American plants. Now, researchers must also consider potential effects on the **habitat** of endangered species.

Continual changes in the criteria that must be addressed in the petitions are challenging to researchers. To reduce the confusion, the Technical Advisory Group is preparing standard guidelines to cover both the initial notification of intent to begin work on a new weed and detailed guidelines for preparing the petition to release a new agent. An interim draft of the new guidelines has been released.

How weed biocontrol and the Endangered Species Act work together

Scott Stenquist

Noxious weeds and wildlife habitat

The U.S. Fish and Wildlife Service's National Wildlife Refuge system is dedicated to managing the estimated 700 bird, 220 mammal, 250 reptile and amphibian, and 200 fish species that inhabit these refuges. The 92-million-acre system includes 511 units, in all 50 states, territories, and possessions. Habitat on the national wildlife refuges is used by migratory birds (both game and nongame), state sensitive species, state threatened or endangered species, and federally designated threatened or endangered species. Some 57 of these refuge units were acquired under the federal Endangered Species Act of 1973.

Refuges are intended to provide fish and wildlife habitat, but noxious weeds are challenging the integrity of that habitat; threatening fish, wildlife, and endangered species; and affecting biodiversity. The refuges use weed biocontrol as part of an integrated weed-

management program. The Service employs regional integrated pest- and weed-management coordinators (listed in appendix 1), who assist in implementing pest-management policies. They use biocontrol agents, chemicals, and cultural, mechanical, and physical methods, which benefit trust resources and provide long-term, environmentally sound solutions to pest problems both on and off lands managed by the Service.

The Service's role in the Technical Advisory Group

***Sphenoptera jugoslavica* on diffuse knapweed.**

Since 1995, Bryan Arroyo has represented the Service on the USDA's Technology Advisory Group for the Biological Control of Weeds. He is important in the communication chain in reviewing petitions and pre-petition advice that come before the group, especially for endangered species review. The interest of the Group is not limited to endangered species because noxious weeds affect many other species in the national wildlife refuges and in other lands managed by the Service. We are committed to participating early in the process with pre-proposals, petitions, and researchers; to work cooperatively with partners; to improve procedures; and to participate actively in the advisory group. Pre-proposals and petitions for biocontrol should address the permanence of an agent in the ecosystem, the agent's life history, its habitat range, host specificity, possible threat to native species, and biological interactions with listed and candidate threatened or endangered species.

The Service's role in weed biocontrol

The Service's views on weed biocontrol were clearly stated in an August 15, 1997, letter from E. LaVerne Smith, Chief, Division of Endangered Species, to Dawn Wade, USDA-APHIS-PPQ:

> The U.S. Fish and Wildlife Service strongly supports the development, and legal responsible use of appropriate, safe, and effective biological control agents on nuisance nonindigenous or invasive species. As the basis for approval, biological control organisms and strategies for their use must have undergone careful, comprehensive, and transparent testing and evaluation throughout their potential range to ensure their host specificity and determine their effects on all nontarget organisms, especially federally listed species or those under consideration for designation under the Endangered Species Act. Biocontrol organisms imported into, transported within, and released into the United States, should be free of pathogens or parasites, so as not to unintentionally introduce other nonindigenous organisms. Approval must also involve open public review, as well as scientific peer review of test results, environmental risk assessment, and other applicable analysis. If biocontrol organisms are the most effective and appropriate means

available, they should be used on National Wildlife Refuges and other lands and waters under the jurisdiction of the Service.

***Pterolonche inspersa* on diffuse knapweed.**

The Service's Director, Jamie Rapport Clark, during her Senate confirmation hearing on 31 July 1997, stated, "The Service needs to communicate the fundamental message that the fate of wildlife and humans alike is linked to the well-being of the environment around us." When the environment is affected by noxious weeds, fish and wildlife – and people – are also affected. We need to continue working together to improve integrated weed-management techniques, including biocontrol for noxious weeds.

Addresses for regional coordinators and affiliates are listed in appendix 1, and relevant web sites are listed in Appendix 2.

4. Safety

Host-specificity screening of weed-eating insects

Quentin Paynter and Jeffrey L. Littlefield

Safety first

Safety is paramount in biocontrol programs: the last thing a responsible practitioner wants to do is introduce a beneficial organism that turns into a pest. Great care is needed in selecting agents that are adequately host specific to be introduced into a new environment. Examples of insect biocontrol-agents attacking plants other than their intended targets are seldom published, and no examples of extinctions of nontarget plant species have been reported. Nevertheless, examples of nontarget organisms being attacked by biocontrol agents exist. These examples fall into two categories, in which the undesirable effects on nontarget organisms were either from early biocontrol programs with inadequate screening – compared to current safety standards – or from programs where the results of specificity tests meant that nontarget effects might have been expected. Thus, these examples should not be considered failures of the testing procedure, but the result of inadequate public debate during the decision process before release.

Selecting candidate plants and agents for specificity testing

Considering the number of potential agents attacking a target weed can be extremely daunting, as would be the cost of testing all of them to determine their host specificity. The biocontrol practitioner wants to exclude nonspecific agents at the earliest stages of a

control program to reduce costs, save time, and increase the chance of success. A literature search or field surveys of the potential agent can often eliminate much of this task without specificity testing. These methods of excluding potential agents run the slight risk of eliminating species that are more specific than either host records (for example, mistakes in the literature or the misidentification of the plant or insect species) or their presence on other plants in the field might indicate (because insects sometimes rest on nonhost plants without attacking them). These simple approaches should allow a researcher to discount many species from further consideration with certainty. Relying solely on observational evidence, however, could be a negligent approach in determining the specificity of an agent because this organism has never been exposed to the native plants growing in the area of introduction, and little evidence is available for appraising the risk to these nontarget species. Specificity testing is clearly essential to satisfy fears that an insect may attack these native or economically important plant species.

Host-specificity testing has financial and practical constraints. Biocontrol workers cannot test every plant that may be exposed to a candidate agent after its release. Such testing would take enormous amounts of time, costs would be prohibitive, and testing would be unnecessary for most plants. Biocontrol workers have therefore sought ways of selecting test plants that are practicable but do not compromise safety. Certain plant species may be excluded from specificity tests by obviously incompatible life histories, structures, and processes from those of the target weed. Unfortunately, not all choices are obvious. Much has been written about the science of specificity testing needed to make the selection of test plants more efficient. Recommendations for choosing test plants have recently become the basis of technical guidelines in support of the Food & Agriculture Organization of the United Nations code of conduct for importing and releasing biocontrol agents. These guidelines recommend that a list of test plants should contain representative plants closely related to the target weed, especially those considered rare, threatened, or endangered; plants from which the candidate agent has been recorded; host plants of species closely related to the candidate agent; plants with structural or biochemical characteristics similar to those of the target weed; and crop plants not previously exposed to the candidate agent and being grown in the area where control of the weed is desired.

Testing representative populations of biocontrol agents or test plants

The population of the candidate agent should be genetically diverse to provide for a typical expression of host acceptance and use, but these populations must be selected with care because potential biotypes or races may have different host ranges. Representative individuals for testing are often selected from a single or several sites; collections of insects for field release are often made from these same sites. In selecting individual insects for testing, researchers should watch for potentially inherited differences in response based on age, life stage, or sex of the insect, as well as differences related to previous feeding by the insect or to disease in the population.

Conversely, when plants are selected for testing, differences related to plant age, tissue type, plant quality, potential biotypes, variability in or presence of plant defense compounds caused by disease or damage, or differences in the use of intact rather than excised tissues may alter the acceptance of the plant for oviposition or feeding by the insect. Environmental conditions – especially light, temperature, and humidity – also affect insect-plant interactions.

Types of tests

The sequence of events leading from finding the host plant habitat to the eventual selection, acceptance, and successful use of the individual host plant by a herbivore is complex. In host specificity testing, experiments are generally confined to the late stages of host selection – that is, when the insect selects the plant for oviposition or feeding – and the suitability of the plant for the emergence of insect offspring is determined.

Two tests are usually performed to assess the potential host range of a herbivore: **oviposition tests** determine the suitability of test plants for selection and oviposition by the adult female; and **feeding tests** determine the suitability of test plants for successful development of the insect from egg to adult and for the emergence or development of individuals. Oviposition and feeding tests may be broken down into two general categories: **no-choice tests**, in which the individual agent is forced to select the test plant or starve or not lay eggs; or **multiple-choice tests**, in which the organism is exposed to several potential hosts for selection. No-choice tests provide a simple way to determine which plant species are definitely not suitable hosts and quickly eliminate them from further consideration. Such tests are highly artificial because they do not consider the mechanisms of host selection by the insect and may lead to the rejection of possible host-specific agents. Multiple-choice tests are often better predictors of the potential host range of the organism because they introduce the element of choice, which is more typical of natural conditions. These tests are more difficult to set up compared to no-choice tests, and fewer plants may be tested. Multiple-choice tests are often used after no-choice tests to further delineate the host range.

For safety, preliminary specificity tests are often performed in the native range of the biocontrol agent. Testing in the native range has several advantages: the agent will not have to be cultured under quarantine, which can sometimes prove difficult; fresh agents can be collected from the field should problems arise in maintaining a culture; and more realistic specificity tests can be performed under field conditions. Nevertheless, specificity testing may be essential in the country of introduction because importing test plants into the agent's country is undesirable; for example, rare California *Cirsium* spp. thistles could become weeds in Europe. Sometimes the complete screening process is conducted at a domestic quarantine facility, especially if the country of origin lacks adequate facilities or trained personnel to conduct these tests. Often, the choice is a matter of economics: equipment, personnel, or test plants may be more readily available in the country of introduction, or currency-exchange rates may not favor doing the work overseas.

Assessing host specificity

Host specificity is a variable term. Ideally, biocontrol practitioners would like the insect to feed and develop **only** on the target species. Many tested biocontrol agents feed on species related to the target weed, either in the same genus or in related genera. When other plant species are used by the herbivore during the testing procedure, the investigator must decide if feeding is an artifact of the testing procedure or truly indicates the potential host range of the organism – and, if so, whether the damage is likely to be significant. To further delimit the potential host range of a herbivore, the ecological context in which the organism will interact with its potential hosts must also be considered. Such ecological questions may be: Does the life cycle of the nontarget species coincide with the activ-

ity of the insect? Is the herbivore constrained by specific ecological or physiological factors, such as habitat, elevation, moisture, and nutritional requirements? Are potential nontarget species geographically or ecologically isolated from the target species? Can the organism maintain itself on nontarget plants or does feeding result in significant damage to these plant species or to their populations?

Summary

Defining host specificity in an organism is often complex, but it must be defined before the organism can be released into a new environment. Predictions about the potential host range of an organism should be based on biological, behavioral, ecological, and taxonomic information or considerations, as well as on laboratory and field experiments. Researchers should be aware of the limitations and shortcomings of the traditional testing procedures so as not to reject host-specific organisms but still maintain a high degree of safety. In the future, a greater demand will be placed on demonstrating the safety of biocontrol organisms before introducing them. Increasing the reliability of host-specificity testing must still rely on traditional testing techniques, but increasing understanding of the key elements of host selection, the taxonomic and phylogenetic relations of the organisms, and the ecological context in which the organism will be placed is also a critical need.

The role of the Albany, CA, quarantine facility in biocontrol of western weeds

Joseph K. Balciunas

Quarantine, an essential step in the biocontrol pipeline

The process of developing a biocontrol agent for a weed is like a pipeline; it begins with exploring in the native region of the weed to find natural enemies that are potential biocontrol agents. Once a potential agent has been found, it cannot simply be shipped to the United States, even if the recipient is a government agency or a university. Other papers in this book discuss the complexity of federal and state regulations on importing live herbivorous insects. The regulations require, among other things, that a living insect or pathogen from overseas that feeds on or damages plants must be shipped directly into a secure quarantine facility.

Safety, the primary role of quarantine

A quarantine facility must be built and operated to assure that alien organisms will not escape. The extent of the safeguards required to prevent unintentional release of an overseas organism are tiered, with facilities that handle pathogens requiring the most elaborate precautions. In the United States, the Department of Agriculture's APHIS, after inspecting a newly built quarantine facility, approves or "certifies" it and periodically reinspects it. Some states, like California, have additional regulations and inspections. Once a potential agent has arrived in the facility, researchers will devote most of their effort for the next 2 to 7 years to determining whether the agent is safe enough for release. They conduct both no-choice and multiple-choice host-specificity tests to determine the risk to crops or native plants. If the researchers find that the potential agent is safe enough, they

summarize their results, along with any information they have from overseas or the literature, and present a "petition for release" to the Technical Advisory Group. If the Group approves, they forward their recommendations to APHIS, which may then grant a federal release permit. The permit is contingent on getting approval from the state or states in which the agents are intended for release.

Other associated tasks

Most quarantine facilities do far more than just host-specificity tests. The Albany facility, which for many decades was the only weed-biocontrol facility in the United States, is a good example. The many tasks (the pipeline) performed there are listed below:

- Select target weed;
- Coordinate overseas surveys for natural enemies;
- Guide preliminary testing overseas;
- Maintain containment, accessory structures, and records;
- Determine host range;
- Assure agent identity;
- Obtain permits for release;
- Determine agents are clean before release;
- Release and establish agents at selected field sites;
- Redistribute agents; and,
- Evaluate effects of released agents on target weeds and nontarget plants.

At the Albany quarantine facility, as the only federal weed-biocontrol researchers in the West, we stay abreast of the weed problems here, follow the research by other agencies both in the United States and abroad, and help select new targets for biocontrol research by the Agricultural Research Service (ARS) or other agencies. We help coordinate the overseas surveys by ARS scientists or other investigators and frequently conduct some of these surveys ourselves. We try to assure that only the best candidate insects get to the quarantine facility by providing guidance to our overseas colleagues in selecting agents and, if possible, by doing preliminary host-specificity tests overseas ourselves. Final host-range screening, especially of weeds native to the United States, must also be done under quarantine.

We must confirm the identity of the insect by sending specimens to the leading authority for that group of insects. If the insect gains approval for release, we must assure that they are "clean" – that is, they are free of parasites and diseases that might limit their effectiveness. Working with cooperators, we select a few release sites. The sites are then monitored for establishment, and when the populations of the agent are sufficiently robust, redistribution from these "nursery sites" begins. For the next 5 to 10 years (at a minimum), we will continue to monitor both the target weed and other potential hosts for effects of the released agent. All information gained from this research is made available to resource managers and scientists through talks, technical articles, and scientific publications.

Weed-biocontrol facilities – Where are they?

***Cheilosia corydon* on musk thistle.**

In a pinch, a quarantine facility designed for clearing parasitoids of insect pests can be used to clear a potential weed-biocontrol agent, but most agents are cleared through the specialized, but not so numerous, weed-biocontrol quarantine facilities. The major, currently active, weed-biocontrol quarantine facilities in North America are listed below, along with some of their current primary-target weeds. Of these, the ARS facility in Albany has historically been the most important, especially in the West. During its 45-year history, it has cleared nearly 50 agents for release against two-dozen target weeds, almost all of which live in the West. Even combined, all of the other, newer, weed-biocontrol quarantine facilities in America have cleared and released only a small fraction by comparison. In the late 1980s, the staff at the Albany quarantine facility was reduced from five scientists to one, the current staffing. A staff increase in 1998 should allow the Albany facility to resume a more active and effective role, however.

Major weed-biocontrol quarantine facilities in North America

City	*State, Country*	*Agency*	*Some current weed targets*
Albany	California, USA	ARS	Yellow starthistle, Scotch thistle
Gainesville	Florida, USA	ARS, University of Florida	Hydrilla, melaleuca, banana peppertree
Bozeman	Montana, USA	Montana State University, Forest Service	Knapweeds, leafy spurge, skeleton weed
Mission	Texas, USA	APHIS	Knapweeds, leafy spurge
Temple	Texas, USA	ARS	Saltcedar
Lethbridge	Alberta, Canada	Agriculture Canada	Houndstongue, knapweeds, thistles

Host-specificity as a measure of safety in weed biocontrol

Peter B. McEvoy

Host specificity

The safe and effective use of biocontrol requires assessing the control organism's ability to harm nontarget organisms, survive, reproduce, disperse, and evolve. Ideally,

biocontrol of pests is effective, gentle on the environment, and largely self-sustaining, with minimum need for repeated and costly pest-control actions. Some of the very characteristics that make biocontrol agents effective, however, also make them potentially dangerous invaders. Biocontrol introductions are effectively irreversible; once a control organism establishes and flourishes in the new environment, calling it back is difficult and expensive at best. So a decision to release a new biocontrol agent requires evidence that the organism is necessary, safe, and effective. Here, I examine host specificity of biocontrol agents, which is one of the primary criteria that scientists and regulators use to evaluate and rank the risks that biocontrol agents pose for nontarget organisms.

Biocontrol is founded on two ecological principles: one organism can be used to control another, and some control organisms have a limited host range. **Host range** generally refers to the set of species on which a control organism can feed and develop in nature. **Host specificity** means only a small set of plants allow a control organism to feed and develop in nature. Host-specificity tests typically measure the potential of the control organism to complete its life cycle on the target organism and also on the nontarget organisms it consumes (eats, parasitizes, or infects), but that's not the whole story. Although such host-specificity tests are necessary to estimate the probability and severity of target and nontarget effects, they are not sufficient because a control organism may harm a nontarget organism in many ways – from directly feeding on it, to interfering with it as a competitor, to indirectly interacting through an intermediate species such as a shared natural enemy or a shared host.

Additional tests beyond specificity are needed. The potential to survive and reproduce requires assessing the control agent's rate of increase to predict the conditions likely to generate outbreaks. The potential to disperse requires assessing its movement, whether by active or passive transport, to estimate the probability it will move a given distance in a given amount of time. The potential of the control agent to evolve and adapt to new hosts and environmental conditions requires examining its evolutionary history and the interplay of genetic variation, natural selection, and ecological opportunity for organism interactions. For agents with potential to harm other organisms, the risks become greater (and harder to predict) as the control agent's ability to survive, reproduce, disperse, and evolve increases.

The purpose of host-specificity studies on candidate biocontrol agents is to predict which organisms are likely to be attacked in the release environment. Traditionally, in host tests, vulnerability is equated with suitability for larval development, but this assumption can be unreliable for predicting host use in the field because host selection is a hierarchical sequence of opportunities and constraints, of which the suitability for development is just one component. Thus, screening tests of potential control agents and their hosts must include investigating how the probability and intensity of their interaction depends on phylogenetic, genetic, physiological, behavioral, and ecological constraints. The boundaries of the physiological host range measured in the laboratory may be unacceptably broad, but the estimate of the host range grows progressively narrower (and possibly more acceptable) as behavioral and ecological constraints are considered. Once the probability and intensity of host use are known, the consequences for the host population must be estimated.

Phylogenetic constraints

Phylogeny (genealogy) of insects and plants offers clues to the evolutionary stability of the host range and an indication of where to look on the tree of life for test plants to be screened in host-specificity tests. In many groups of insects, the tendency is for related insects to feed on related plants – that is, diets are phylogenetically conservative – though some associations can be found in which related insects feed on taxonomically unrelated plants. Phylogenetic analysis helps in devising a range of test plants sufficient to cover the potential host range; interpolating within the range of the data is better than extrapolating beyond it. Recent studies, summarized by Futuyama (1988), on the evolutionary stability of the host range have shown that, in a sample of 25 insect groups,

- Shifts among plant families are relatively rare, but shifts within plant families are relatively common.
- Conservative plant-insect associations are probably very old (about 70 to 100 million years old)
- The exception, rather than the rule, is finding close concordance in insect and plant phylogenies matching different insect species with different plant species in a tight coevolutionary relation.
- Broad concordance is found higher in the taxonomic hierarchy, and similar host ranges are revealed by comparing related insects in different biogeographic regions, another indication that diets are phylogenetically conservative.

Genetic constraints

All organisms harbor genetic variation and can respond to environmental change by shifts in their genetic composition. Host adaptation, or host shifts, or both can be easily demonstrated in laboratory selection-experiments, and evidence of host adaptation and host shifts by insects in the field is growing. Even morphological changes in traits affecting host use have been observed to evolve over short intervals in response to changing environmental circumstances. Thus, host adaptation and host shifts by biocontrol agents are possible, and they become probable given sufficient genetic variation, strong selection, and ecological opportunity. Tests of the evolutionary stability of the host range require screening for heritable variation in traits defining host use; weighing ecological sources of selection (for example, the rarity of normal host, competition, and host-associated predation); and estimating the ecological opportunity for interactions between control agent and target organism in space and time. Microevolutionary processes can cause gene-frequency changes in target and nontarget hosts (leading to changes in resistance) and in control agents (leading to changes in virulence), but the likelihood of such changes is not well known.

Physiological constraints

By convention, the primary tier for host-specificity testing is based on suitability of the plant for biocontrol-agent feeding and development. A **potential host** is a plant on which the control organism can complete its life cycle. Under laboratory conditions, suitability of a host is likely to be determined by chemicals in the diet, including attractants,

repellents, nutrients, toxins, and digestibility-reducing substances. The potential for an animal to eat a nontarget host is more likely to be expressed for "starved" rather than for "satiated" control agents, and in no-choice, as opposed to multiple-choice, host tests. Laboratory tests should include assessing adult feeding and oviposition and other useful attributes, but usually the tests are designed to answer a narrow question: Can the control agent complete its development on the nontarget organism? If the answer is no, then no further testing is needed. If the answer is yes, then further testing is required. Testing of agents in the laboratory rather than the field has been widely criticized by scientists because the host ranges of many arthropods and pathogens are artificially increased under artificial conditions. A way around this impasse is to point out that positive results at the primary tier of testing should simply trigger further, secondary tiers of testing under more natural conditions to discover possible mitigating factors.

Behavioral constraints

A secondary tier is based on consumer preferences: suitable hosts may not be selected by consumers that are allowed the freedom to choose. A plant may be suitable as food to a control organism in the laboratory but unsuitable as food or habitat in the wild where environmental conditions – or interactions with competitors, predators, or parasites – may be hazardous to the control agent's health. A female chooses the number, timing, and location of eggs, and her choice may limit opportunities for offspring to harm nontarget plants. Consumer preferences depend on a variety of cues (based on touch, sight, or smell) and the ways cues are perceived by the sensory system, as well as how signals are processed and translated into a response by the organism. Mobile consumers pose greater risks because they can shop around; they are more likely as adults or larvae to encounter nontarget organisms than are insects that stay at home on the target host. Thus, risks can be assessed more accurately by including studies of control-agent behavior, and the behavioral host range (preferred host range) is generally less than the physiological host range (the host range suitable for feeding and development).

Ecological constraints

A third tier is based on the probability of encounter between insect and plant and the consequences of such encounters. A rough estimate of the probability of encounter can be obtained by mapping the potential distribution and abundance of the control agent onto the current distribution and abundance of the plant. Because of uncertainties about what the potential range of the control agent might be, assuming that the potential range will fill an entire biogeographic region is easier, even though the actual range will be less. Then the risk of control-agent introductions should be judged by the joint attributes of the agent and the recipient environment. The same control agent can be a hazard in one area and benign in another, simply because the former contains potential nontargets and the latter does not. If the control agent and the nontarget organism are likely to interact, then the consequences must be estimated. This estimate is very difficult in practice, but the questions below can serve to guide it:

- How abundant is the herbivore?
- Does the herbivore feed on one species or multiple species in a plant genus or does it feed on many plant species from different plant families?

- Is the plant a preferred food species?
- How abundant is the plant, compared with more-preferred plant species?
- To what extent do the spatial ranges of the herbivore and plant overlap?
- Is the abundance of the herbivore limited by the availability of the plant species in question?
- Is the plant species sufficiently abundant to be subject to density-dependence in its birth, death, or dispersal rates?
- To what extent do the herbivore and plant disperse from patch to patch, both within and between generations?
- What is the timing of herbivory in the life cycle of the plant?
- Does herbivory relax the effect of density-dependence, or does it occur after density-dependence has already reduced plant numbers?
- Can the herbivore make rapid numerical responses to change in plant density by dispersing and aggregating?
- What are the relative magnitudes of the intrinsic rate of increase for the plant and the herbivore?
- To what extent is the current rate of herbivory determined by herbivory at various times in the past?
- How important are delays in determining the patterns of herbivore and plant populations?
- Are some age- or size-classes of the plant invulnerable, and how important are age-structure effects in general?

Uncertainty and risk

Host-specificity testing and safety in biocontrol continue to be active areas of research today. The most important uncertainties have to do with evolution and indirect effects. The public should learn about the risks of biocontrol and participate in decisions related to selecting target and control organisms, if the process is to be credible and legitimate. Most people are willing to accept risk in return for benefits, especially if the risks are familiar and voluntary. Finally, some common-sense principles of making decisions under uncertainty should be borne in mind (Ludwig *et al*. 1993):

> *"We must consider a variety of plausible hypotheses about the world; consider a variety of possible strategies; favor actions that are robust to uncertainties; hedge; favor actions that are informative; probe and experiment; monitor results; update assessments and modify policy accordingly; and favor actions that are reversible."*

5. Implementation

Selecting effective weed biocontrol agents

Alec McClay

The need for prediction

Classical biocontrol agents for weeds should be safe for nontarget species, and they should be effective in controlling their target weeds. Safety is, almost entirely, a matter of selecting host-specific agents. In deciding about whether to introduce any particular agent, both safety and effectiveness must be taken into account. Because the benefits to be realized from introducing an agent are harder to predict than the risks, evidence of risk usually overrides predictions of benefit. If we could always predict effectiveness of a biocontrol agent accurately, we could do accurate risk-benefit analyses.

Economic incentives to find ways of predicting success are always present. Delays in finding and releasing effective biocontrol agents mean that the weed continues to cause losses, money spent on screening agents has been wasted, sponsors lose patience, and biocontrol loses credibility. If simple and reliable ways could be found to predict effectiveness, the best agents could be released early in a project, and the long lead-time usually associated with successful biocontrol could be reduced. To be useful, however, any selection or prediction method must be less expensive and time-consuming than simply screening and releasing the agents.

Requirements for success

For a weed-biocontrol agent to be successful, it must first be able to establish where the weed is to be controlled. It must therefore be matched to the population of the target weed that grows there, and to the area's environmental (especially climatic) conditions. Second, the agent must cause enough damage to the target weed to reduce its population significantly. This need implies that the agent must become abundant and must cause some kind of damage to which the target weed is susceptible. Defining what constitutes the right kind of damage to control a particular weed is one of the most important but elusive issues in selecting biocontrol agents.

Approaches for predicting success

Some proposals for selecting effective agents focus primarily on the traits of the agent. For example, the numerical scoring systems of Harris (1973) and Goeden (1983) take into account factors such as the type of damage inflicted, number of generations, fecundity, distribution, and size. The Wapshere (1985) system focuses on the importance of the organism in reducing weed populations in the native range, but it also recognizes that organisms heavily suppressed by predators or parasites in their native range may be effective biocontrol agents if they escape from these enemies in the area of introduction. Crawley's historical analysis (1989) found few definite trends associated with success, but suggested that agents with a high reproductive rate were more likely to become established, and that weevils and chrysomelids had higher rates of successful control than did other insect groups.

Growth characteristics and population dynamics of the weed have been studied as a possible basis for selecting effective biocontrol agents. The hope is that such studies will reveal weak points in the weed's life cycle, and that biocontrol agents can be chosen to target these weak points. These studies may focus on the native range of the weed, the area of introduction, or both. A related approach is to assess the susceptibility of individual plants to different kinds of simulated insect feeding damage, which may indicate the plant's ability to recover from, or compensate for, stresses such as defoliation. All of these approaches depend on fairly lengthy studies, which may be difficult to fund in the context of an applied problem. So far, these plant-centered methods have been used extensively in only a few projects.

No recent attempts have been made to validate scoring systems such as the Harris and Goeden systems by analyzing historical data on the success or failure of projects, although much information on biocontrol has accumulated since the analysis by Crawley in 1989. A renewed attempt to analyze systematically an updated world database on weed biocontrol projects might now give some useful insights into factors associated with success or failure. This analysis might suggest answers to questions such as whether common or easily reared organisms are more likely to be effective than rare or difficult-to-handle ones.

Practical strategies

Because no magic formula has been found to predict the effectiveness of an agent, what practical strategies can be used to maximize the chances of finding effective agents and minimize the time and expense? The first step is often a literature survey to determine what natural enemies (insects, other arthropods, diseases, and nematodes) have been reported attacking the weed in its native range. This survey often suggests possible candidate agents, but a field survey will almost always reveal additional species.

The field survey is an important component of any biocontrol project; effective agents cannot be selected unless they are first found in surveys. The survey should therefore be planned with care. Survey areas should be selected in consultation with botanists who have studied the evolution and biogeography of the group to which the weed belongs, to ensure that they include the center of origin of the weed. New approaches, such as the use of molecular markers and phylogenetic reconstruction, may help in identifying these areas. Survey areas should ideally also be climatically matched to the proposed areas of introduction. The survey should be comprehensive, looking for arthropods, pathogens, and nematodes attacking all parts of the plant.

Many of the species found in field and literature surveys can be quickly rejected, including species already known to be in the area of introduction, known pest species, those whose known host range is too wide, those belonging to taxonomic groups that are generally not host specific, and those that feed on nonessential parts of the plant. The problem, then, is to select candidate species from the remaining pool.

An informal consultation suggested that practicing weed-biocontrol workers tend to be very skeptical about general schemes for selecting agents or predicting their effects. They do, however, use many of the factors in the Harris, Goeden, and Wapshere schemes, in an informal or intuitive way, as guides to candidate selection. These factors include the type of damage caused to the plant, reproductive rate, number of generations,

and climatic adaptation. Certain taxonomic groups, such as weevils and chrysomelids, tend to be preferred because of their good track record. In addition, ease of collecting, handling, and rearing, and the need for rapid results to satisfy project sponsors, are often quoted. Some workers believe that common or widespread organisms are likely to make better biocontrol agents than are rare species, though the basis for this belief needs to be investigated further.

A commonly used strategy is to select agents that together will attack all parts of the plant (such as a seed-feeder, a stem-borer, a defoliator, and a root-feeder). Another is to select agents related to species that have been successful against related or biologically similar weeds.

Before beginning extensive host-specificity testing, or at least as part of the first round of tests, all candidate agents should be tested for acceptance of the target weed, using plants from the proposed area of introduction. This testing is easy to do, and avoids the risk that the agent may have been collected from a misidentified host plant, or from a different strain or form of the plant, and may not accept the target population.

Biocontrol: A lottery?

Biocontrol of weeds has been compared to a lottery, in which we keep releasing agents until, by chance, we find the effective one. I prefer to compare it to a horse race, in which our previous studies and experience give us at least some chance of predicting the winners. This analogy suggests an exercise that might be useful. What if all biocontrol researchers were expected, before introducing a new agent, to make explicit predictions of the results, and to give reasons for their predictions? Such predictions were made, for example, by some of the scientists studying new biocontrol agents for purple loosestrife. Because of natural human optimism, the scientists most directly involved would not necessarily be in the best position to make predictions. We could provide, perhaps on a web site, a summary of the available biological information on the agent, the weed, and the environment in the release area, and invite any interested parties to "place their bets" and justify their predictions. Over time, a comparison of these predictions with the actual performance of the agent might help to sharpen our collective ability to select effective agents.

Managing releases of weed biocontrol agents

Richard W. Hansen

Field-insectary and general releases

Releases of weed-biocontrol agents may generally be considered as either field-insectary or general releases. **Field insectaries** are weed-infested sites selected for propagating biocontrol agents. Presumably, these sites have the characteristics believed optimal for agent survival, reproduction, and thus population growth. Field insectaries are primarily used to produce large numbers of biocontrol agents over time, and they require a comparatively high degree of monitoring and other management. They may also be used in research, providing information on sampling methods, effects of site variables on agent populations, and effects of agents on target weeds. Because field-insectary sites are rela-

tively few compared to the areas infested by the target weed, weed control is not their primary goal.

General releases (or "control releases") are widespread distributions of biocontrol agents intended to provide large-scale weed control over time. The releases are numerous relative to the distribution of the target weed, with their number limited only by how many agents are available, the resources available to collect and distribute them, the agent's dispersive abilities, and the portion of weed-infested area actually suitable for agent survival. General releases require comparatively little monitoring and management.

Management considerations for field-insectary sites generally fall into three areas: sampling (monitoring), decision thresholds, and collection and distribution. **Sampling** is collecting and analyzing a small part of a population to gather reliable information about that population as a whole. Typically, sampling programs for weed-biocontrol agents are designed to estimate the size of the agent population, but they may also be used to quantify such population characteristics as sex ratio, reproductive status, or the effects of natural enemies. **Decision thresholds** represent those points when sampling information is interpreted and then used to decide what future direction insectary-site management should take. Finally, **collection and distribution** is collecting agents from suitable insectary sites and distributing them to the general-release sites.

Sampling programs for insects in general, and weed-biocontrol agents in particular, are as varied as the organisms themselves. Generally, they require a thorough knowledge of agent biology and the relation of life-history characteristics to living and nonliving factors in the environment, especially their relation to host-plant biology. Sampling programs require a careful balance between the ease of use and the accuracy and precision of the data collected (that is, the breadth of information desired and the statistical validity of the data). Sampling methods must also be repeatable by a variety of different people, under a wide range of site conditions, and over time (both within and among years).

Since 1988, USDA-APHIS-PPQ has coordinated a national distribution program for leafy spurge biocontrol agents that is currently active in 19 states. Based on my experiences with the leafy spurge program, the following outline highlights some factors I believe should be considered in developing sampling and redistribution programs for weed-biocontrol agents.

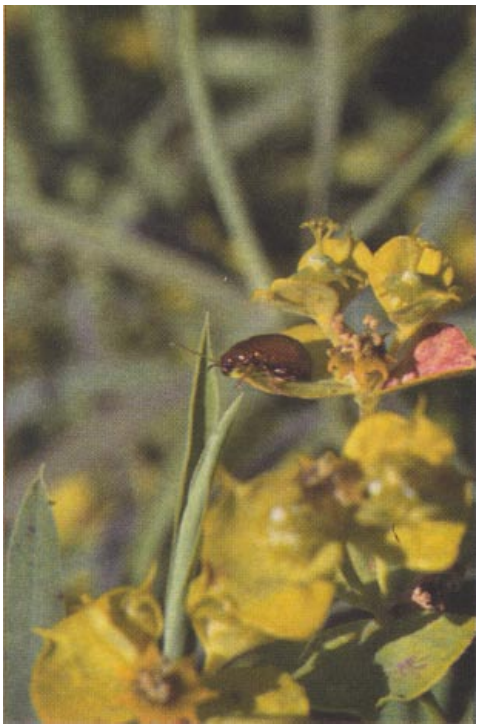
Sampling populations of weed-biocontrol agents

- **What?** The objective or objectives of the sampling program must be clearly defined.

- **Where?** Release locations must be permanently marked so they can be found year after year, often by different people; latitude and longitude coordinates derived from geographic positioning systems (GPS), and site maps can assist with this effort. The sampler must also be prepared to search for an agent population that has migrated away from the marked release location.

- **When?** The agent's life cycle must be understood so that the life stage best suited for sampling can be identified. So that sampling visits can be scheduled during the year, the seasonal abundance of the target life-stage should be known; phenological models based on degree-days may help. Finally, the diurnal distribution patterns of the target life-stage, and the effects of weather on these patterns, must be known so that sampling visits can be properly scheduled during the day of a sampling visit.

- **How?** Consistent sampling protocols (number of samples to be collected, spatial arrangement of samples, and data recording and reporting procedures) must be developed. Any equipment required must be purchased or constructed, tested, and supplied to samplers. Voucher specimens should be collected and retained to confirm, if necessary, the identification of the agent.



***Apthona cyparissae* on leafy spurge.**

Collecting and distributing biocontrol agents

- **What?** A **collection threshold –** a sampling result that determines when the population is large enough to permit collecting – must be identified.

- **Where?** The basic considerations described in the previous section are also relevant here. Additionally, the areas of a field-insectary site where agent densities are highest should be identified to optimize collecting efficiency.

- **When?** For each agent, the target life-stage and the seasonal and diurnal distribution patterns of that life stage need to be identified and measured. Generally, agent collections should be timed to coincide with the maximum abundance of the target life-stage, unless other considerations (for example, agent sex ratio or reproductive status) are important.

- **How?** Before you start collecting, I recommend that samples of the target life-stage be provided for taxonomists and microbiologists to confirm its identity and the absence of parasites and pathogens before distribution. Procedures for collecting, sorting, counting, and packaging the agent must be developed. Different protocols may be needed for local, intrastate, or interstate distribution, and any necessary federal or state permits must be acquired. Any equipment required must be built, if necessary, and provided to collectors. Short- and long-term storage procedures must be developed, and local and long-distance shipment options identified. Finally, recipients of the collected agents should be aware of proper release protocols so that subsequent field releases may be timely, maximizing agent vigor and survival.

Why do weed biocontrol agents fail?

Eric M. Coombs, Gary L. Piper, and Baldo Villegas

Tips for success

We intend this abstract to help local practitioners increase the probability of successfully establishing weed-biocontrol agents. Identifying and avoiding common errors will help. We have grouped the causes of failure into three general categories: nonliving, living, and procedural. Procedural errors – or the human factor – are often the sources of failure in biocontrol. Thus, we might best describe our contribution as, "Do as we say, not as we have done, and not as we have seen done."

In the papers we read, most failures of biocontrol were attributed either to climate or biological factors. Many sources made generalizations about the taxonomic categorization of biocontrol agents (order, family, and genus). We think that each case should be individually appraised based on the relation between the biocontrol agent and its environment (nonliving and living) and the procedures used. We acknowledge that factors in one category can be influenced by those in another, and that failures can be attributed to multiple causes.

Success and failure are often reported by large-scale political units (country, state, or county). Rarely is the ecosystem approach used in evaluating the success of biocontrol. Project success happens in stages: during introduction, recovery, establishment, and redistribution of the biocontrol agent, and in suppression of the target host. Any stage of the process can fail, especially as it relates to the number of sites targeted.

During the past decade, more agencies and other interested parties chose to incorporate biocontrol as part of their integrated pest-management program against weeds. Because the number of people lacking expertise and experience now working in biocontrol is growing, local failures have increased. Fortunately, when a biocontrol agent becomes abundant in several areas, failure at local sites becomes less important because additional releases are easy and economical. But ease of obtaining additional releases should not serve as an excuse for carelessness; we have heard it said, "Nothing breeds failure in biological control as well as a success."

Few published sources identify procedural or human factors that influence the success of weed biocontrol. Few researchers mention procedural flaws in their reports, perhaps to avoid embarrassing colleagues or jeopardizing their own research funding. The examples we list represent the collective experience of several thousand releases made by or in cooperation with the authors and our many colleagues.

Adequately training and providing information to secondary users (those who receive biocontrol agents after they have already been established at the local scale) will help improve the agent's establishment and success. The transfer of this knowledge has been improved by hands-on field days, technical bulletins, workshops, and one-on-one training.

Techniques for collecting and redistributing biocontrol agents evolve, and costs per agent are inversely proportional to their abundance and the ease of collecting them since the original release. Involving local cooperators helps instill a sense of ownership and

pride in managing their biocontrol agents and improves the chances for successfully establishing them and achieving control.

Following are the categories and associated factors that may contribute to failures in weed biocontrol.

Nonliving Factors

Climate – temperature, precipitation (intensity, duration, season, frequency)

Site – characteristics-soil, slope, aspect, shade, moisture

Elevation – temperature, precipitation

Latitude – weather extremes, seasons, day length

Fire – frequency, intensity

Living Factors

Community

Native species – predators, parasites (new associations)

Natural enemies – predators, parasites (old associations)

Host density – too dense or too sparse (microhabitat, microclimate)

Competition – with other biocontrol agents

Succession – change in community structure and composition

Other vegetation – nectar source, interference, predator habitat

Organism

Synchronization – opportunity for oviposition and development

Physiology – biotype differences (plant and environmental), health (disease, parasites, reserves), hygroscopic larvae

Fecundity – mating and ability to reproduce and increase

Behavior – host and mate searching, escape

Genetic diversity – insufficient gene pool

Emigration – moving to another location

Procedural Factors

Before release

Site selection – grazing, flooding, roads, fire, accessibility, pesticides, refugia

Colony source – laboratory-reared, biotype, synchrony

Collection method – physical damage to bioagents

***Tytaluctuosa* sp. on field bindweed.**

Shipment – method and duration, humidity, temperature, food, refugia, season, predators, mating

Proximity to nursery site – competition with other biocontrol agents, premature harvest

Time in quarantine – life-span remaining

Quality – source, health (parasites, pathogens), maturity

Quantity – number in release, sex ratios, genetic diversity, disruption

Sex ratio – breeding opportunity

Release

Method – open vs. cage, speed, canopy, escape route

Wrong agent – biocontrol agent misidentified, accidental species

Wrong host – host misidentified

Timing – temperature and time of day, season, weather pattern

Confinement – density and duration in cages

Life stage – susceptibility to mortality (host and biocontrol agent)

Documentation – no record made or retained

After release

Site management – ownership, land use

Detection – unable to find biocontrol agent

Vandalism – destruction of cages, plants, and biocontrol agents

Personnel

Inadequacy – untrained, uninterested; trample site, over harvest, premature harvest

Continuity – high turnover rate, lack of experience, losing data

Prioritization – shift projects before completion, no follow-up

Status of weed biocontrol in the Northwest

Eric M. Coombs

Biocontrol of weeds in Oregon has been coordinated by the Oregon Department of Agriculture's Noxious-Weed Control Program since 1974. Before 1974, projects were implemented through cooperative efforts between the United States Department of Agriculture's Agricultural Research Service, Oregon State University, and the Oregon Department of Agriculture. The Oregon Department of Agriculture runs one of the most intensive implementation programs for biocontrol of weeds in the United States. The general status of weed biocontrol in the Pacific Northwest (Oregon, Washington, and Idaho) is in the current-year publication of the Pacific Northwest Weed Control Handbook, available from university extension offices.

Western Oregon meadow before (1987) and after (1990) three biocontrol agents affected the poisonous weed tansy ragwort. Each of the agents attacks a different part of the plant: one is a seed-head fly, another is a moth with larvae that feed on leaves and buds, and the third is a flea beetle with larvae that live in and feed on the roots. Reductions in weed populations like those in this picture were realized throughout the range of tansy ragwort in the western United States. The economic benefits in Oregon alone are estimated to be about $5 million a year. Larvae of the defoliating moth were also tested and used in Canada, Australia, and New Zealand, but were found to attack native – but not threatened or endangered-species in the same genus as tansy ragwort.

Since 1947, 60 species of classical biocontrol agents have been introduced against 21 species of weeds. Of the 60 species, 8 failed to establish (4 died out after an initial recovery), the status of 8 is unknown (3 may have died out), and 44 are established (of which 23 have been widely redistributed). The agents include 33 beetles, 14 flies and midges, 9 moths, 2 mites, I nematode, and I rust fungus. Several biocontrol agents became associated with host plants for which they were not introduced. Several weeds are significantly affected by accidentally introduced insects and some native species (for example, poison-hemlock and Scotch broom).

Successful biocontrol projects in Oregon include Klamath weed, tansy ragwort, and – to a lesser extent – Mediterranean sage. The biocontrol of tansy ragwort in western Oregon has reduced agricultural losses by $5 million per year. Several biocontrol projects have demonstrated some preliminary success, including those against purple loosestrife, musk thistle, leafy spurge, and yellow starthistle.

Additional biocontrol agents are being tested for leafy spurge, Scotch broom, gorse, Dalmatian toadflax, Canada thistle, musk thistle, rush skeletonweed, Russian knapweed, and yellow starthistle. Other weeds targeted for biocontrol include Scotch thistle, field bindweed, Russian thistle, and houndstongue.

Successfully implementing biocontrol requires cooperation. Cooperative networks help improve the selection of release sites. Thorough documentation of biocontrol-agent releases is important and provides crucial information for project monitoring. Geographic information systems and computers are valuable tools that can improve the efficiency of releases. Geographic-positioning-system devices improve the accuracy of release-site positions and help in relocating them.

Similar plants of the wetland weed purple loosestrife, with (right) and without attacks by two species of leaf-feeding beetles, at the U. S. Fish and Wildlife Service's Baskett Slough Refuge in western Oregon. Larvae of the beetles, first introduced into western North America in 1992, have reduced loosestrife densities and prevented seed production at some sites. Beetles are being redistributed to loosestrife infestations, along with two other biocontrol agents, root-feeding and seed-feeding weevils.

Each biocontrol project goes through four basic phases: introduction, establishment, distribution, and monitoring. The introduction phase begins with the initial release of a new biocontrol agent and continues until the agent is established. New biocontrol agents are given top priority, and they are often released on the day of receipt to minimize mortality. In Oregon, a biocontrol agent is considered established after it has been recovered for three consecutive years. The distribution phase begins when surplus biocontrol agents are collected for redistribution to other sites in Oregon and neighboring states. It generally takes 3 to 5 years for populations to become collectible. During the initial distribution phase, efforts are made to include a variety of habitat types throughout the state. Biocontrol agents from a local nursery are best used for nearby and similar infestations. The monitoring phase begins when the biocontrol agents have been released in at least half of the infested townships in the state. Biocontrol-agent populations are then monitored by local cooperators, and agents are collected and redistributed as needed. During the monitoring phase, efficacy of the biocontrol agents on target weeds is inventoried when sufficient funding and staff are available.

Two tables (following), modified from the 1998 Pacific Northwest Weed Control Handbook, show the general status of weed-biocontrol in our region.

Status of Weed-Biocontrol Agents in Oregon, Washington, Idaho, and California[1]

WEED		BIOCONTROL AGENT		DISTRIBUTION[2]				ATTACK RATE[3]				CONTROL[4]				AVAILABILITY[5]			
Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
Alligator weed	*Alternanthera philoxeroides*	*Agasicles hygrophila*	Leaf beetle	–	–	–	F	–	–	–	–	–	–	–	–	–	–	–	–
Bachelor's button	*Centaurea cyanus*	*Chaetorellia australis*	Seed-head fly	W	W	W	L	H	H	M	S	E	G	G	P	M	M	M	M
		Urophora quadrifasciata[6]	Seed-head gall fly	W	W	–	–	M	L	–	–	U	P	–	–	M	M	–	–
Bindweed, field	*Convolvulus arvensis*	*Aceria malherbae*	Bud/leaf gall mite	–	L	–	–	–	–	–	–	–	U	–	–	–	U	–	–
Broom, Scotch	*Cytisus scoparius*	*Apion fuscirostre*	Seed weevil	W	L	–	W	H	L	–	M	G	F	–	P	M	L	–	M
		Leucoptera spartifoliella	Twig-mining moth	W	L	–	W	M	M	–	M	F	U	–	P	M	L	–	M
Gorse	*Ulex europaeus*	*Exapion ulicis*	Seed weevil	W	L	–	W	H	H	–	H	G	G	–	P	M	L	–	M
		Tetranychus lintearius	Spider mite	W	L	–	L	H	M	–	S	G	F	–	U	M	L	–	L
Halogeton	*Halogeton glomeratus*	*Coleophora parthenica*	Stem-boring moth	–	–	F	F	–	–	–	–	–	–	–	–	–	–	–	–
Hydrilla	*Hydrilla verticillata*	*Bagous affinis*	Tuber-mining weevil	–	–	–	F	–	–	–	–	–	–	–	–	–	–	–	–
		Hydrellia pakistanae	Leaf-mining fly	–	–	–	F	–	–	–	–	–	–	–	–	–	–	–	–
Knapweed, brown	*Centaurea jacea*	*Urophora quadrifasciata*[6]	Seed-head gall fly	L	L	U	–	L	M	U	-	U	U	U	-	L	M	U	-
Knapweed, diffuse	*Centaurea diffusa*	*Bangasternus fausti*	Seed-head weevil	L	U	U	L	M	U	U	S	G	U	U	U	L	U	U	L
		Cyphocleonus achates	Root weevil	L	–	–	–	U	–	–	-	U	–	–	-	U	–	–	-
		Larinus minutus	Seed-head weevil	L	L	–	L	M	H	–	L	G	G	–	U	L	M	–	L
		Metzneria paucipunctella	Seed-head moth	L	L	–	–	S	L	–	–	P	U	–	–	L	M	–	–
		Pterolonche inspersa	Root-boring moth	L	F	U	–	S	–	U	–	U	–	U	–	U	–	U	–
		Sphenoptera jugoslavica	Root-boring beetle	W	W	W	W	H	H	H	H	G	G	G	U	M	M	M	L
		Urophora affinis	Seed-head gall fly	W	W	W	W	M	H	M	L	G	G	F	P	M	M	M	L
		Urophora quadrifasciata	Seed-head gall fly	W	W	W	L	H	H	M	S	G	G	F	P	M	M	M	L

WEED		BIOCONTROL AGENT		DISTRIBUTION[2]				ATTACK RATE[3]				CONTROL[4]				AVAILABILITY[5]			
Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
Knapweed, meadow	*Centaurea jacea* × *nigra*	*Urophora quadrifasciata*[6]	Seed-head gall fly	L	L	–	–	L	M	–	–	U	F	–	–	L	M	–	–
		Metzneria paucipunctella[6]	Seed-head moth	L	–	–	–	S	–	–	–	P	–	–	–	L	–	–	–
Knapweed, Russian	*Acroptilon repens*	*Subanguina picridis*	Gall nematode	L	L	–	–	S	U	–	–	F	U	–	–	U	U	–	–
Knapweed, spotted	*Centaurea maculosa*	*Agapeta zoegana*	Root-boring moth	L	L	L	L	H	M	U	S	G	U	U	U	M	L	U	U
		Bangasternus fausti	Seed-head weevil	L	U	U	–	L	U	U	–	G	U	U	–	L	U	U	–
		Chaetorellia acrolophi	Seed-head fly	L	L	–	–	L	L	–	–	U	U	–	–	U	L	–	–
		Cyphocleonus achates	Root weevil	L	L	U	L	L	L	U	S	U	F	U	U	L	L	U	U
		Larinus minutus	Seed-head weevil	L	L	L	L	H	H	M	L	G	G	F	U	M	M	U	L
		Larinus obtusus	Seed-head weevil	U	L	–	–	U	L	–	–	U	U	–	–	U	U	–	–
		Metzneria paucipunctella	Seed-head moth	W	W	W	–	H	H	M	–	G	G	G	–	M	M	M	–
		Pterolonche inspersa[6]	Root-boring moth	U	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–
		Sphenoptera jugoslavica	Root-boring beetle	L	–	–	–	M	–	–	–	G	–	–	–	L	–	–	–
		Terellia virens	Seed-head fly	L	U	–	L	M	U	–	L	G	U	–	U	L	U	–	U
		Urophora affinis	Seed-head gall fly	W	W	W	W	M	H	M	L	G	G	G	P	M	M	M	L
		Urophora quadrifasciata	Seed-head gall fly	W	W	W	W	H	H	M	S	G	G	G	P	M	M	M	L
Knapweed, squarrose	*Centaurea virgata*	*Bangasternus fausti*[6]	Seed-head weevil	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–	U
		Cyphocleonus achates[6]	Root weevil	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–	U
		Larinus minutus[6]	Seed-head weevil	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–	U
		Urophora affinis[6]	Seed-head gall fly	L	–	–	L	S	–	–	S	U	–	–	P	L	–	–	U
		Urophora quadritasciata[6]	Seed-head gall fly	L	–	–	L	M	–	–	L	U	–	–	P	L	–	–	M
Loosestrife, purple	*Lythrum salicaria*	*Galerucella calmariensis*	Leaf beetle	L	L	L	–	H	H	S	–	E	E	U	–	M	M	U	–
		Galerucella pusilla	Leaf beetle	L	L	L	–	H	H	S	–	E	E	U	–	M	M	U	–

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Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
		Hylobius transversovittatus	Root weevil	L	L	U	U	M	L	U	U	G	U	U	U	L	L	U	U
		Nanophyes marmoratus	Flower-bud weevil	L	U	U	U	M	U	U	U	F	U	U	U	L	U	U	U
Puncturevine	*Tribulus terrestris*	*Microlarinus lareynii*	Stem-boring weevil	F	F	F	W	–	–	–	H	–	–	–	E	–	–	–	M
		Microlarinus lypriformis	Seed weevil	F	F	F	W	–	–	–	H	–	–	–	E	–	–	–	M
Ragwort, tansy	*Senecio jacobaea*	*Longitarsus jacobaeae*	Root/defoliating beetle	W	W	–	W	H	H	–	H	E	E	–	E	M	M	–	L
		Pegohylemyia seneciella	Seed-head fly	W	W	–	U	H	H	–	U	F	G	–	U	M	M	–	U
		Tyria jacobaeae	Defoliating moth	W	W	–	W	H	H	–	L	E	E	–	E	M	M	–	L
Sage, Mediterranean	*Salvia aethiopis*	*Phrydiuchus spilmani*	Crown/root weevil	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		Phrydiuchus tau	Crown/root weevil	W	–	W	W	H	–	H	M	G	–	U	U	M	–	M	M
St. Johnswort	*Hypericum perforatum*	*Agrilus hyperici*	Root-boring beetle	L	L	W	W	H	H	H	L	E	E	E	U	M	L	M	L
		Aplocera plagiata	Defoliating moth	L	W	W	–	M	M	M	–	G	F	F	–	M	M	M	U
		Chrysolina hyperici	Leaf beetle	W	W	W	U	H	H	H	U	E	E	E	U	M	M	M	U
		Chrysolina quadrigemina	Leaf beetle	W	W	W	W	H	H	H	H	E	E	E	E	M	M	M	M
		Zeuxidiplosis giardi	Bud gall midge	F	F	F	L	–	–	–	L	–	–	–	P	–	–	–	L
Skeletonweed, rush	*Chondrilla juncea*	*Cystiphora schmidti*	Stem/leaf gall midge	W	W	W	W	H	H	H	M	G	E	G	F	M	M	M	M
		Eriophyes chondrillae	Bud gall mite	W	W	W	W	H	H	H	M	G	E	E	G	M	M	M	M
		Puccinia chondrillina	Leaf rust fungus	W	W	W	W	H	H	H	M	G	E	F	E	M	M	M	M
Spurge, leafy	*Euphorbia esula*	*Aphthona abdominalis*	Root/defoliating beetle	U	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–
		Aphthona cyparissiae	Root/defoliating beetle	L	L	L	–	H	M	L	–	E	F	U	–	M	L	U	–
		Aphthona czwalinae	Root/defoliating beetle	L	L	L	–	H	L	L	–	E	U	U	–	L	U	U	–
		Aphthona flava	Root/defoliating beetle	L	L	L	–	M	M	L	–	F	F	U	–	U	L	U	–
		Aphthona lacertosa	Root/defoliating beetle	L	L	L	–	H	M	L	–	E	U	U	–	L	L	U	–

WEED		BIOCONTROL AGENT		DISTRIBUTION[2]				ATTACK RATE[3]				CONTROL[4]				AVAILABILITY[5]			
Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
		Aphthona nigriscutis	Root/defoliating beetle	W	L	L	–	H	M	L	–	E	F	U	–	M	U	U	–
		Chemaesphecia crassicornis	Root-boring moth	U	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–
		Chamaesphecia tenthrediniformis	Root-boring moth	–	–	F	–	–	–	–	–	–	–	–	–	-	–	–	–
		Oberea erythrocephala	Root-boring beetle	L	U	U	–	S	U	U	–	U	U	U	–	L	U	U	–
		Spurgia esulae	Shoot-tip gall midge	F	F	L	–	–	–	S	–	–	–	U	–	–	–	U	–
Starthistle, yellow	*Centaurea solstitialis*	*Bangesternus orientalis*	Seed-head weevil	W	W	W	W	H	H	M	L	G	G	G	F	M	M	M	M
		Chaetorellia australis	Seed-head fly	W	W	W	L	H	M	M	S	E	G	G	P	M	M	M	M
		Eustenopus villosus	Seed-head weevil	W	W	L	W	H	H	H	H	E	E	E	E	M	M	L	M
		Larinus curtus	Seed-head weevil	L	L	L	L	H	L	M	L	G	F	G	U	M	U	M	U
		Urophora jaculata	Seed-head gall fly	–	F	F	F	–	–	–	–	–	–	–	–	–	–	–	–
		Urophora sirunaseva	Seed-head gall fly	W	L	L	W	H	M	L	M	F	F	U	P	M	L	L	M
Thistle, bull	*Cirsium vulgare*	*Rhinocyllus conicus*[6]	Seed-head weevil	L	W	–	–	S	M	–	–	P	F	–	–	L	M	–	–
		Urophora stylata	Seed-head gall fly	W	L	–	L	H	M	–	S	G	F	–	U	M	U	–	U
Thistle, Canada	*Cirsium arvense*	*Altica carduorum*	Leaf beetle	F	F	F	F	–	–	–	–	–	–	–	–	–	–	–	–
		Ceutorhynchus litura	Crown/root weevil	L	F	L	–	L	–	M	–	G	–	U	–	L	–	L	–
		Rhinocyllus conicus[6]	Seed-head weevil	W	W	L	L	H	H	L	U	F	G	F	P	M	M	L	U
		Urophora cardui	Stem gall fly	W	L	U	L	H	M	U	U	F	F	U	U	M	M	U	U
Thistle, Italian	*Carduus pycnocephalus*	*Rhinocyllus conicus*	Seed-head weevil	W	–	L	W	H	–	H	H	G	–	U	G	M	–	L	M
		Trichosirocalus horridus[6]	Crown/root weevil	U	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–
Thistle, milk	*Silybum marianum*	*Rhinocyllus conicus*	Seed-head weevil	W	–	–	W	H	–	–	H	G	–	–	P	M	–	–	M
Thistle, musk	*Carduus nutans*	*Rhinocyllus conicus*	Seed-head weevil	W	W	W	W	H	H	H	H	G	E	G	E	M	M	M	M

WEED		BIOCONTROL AGENT		DISTRIBUTION[2]				ATTACK RATE[3]				CONTROL[4]				AVAILABILITY[5]			
Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
		Trichosirocalus horridus	Crown/root weevil	U	–	W	–	U	–	M	–	U	–	G	–	U	–	M	–
Thistle, plumeless	*Carduus acanthoides*	*Rhinocyllus conicus*	Seed-head weevil	–	W	W	L	–	H	H	U	–	E	G	U	–	M	M	U
		Trichosirocalus horridus	Crown/root weevil	–	L	–	–	–	L	–	–	–	U	–	–	–	U	–	–
Thistle, Russian	*Salsola kali*	*Coleophora klimeschiella*	Leaf-mining moth	–	L	L	W	–	M	U	H	–	P	P	P	–	L	L	M
		Coleophora parthenica	Stem-boring moth	–	–	F	W	–	–	–	H	–	–	–	P	–	–	–	M
Thistle, Scotch	*Onopordum acanthium*	*Rhinocyllus conicus*[6]	Seed-head weevil	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		Trichosirocalus horridus[6]	Crown/root weevil	U	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–
Thistle, slender-flower	*Carduus tenuiflorus*	*Rhinocyllus conicus*	Seed-head weevil	W	–	–	W	H	–	–	H	G	–	–	G	M	–	–	M
Toadflax, Dalmatian	*Linaria dalmatica*	*Calophasia lunula*	Defoliating moth	U	W	L	–	U	H	L	–	U	G	U	–	U	M	L	–
Toadflax, yellow	*Linaria vulgaris*	*Calophasia lunula*	Defoliating moth	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Waterhyacinth	*Eichhornia crassipes*	*Neochetina bruchi*	Leaf-feeding weevil	–	–	–	F	–	–	–	–	–	–	–	–	–	–	–	–
		Neochetina eichhorniae	Leaf-feeding weevil	–	–	–	L	–	–	–	U	–	–	–	P	–	–	–	L
		Sameodes albiguttalis	Stem-boring moth	–	–	–	F	–	–	–	–	–	–	–	–	–	–	–	–

[1]Source: Adapted from William *et al*. (1998).
[2]Distribution within host range: W = widespread; L = limited sites; F = failed to establish; U = unknown status; – = not released.
[3]Attack rate on host: H = heavy (> 70%); M = medium (> 30%); L = light (> 10%); S = slight (< 1%); U = unknown status.
[4]Control ability on seeds, plant density, or both: E = excellent; G = good; F = fair; P = poor; U = undetermined.
[5]Availability for redistribution: M = mass collection; L = limited; U = unavailable. Limited availability indicates agent populations are slow in building or are recently introduced. Work on these species should be coordinated through biocontrol specialists at the state department of agriculture or state university.
[6]Natural enemies that were not originally imported for use against this weed.
Collection, transportation, or both of biocontrol agents may require special permits and procedures. Always contact your state's department of agriculture before bringing any biocontrol agents in from another state.

Status of accidental weed-biocontrol agents in Oregon, Washington, Idaho, and California[1]

Weed		BIOCONTROL AGENT		DISTRIBUTION[2]				ATTACK RATE[3]				CONTROL[4]				AVAILABILITY[5]			
Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
Bachelor's button	*Centaurea cyanus*	*Puccinia cyanae*	Rust fungus	L	L	–	–	M	M	–	–	F	F	–	–	L	L	–	–
Broom, French	*Genista monspessulana*	*Aceria genistae*	Gall mite	–	–	–	L	–	–	–	U	–	–	–	U	–	–	–	U
Broom, Portuguese	*Cytisus striatus*	*Apion fuscirostre*	Seed weevil	L	–	–	–	S	–	–	–	P	–	–	–	L	–	–	–
Broom, Scotch	*Cytisus scoparius*	*Aceria genistae*	Gall mite	W	–	–	L	H	M	–	U	P	U	–	U	M	M	–	U
		Agonopterix nervosa	Shoot-tip moth	W	W	–	U	H	M	–	U	P	U	–	U	M	M	–	U
		Arytaina spartiophila	Sap-sucking psillid	W	W	–	–	H	H	–	–	U	U	–	–	M	M	–	–
		Dictyonota fuligosa	Sap-sucking lace bug	W	W	–	–	L	L	–	–	U	U	–	–	L	L	–	–
		Gargara genistae	Sap-sucking tree hopper	W	W	–	–	L	L	–	–	P	P	–	–	M	M	–	–
		Orthotylus concolor	Sap-sucking plant bug	W	W	–	–	H	H	–	–	U	U	–	–	M	M	–	–
		Orthotylus viridis	Sap-sucking plant bug	L	L	–	–	L	L	–	–	U	U	–	–	L	L	–	–
Gorse	*Ulex europaeus*	*Aceria genistae*	Gall mite	W	–	–	L	H	–	–	U	P	–	–	U	M	–	–	U
		Agopnopterix nervosa	Shoot-tip moth	W	W	–	U	M	M	–	U	U	U	–	U	M	M	–	U
Hemlock, poison	*Conium maculatum*	*Agonopterix alstroemeriana*	Defoliating moth	W	W	W	W	M	H	M	M	G	E	G	U	M	M	M	M
Knapweed, diffuse	*Centaurea diffusa*	*Puccinia jacaeae*	Rust fungus	L	L	L	L	S	S	S	S	P	P	P	P	L	L	L	L
Knapweed, Russian	*Acroptilon repens*	*Puccinia acrolophi*	Rust fungus	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–	U
Mullein, common	*Verbascum thapsus*	*Gymnetron tetrum*	Seed-head weevil	W	W	W	W	H	H	H	H	P	P	P	P	M	M	M	M

Weed		BIOCONTROL AGENT		DISTRIBUTION[2]				ATTACK RATE[3]				CONTROL[4]				AVAILABILITY[5]			
Common name	Scientific name	Scientific name	Type of agent	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA	OR	WA	ID	CA
Mullein, moth	*Verbascum blatteria*	*Gymnetron tetrum*	Seed-head weevil	L	L	–	–	L	H	–	–	P	G	–	–	L	M	–	–
Purslane, common	*Portulaca oleracea*	*Hypurus bertrandiperris*	Leaf-mining weevil	–	–	–	U	–	–	–	U	–	–	–	U	–	–	–	U
		Schizocerella pilicornis	Leaf-mining sawfly	–	–	–	W	–	–	–	H	–	–	–	E	–	–	–	L
Starthistle, yellow	*Centaurea solstitialis*	*Chaetorellia succinea*	Seed-head fly	W	U	–	W	H	U	–	M	E	U	–	E	M	U	–	M
Thistle, artichoke	*Cynara cardunculus*	*Terellia fuscicornis*	Seed-head fly	–	–	–	L	–	–	–	H	–	–	–	U	–	–	–	M
Thistle, bull	*Cirsium vulgare*	*Puccinia carduorum*	Rust fungus	W	W	–	W	L	L	–	U	P	P	–	P	L	L	–	M
Thistle, Canada	*Cirsium arvense*	*Larinus planus*	Seed-head weevil	L	W	L	–	H	M	L	–	F	F	F	–	M	M	L	–
		Puccinia carduorum	Rust fungus	W	W	–	W	L	L	–	U	P	P	–	P	L	L	–	M
Thistle, Italian	*Carduus pycnocephalus*	*Puccinia carduorum*	Rust fungus	–	–	–	W	–	–	–	U	–	–	–	P	–	–	–	M
Thistle, milk	*Silybum marianum*	*Terellia fuscicornis*	Seed-head fly	–	–	–	L	–	–	–	L	–	–	–	P	–	–	–	L
Thistle, musk	*Carduus nutans*	*Cassida rubiginosa*	Leaf beetle	–	–	L	–	–	–	S	–	–	–	U	–	–	–	U	–
Toadflax, yellow	*Linaria vulgaris*	*Brachypterolus pulicarius*	Flower beetle	L	L	L	–	M	M	M	–	F	F	F	–	L	L	L	–
		Gymnetron antirrhini	Seed-head weevil	L	L	L	L	M	H	H	U	U	G	U	U	L	L	L	U

[1]Source: Adapted from William *et al*. (1998).
[2]Distribution within host range: W = widespread; L = limited sites; F = failed to establish; U = unknown status; – = not released.
[3]Attack rate on host: H = heavy (> 70%); M = medium (> 30%); L = light (> 10%); S = slight (< 1%); U = unknown status.
[4]Control ability on seeds, plant density, or both: E = excellent; G = good; F = fair; P = poor; U = undetermined.
[5]Availability for redistribution: M = mass collection; L = limited; U = unavailable. Limited availability indicates agent populations are slow in building or are recently introduced. Work on these species should be coordinated through biocontrol specialists at the state department of agriculture or state university.
Collection, transportation, or both of biocontrol agents may require special permits and procedures. Always contact your state's department of agriculture before bringing any biocontrol agents in from another state.

Status of weed biocontrol in California

Baldo Villegas

***Eustenopsis villosis* on yellow starthistle.**

In 1978, the Biological Control Program of the California Department of Food and Agriculture coordinated a multiagency effort that led to the successful redistribution of the stem-boring moth *Coleophora parthenica,* a new agent for the biocontrol of Russian thistle in California. Since then, the Department has been coordinating the biocontrol of weeds in California through an informal distribution protocol developed with the County Agriculture Commissioners and Sealers Association. This protocol requires the active participation by county biologists in distributing biocontrol agents and training participants in workshops held at nursery sites by Department personnel. To date, the distribution program has been used for biocontrol agents released against yellow starthistle, Italian thistle, musk thistle, Klamath weed, and waterhyacinth. The program has resulted in widespread distribution of these biocontrol agents across California.

Biocontrol projects go through these four basic phases: introduction, establishment, distribution, and monitoring. In California, introductions of new biocontrol agents are coordinated by our Department, in cooperation with federal agencies, universities, agriculture departments of other states, and the county Association. The introduction phase begins with the first release of a new agent at selected sites, and it continues until the agent is established. A biocontrol agent is considered established after it has been recovered for three consecutive years (that is, it has survived two winters). Once populations become locally widespread where they were released initially, some of these sites are turned into "nursery sites" to supply agents for the Department's distribution program. Three years is generally the minimum time for a release site to become a nursery site. Monitoring begins when the biocontrol agents are released at county nursery sites. Populations are monitored by local county biologists and, when populations are large enough to be collectible, the biologists begin in-county redistributions. During monitoring, the biologists quantify and take notes on establishment, off-site movement, and percentage of infestation, so they can make recommendations about the efficacy of the biocontrol agents.

***Larinus curtus* on yellow starthistle.**

So far, 46 species of classical biocontrol agents have been imported into California and released against 21 species of weeds. Of the 46 agents, 8 failed to establish, 1 has unknown status, and 34 are established, 23 of them widely established.

In addition, 22 species were found on 18 weeds or host plants that were not part of a targeted release. These host associations were sometimes the result of native species attacking weeds closely allied to their native hosts (like *Uresiphita reversalis* on French broom), unknown introductions of insects from other parts of the world (like *Agonopterix alstroemeriana* on poison-hemlock), accidental introductions (like *Chaetorellia succinea* on yellow starthistle), or natural spread of the agent from releases in another state or country (like *Urophora quadrifaciata* – from, Canada – on spotted and diffuse knapweeds. Sometimes, these new associations have resulted in various degrees of fortuitous biocontrol of the weeds.

Additional new biocontrol agents are being tested for alligator weed, Cape ivy, Dalmatian toadflax, gorse, musk thistle, Russian knapweed, Russian thistle, Scotch broom, tamarisk, and yellow starthistle.

6. Monitoring

Monitoring goals in weed biocontrol

Michael J. Pitcairn

Why monitor?

The goal of a biocontrol program is to establish a self-sustaining population of natural enemies that results in reducing the targeted pest population. Monitoring is one of several steps necessary in reaching this goal and is as necessary as the other steps in a biocontrol effort: foreign exploration, host-specificity testing, quarantine processing and validation, and release and establishment. Monitoring provides feedback on the vitality of the natural-enemy population, its effects on the target weed, and an assessment of the success of the program. If the program is deemed unsuccessful, monitoring will indicate what changes or additional efforts are needed. Monitoring in weed biocontrol can be conducted for at least four different purposes, each with its own goal: to assess agent establishment, intensity of agent attack, effect of the agent on the weed, and project benefits.

Is the agent established?

After release of the biocontrol agent, the focus is on determining if the agent survives, reproduces, and establishes a self-sustaining population. Establishment is usually defined as field survival for 3 years. Thus, if a biocontrol agent survives through two winters and is recovered after the second winter, it is considered established. Recoveries later in the same summer as the release is not establishment nor are recoveries the next spring. After two winters, recoveries do suggest establishment.

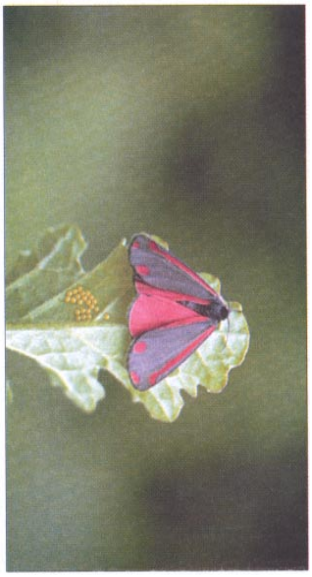
Reviews of several biocontrol efforts have shown that about one-third of the agents approved for introduction fail to establish in their new country. Failure to establish can be attributed, in part, to poor climatic adaptation and the narrow ecological requirements of many biocontrol agents. Establishment success can be increased by paying attention to the agent's habitat requirements. For example, the black-dot spurge flea beetle on leafy spurge requires dry, open sites on coarse soils of the Canadian prairies, and some failures arose from releases elsewhere on lush, robust stands of spurge. Some failures are inevitable, however, because little is known about the site requirements of the agent in a new region. Trial and error is usually necessary and **documenting failures as well as successes is important** in developing a better understanding of an agent's habitat requirements.

The objective of this step is to recover the biocontrol agent at least two years after release and determine if it is increasing in abundance. Thus, quantitative samples are not necessary; a rapid sampling method, such as use of a sweep net or looking at the host plant for damage or presence of adults, is preferred. If the biocontrol agent is new to the United States, a sample of 10-15 adults should be sent to taxonomic specialists to verify species. Adult insects can be shipped immersed in alcohol, and the land-grant university in your state should be able to identify them at minimal or no charge. Verifying species is usually not necessary for releases from domestic sources that have already been verified.

How intensive is the attack?

Once an agent is established, the intensity of attack needs to be determined – that is, the proportion of the resource exploited by the agent – for example, the degree of defoliation or the proportion of flower heads attacked. For a biocontrol agent to be considered successful, we expect the rate of attack to increase over time. If the density of the agent remains low, as reflected in a low attack rate, the agent may have failed to adapt to the local climate or to the genotype of the host – in which case, the appropriate biotype may be needed to improve results. An example of the need for local adaptation was documented in the release of the Klamath weed beetle into British Columbia. Klamath weed is a poisonous plant from Europe that invaded rangelands in the western United States, especially the Pacific Northwest, and Canada. By 1944, it had infested more than 2 million acres in California alone. Ranches in California and Oregon were rendered almost worthless by Klamath weed infestations. The Klamath weed beetle was introduced from Europe and successfully reduced Klamath weed to less than 1% of its former abundance in California and Oregon. The savings to California agriculture were estimated to be $21 million between 1953 and 1959, at an estimated annual rate of $3.5 million in 1964 dollars.

What happened in British Columbia was different, however; there, in contrast to California and Oregon, densities of the Klamath weed beetle remained low for 8 to 13 years after release; then, the beetles increased rapidly and depressed their host to about 1% of its former density within 3 years. The reason for the initially poor performance was that the original beetles, obtained from southern France via Australia and California, remained on the foliage in the fall until they were killed by early frost. Now, the beetles seek shelter at 4º C and reemerge to oviposit on the next warm day.



Cinnabar moth with eggs, on tansy ragwort.

Cinnabar moth larvae feeding on a tansy ragwort plant.

Cinnabar moth larvae clustered on a defoliated tansy ragwort stalk.

The history of the cinnabar moth on tansy ragwort in eastern Canada was similar: it became established from only two pairs of moths surviving from the release of several thousand larvae (establishment rate << 1%). The population remained small for 4 years, increased in year five to achieve 11% defoliation, and stripped the weed of foliage and flowers in year six. After 9 years of field selection, larvae from this colony established in eight of nine releases (establishment rate > 85%). This kind of accommodation to the local climate described in these two examples is not always assured, but it may be speeded up by releasing the appropriate biotype.

How has the agent affected the weed population?

The objective in monitoring biocontrol-agent effects on the target weed is to determine whether the current agents will be successful by themselves or whether additional agents will be needed and for what sites. Clearly, a light attack is unlikely to control the weed, but a heavy attack will not necessarily reduce plant density. Failure to control a weed with an agent that has a high attack rate suggests that adding an agent to attack another part of the plant is necessary to control the weed. The information needed for this

dual strategy is obtained by monitoring the population dynamics and life-table characteristics (for example, survivorship, seed production) of the weed population along with estimates of the infestation rate of the biocontrol agents. Often, the effects are measured by comparing the weed inside and outside the release area, but this method works only for slow-dispersing agents, such as the flea beetles on leafy spurge. Comparisons are more difficult for rapidly dispersing biocontrol agents, such as seed-head fruit flies. For these species, insecticides or exclusion cages may be needed to obtain agent-free samples. Ideally, the techniques for monitoring the target weed have already been worked out, so measuring only those factors deemed most sensitive to change because of the biocontrol agents will need to be measured.

Larva of a root weevil, *Cyphocleonus achtes,* on spotted knapweed

What were the project's benefits?

Many weed-biocontrol projects conclude with a report on the frequency of attack by the agents and the reduction in density of the weed population, but the project does not end there. The benefits of weed control need to be tied to the social and economic benefits affected by the weed, such as increasing forage yield, reducing erosion, reducing herbicide use, or protecting rare or endangered native plants. These benefits are what originally justified the biocontrol project, and it will not be finished until these benefits are examined.

The difficulty is that the decline in weed density is not linearly related to the benefits of weed biocontrol. Rather, benefits of weed reduction are often not observed until weed density is below some threshold. For example, cattle avoid grazing on pastures with as little as 10% cover of leafy spurge because the latex in the spurge blisters their mouths; at 5% cover, however, cattle can graze around the stems. Thus, in terms of grazing productivity, little benefit will be observed until spurge abundance is reduced below the threshold of 5% cover.

Other, equally valid measures besides forage value can be chosen to monitor the success of biocontrol programs. For example, knapweed infestations increase surface runoff and stream sedimentation and have been suggested to reduce ponderosa pine regeneration. Countering both of these effects could be project goals. Federal land management agencies are concerned with maintaining native plant communities and being good neighbors to surrounding farmers, and both of these efforts may be goals for biocontrol projects. Saskatchewan identified eliminating an annual subsidy of $150,000 for chemical control of leafy spurge as a goal for its biocontrol project. The project was successful in that the subsidy was withdrawn and this goal met. My point in providing these examples is that the goals of each biocontrol project need to be measured in terms other than weed reduction.

Establishing meaningful goals for threshold weed densities requires a preliminary study and, because funds are scarce, these studies are not always done. Biocontrol projects can be very expensive (costing as much as $4 million) and may take 20 years to accomplish. Without specific goals, success cannot be assessed or even whether benefits are likely. Without goals, the project has no end point and, because expectations often differ, some people are likely to be disappointed.

Monitoring insect populations in biocontrol projects

Michael J. Pitcairn

Purposes for monitoring

The four purposes for monitoring in weed-biocontrol projects are measuring and evaluating agent establishment, intensity of agent attack, effects of the agent on the weed, and project benefits. Insect abundance and attack rate are monitored in the first three. Methods for monitoring can be grouped into qualitative (relative) and quantitative (absolute) techniques.

Qualitative estimates

Qualitative monitoring differs from quantitative estimates in having no direct relation to land surface area. Qualitative techniques produce relative estimates of abundance that can be compared from one sampling date to the next. Examples of common qualitative methods include using sweep nets, timed counts, and visual ratings of abundance or damage. Because qualitative techniques are usually highly variable, we recommend a conscientious attempt at uniformity of sampling procedures through time.

Qualitative estimates can often be obtained by sweeping. A sweep net is a standard 15-inch-diameter frame with a cloth bag attached to a pole. The net is passed through the tops of plants to collect insects active during the day. A person may collect samples by swinging the net in 180-degree arcs while walking through the plant canopy. The sample result is reported as the average number of individual insects collected per sweep. Sweep-net samples are highly variable, so we recommend taking several samples of 10 or 20 sweeps each and then averaging them. Also, sweep samples may differ from one sampler to another, so having one person collect all the samples in a given project is best.

Time counts consist of examining plants in the release area and counting the number of biocontrol agents seen in a specified period. The time may be determined by the relative abundance: if the biocontrol agent is uncommon, 10- or 15-minute counts might be used; if the agents are common, 2-minute counts may be enough. Three to five abundance categories may be used; “heavy,” “medium,” “light,” and “none” are descriptive terms that might be used to denote qualitative ratings. The person sampling might also count or otherwise monitor egg masses, damage to leaves or flower heads, or the insects themselves (adults or larvae).

Abundance or damage ratings are obtained by looking at the host plants and assigning their condition within categories of abundance or damage, such as 0, 0-5, 6-25, 26-50,

51-75, or 76-100%. This method is useful when many release sites must be examined and if only a quick assessment of the performance of an agent is needed.

Quantitative techniques

Quantitative techniques provide estimates of insect abundance and are usually directly related to the area of habitat. The results are usually expressed as the number of agents per plant, per plant part (for example, the flower head), or per unit area, which can be estimated as the number per plant times the number of host plants per area. Quantitative estimates are often difficult to obtain and costly. For many weed-biocontrol projects, quantitative sampling methods have been developed by biocontrol researchers for each biocontrol agent, which reduces the cost and effort.

Random sampling methods are important in obtaining quantitative samples. The objective is to remove bias in the choice of sample plants or areas. The Related Readings list contains several texts that discuss quantitative sampling methods for insects, and I recommend them for finding specific information on random-sampling methods.

Keeping records

Record keeping is critical for any monitoring protocol. Data sheets listing the site location; contact person, legal landowner, or both; site characteristics; road map to the site; site map; and biocontrol-agent release history (such as the number released and the date or dates of release). This information needs to be stored where it can easily be retrieved when needed and accessible to anyone working at the site. A standard monitoring form should be created to record all sampling results. Each form should include site name, date of observations, and names of observers.

Monitoring weed populations in biocontrol projects

David A. Pyke

Need for general principles for monitoring

We introduce biocontrol agents – such as insects, fungi, and bacteria – to reduce and control noxious weeds. At the time of introduction, we know that the control organism can kill or severely injure the weed, but we also know that only rarely do the weed and the control organism have exactly the same requirements for growth and survival. Thus, our weed control may be successful in some areas and unsuccessful in others. Determining the success or failure of a weed-control project requires documenting the anticipated rate of control, which then requires repeated observations of the weed in the target community. Monitoring is what provides this documentation, but monitoring can have various forms. No single monitoring plan will be effective for documenting all weed-control projects, but some general principles can guide developing and conducting monitoring to ensure that useful information is gathered for future control projects.

Definition of monitoring

Let's begin with a definition of what **monitoring** is and what it is not. Plant monitoring is collecting and analyzing **repeated** observations or measurements to evaluate **changes** in plant attributes and progress toward meeting a management **objective**. For

biocontrol of weeds, the bolded terms emphasize our expectation that information we gather will reflect a reduction in a weed population during a specified time. Monitoring is not merely an inventory of plants, nor is it research. An inventory is a survey of items. Generally, the survey has no expectation of detecting a change in the plants that are measured. Research and monitoring are similar in that they both have stated objectives, but research is designed to have enough replications and treatments to show what caused the changes. In monitoring, we detect the change, but we cannot be sure of the cause.

Information gathering

The first stage in devising a weed-monitoring plan is to gather and review the existing information on the weed and the methods for controlling it. If we use a biological agent for weed control, we will need to understand how it is likely to affect the weed. During this phase, we learn about the weed's life stages: Is the weed a **perennial**, a plant that lives for several years? Or does it live for one year, an **annual**, or two years, a **biennial**? Does it require seed production to maintain itself in the community? This information can be used to determine which part of the plant to measure and how often to measure it.

Scale of monitoring

We need to consider the scale of interest for our monitoring during the earlier phases of planning. The appropriate scale will depend on the extent of the current weed infestation and the expected time needed for the biocontrol agent to establish and spread. If habitat conditions restrict the weed and biocontrol agents to a single watershed, then we must restrict our scale of interest and our monitoring to that one watershed. If we want to know the general effect of a biocontrol agent over the weed's entire distribution, we must scatter our monitoring throughout the weed's geographic range.

First reality check

At this stage, we should pause a moment for a reality check. What resources – people, vehicles, field equipment, funding, and time – are available for this monitoring project? The design for the monitoring plan may be good, but without the necessary resources, we will fail to collect the information outlined in the plan. We must estimate the resources needed to determine what intensity of monitoring we can handle, and we may elect to obtain preliminary approval of the monitoring project from our supervisors. We should estimate costs of alternative monitoring intensities; then, if the supervisors believe the project warrants an intensive monitoring approach, they may seek the additional resources needed. Otherwise, we need to plan for a less-intensive project that matches the available resources.

Types of monitoring

We can divide the intensity of monitoring into two general categories, qualitative and quantitative. The qualitative techniques are quick, inexpensive methods that can evaluate the whole population and detect large changes in weed populations. The weaknesses associated with these techniques are that they cannot detect small changes in the weeds and depend more on the individual observer than do quantitative methods. Qualitative techniques include photoplots, presence-absence surveys, occurrence mapping, visual estimates of density, and checklist assessments. Although these techniques have some

quantitative aspects, they are considered qualitative because the observer must decide subjectively which class the weed observation belongs in.

All of these qualitative methods for monitoring weed observations are valid, but we must remember not to treat the results with the same confidence as quantitative measures of change in the weed population. Our hope is that the effects of the biocontrol agent will be sufficiently large that qualitative techniques adequately detect the change. Photoplots are excellent qualitative techniques because they provide a record that other people can interpret and judge, independent of the person who took the photograph. Photoplots require a permanent location for future photos and permanent reference points, such as trees, rocks, or distant hills visible in the photo image.

For quantitative monitoring, we measure some attribute of the plant or plant population, such as seed number, plant density, or cover. Statistical estimates of the trait may be obtained by measuring several independent plots or plants within the monitoring location, but this step is not required of quantitative monitoring. The most intensive form of monitoring weed populations is weed demography, in which we obtain estimates of the current density, survivorship, and reproduction of the weed. Demographic information allows us to develop predictive models of future weed population sizes. This intensive approach is often too costly for most monitoring projects, however, and is best left as a research tool. Quantitative techniques are often more repeatable and accurate than their qualitative counterparts, but the greatest weakness is their expense.

Data sheets

We need to gather some general monitoring information for all monitoring sites. A data sheet should include the location of the weed population, if possible, by including global positioning system (GPS) coordinates for at least four points surrounding the weed population. Land ownership should be included on this form. A weed population often crosses several ownership boundaries. All ownerships in a continuous weed population need to be included because neither the weed nor the biocontrol agent will stop at these human boundaries. If legal constraints restrict our activities to one ownership, however, this constraint should be stated on the form. Information on habitat characteristics and history is also included; for example, we should include soil classifications, elevation, topographic relief, associated plant species, current and past climate, and land use history – when they are known – to help us interpret our successes and failures.

Monitoring objectives

The project's objectives need to drive the whole monitoring plan we develop. In forming weed-management objectives, we should state the amount of weed control we expect and the anticipated time needed to reach that amount. For effective weed-biocontrol objectives, we must answer the following questions: How will the control agent attack the weed? How long does the agent need to become established in the weed population? How fast will the agent spread through the weed population? Our measurements should be frequent enough to provide adequate evaluation of the direction of change being detected, in other words, at least four observations. For example, if we expect to meet the objective in less than 5 years, we should make annual observations. For long-term objectives, observations can be less frequent.

Designing the methods

Once the objective and the monitoring intensity are proposed, we need to design the methods for making observations. No matter what intensity of measurement is selected, we will need to identify the boundaries around the sampling area, which can be done by marking the extent of the weed on a map, photo, or on the ground. If the weed is scattered throughout a geographic area, we may need to arbitrarily subdivide the area into units for monitoring.

***Calophasia lunula* on Dalmatian toadflax.**

After the extent of the area to evaluate is determined, further design elements will depend on the intensity of the technique selected. For qualitative techniques, we need to devise methods to ensure the quality of the data, which may mean developing training for the samplers or a quality-assurance protocol to be used during the observation period. For quantitative techniques, we must answer the following questions: What will we measure? What size, shape, and number of plots will we use? How will we place those plots (randomly or systematically) within the population? Will we use permanent or temporary plots? These decisions are not trivial because the chosen design affects how we analyze the data.

Data analysis

Lastly, before we begin to collect data, we need to figure out how we will analyze them. How will we decide if we achieved the objective? For quantitative techniques, we can often summarize the data by presenting average values and an estimate of the variation of the measured average (mean and standard deviation). If we designed untreated areas into the plan, then we can probably compare their measurements with those from the treated area to see if they differ. Statistical analysis can help us interpret these results. For qualitative techniques, we may need to graph the results to interpret them visually. We might analyze these data statistically, but the type of analysis will be different from what would be used with quantitative techniques.

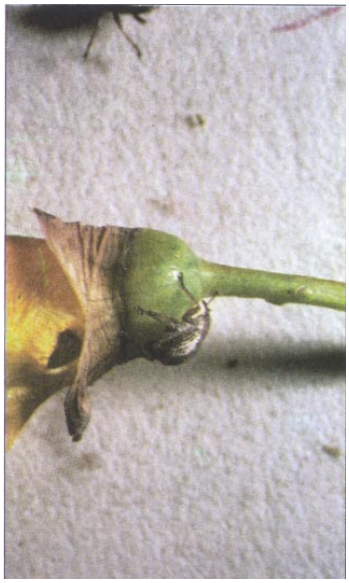
Field tests--and the final reality check

Next, we need to field-test our monitoring plan and make further adjustments – and to make a final reality check. Do we have the resources needed to accomplish the plan? If not, we adjust it until we can afford to gather just the necessary monitoring information to decide if we met the objective. Last, we must write out the plan with sufficient detail that, if new people have to continue the monitoring, they will understand exactly what they need to do. Once the plan has begun, the same methods and design must be continued until the end of the period delineated in our objective. Any changes in how we sample may affect the results and weaken our interpretations.

By applying these monitoring steps, we can determine where biocontrol efforts are successful. Documenting recorded failures will help biocontrol proponents to isolate factors that may have led to the failure so that other practitioners will not make similar mistakes.

Documenting successful weed control with insects or microbes will provide support for other managers in other places who want to try this form of integrated pest management. And it will help them set realistic and achievable weed-management objectives.

***Chysolina hyperici* on St. Johnswort.**



***Apion fuscivestra* on Scotch broom.**

Sources for training and other help

This paper provides a brief overview of monitoring. More detailed training can be obtained through classes on inventory and monitoring offered by the Bureau of Land Management's National Training Center. They list dates and places of classes on the worldwide web at the address http://www.ntc.blm.gov/courses/cmwild.html. A good source of sampling techniques for specific plants is an interagency technical reference titled *Sampling Vegetation Attributes.* The Cooperative Extension Service, Forest Service, Natural Resources Conservation Service, and the Bureau of Land Management jointly prepared it, and the Bureau of Land Management published it in 1996. The reference may be ordered through the Bureau of Land Management, National Applied Resources Sciences Center in Denver, Colorado. Ask for technical reference BLM/RS/ST-96/002+1730.

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Appendices

Appendix 1. Addresses of authors and other resources

Authors

Lloyd A. Andres
Research entomologist (retired)
U.S. Department of Agriculture
Agricultural Research Service
800 Buchanan Street
Albany, CA 94710
(925) 559-5974; fax (925) 559-5982;
landres@pw.usda.gov

Joseph K. Balciunas
Research entomologist
U.S. Department of Agriculture
Agricultural Research Service
800 Buchanan Street
Albany, CA 94710
(925) 559-5978; fax (925) 559-5982;
jbalciun@pw.usda.gov

Eric M. Coombs
Entomologist
Oregon Department of Agriculture
635 Capitol Street NE
Salem, OR 97310
(503) 986-4621; fax (503) 986-4737;
ecoombs@oda.state.or.us

Jack R. Coulson
Director
Biological Control Documentation Center
Insect Biocontrol Laboratory
Plant Sciences Institute
Agricultural Research Service
U.S. Department of Agriculture
National Agricultural Library, 4th Floor
Beltsville, MD 20705
(301) 504-6350; fax (301) 504-6355;
jcoulson@nal.usda.gov

Richard W. Hansen
Entomologist
USDA-APHIS-PPQ
P.O. Box 170278
Montana State University
Bozeman, MT 59717-0278
(406) 994-5037; fax (406) 994-6591;
a348rhansen@attmail.com

Dennis Isaacson
Special projects coordinator
Oregon Department of Agriculture
635 Capitol Street SE
Salem, OR 97310-0110
(503) 986-4633; fax (503) 986-4737;
disaacso@oda.state.or.us

Jeffrey L. Littlefield
Quarantine officer, research scientist
Montana State University
Department of Entomology
Bozeman, MT 59717-3020
(406) 994-4722; fax (406) 994-5597;
ueyjl@montana.edu

George P. Markin
Senior research entomologist
U.S. Department of Agriculture
Forest Service
Rocky Mountain Research Station
Montana State University
Bozeman, MT 59717-0278
(406) 994-4892; fax (406) 994-5916

Alec McClay
Research scientist
Alberta Research Council
P.O. Bag 4000
Vegreville, AB T9C 1T4, Canada
(780) 632-8207; fax (780) 632-8612;
alec@arc.ab.ca

Peter B. McEvoy
Professor
Room 2046 Cordley Hall
Oregon State University
Department of Entomology
Corvallis, OR 97331-2907
(541) 737-5507; fax (541) 737-3643;
mcevoyp@bcc.orst.edu

Quentin Paynter
Research scientist
IIBC c/o CSIRO European Laboratory
Campus International de Baillarguet
34980 Montferrier-sur Lez
Cedex France
(33) 04 67 59 31 00
fax (33) 04 67 59 90 40;
paynter@ensam.inra.fr

Gary L. Piper
Professor
Department of Entomology
Washington State University
Pullman, WA 99164
(509) 335-1947; fax (509) 335-1009;
glpiper@wsu.edu

Michael J. Pitcairn
Associate environmental research scientist
California Department of Food and
Agriculture
Biological Control Program
3288 Meadowview Road
Sacramento, CA 95832
(916) 262-2049; fax (916) 262-2059;
mpitcairn@cdfa.ca.gov

Robert E. Pizel
Senior staff officer
Environmental protection specialist
U.S. Department of Agriculture
Animal and Plant Health Inspection Service
Environmental Analysis and Documentation
4700 River Road
Riverdale, MD 20737
(301) 734-5861; fax (301) 734-3640;
robert.e.pizel@aphisnotes.usda.gov

David A. Pyke
Research plant ecologist
U.S. Geological Survey
Biological Resources Division
Forest and Rangeland Ecosystem
Science Center
3200 SW Jefferson Way
Corvallis, OR 97331
(541) 750-7334; fax (541) 758-7761;
pyked@fsl.orst.edu

Scott Stenquist
Regional integrated pest/weed
management coordinator
Refuges and Wildlife
U.S. Fish and Wildlife Service
911 NE 11th Avenue
Waterways Experimental Station
Portland, OR 97232
(503) 231-6172 (voice mail)
(503) 231-6171 (secretary);
fax (5 03) 2331-2364;
Scott_Stenquist@mail.fws.gov

Baldo Villegas
Associate environmental research scientist
Biological Control
California Department of Food and Agriculture
3288 Meadowview Road
Sacramento, CA 95832
(916) 262-2051; fax (916) 262-2059;
bvillega@cdfa.ca.gov

Pacific Northwest 1998 weed-control handbook, to order:

In Oregon
Publication Orders
Extension & Station Communications
Oregon State University
422 Kerr Administration
Corvallis, OR 97331-2119
(541) 737-2513; fax (541) 737-0817;
puborder@ccmail.orst.edu

In Washington
Bulletin Office, Cooperative Extension
Washington State University
P.O. Box 645912
Pullman, WA 99164-5912
(509) 335-2857 or 1-800-723-1763;
fax (509) 335-3006;
bulletin@coopex.cahe.wsu.edu
Web http//caheinfo.wsu.edu

In Idaho
Agricultural Publications
College of Agriculture
University of Idaho
Moscow, ID 83844-2240
(208) 885-7982; fax (208) 885-4648;
cking@uidaho.edu

Members of the Technical Advisory Group (as of February 1998)

A.F. Cofrancesco, Chair
U.S. Army Corps of Engineers
Waterways Experimental Station
ATTN: WESER-A
3030 Halls Ferry Road
Vicksburg, MD 39180-3182
(601) 634-3182; fax (601) 634-2398;
cofrana@exl.wes.army.mil

Harold W. Browning
USDA-CSREES
University of Florida
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred, FL 33850-2299
(941) 956-1151; fax (941) 956-3579 or
(941) 956-4631;
hwbr@icon.lal.ufl.edu

Jack R. Coulson
USDA-ARS, Biological Control
Documentation Center
National Agricultural Library, 4th floor
Beltsville, MD 20705
(301) 504-6350; (301) 504-6355;
jcoulson@nal.usda.gov

Gary Johnston
USDI, National Park Service
1849 C Street, NW
Room 3223-MIB
Washington, DC 20240
(202) 208-5886; fax (202) 208-4620;
gary_johnston@nps.gov

William P. Gregg
U.S. Geological Survey
Biological Resources Division
12201 Sunrise Valley Drive, MS 300
Reston, VA 20192
(703) 648-4067; fax (703) 648-4039;
William_Gregg@nbs.gov

Ernest S. Delfosse
USDA-ARS
Room 218, Building 005, BARC-West
10300 Baltimore Boulevard
Beltsville, MD 20705-2350
(301) 504-6470;
esd@ars.usda.gov

Polly Lehtonen, Executive Secretary
(nonvoting member)
USDA-APHIS-PPQ
4700 River Road, Unit 133
Riverdale, MD 20737-1236
(301) 734-4394; fax (301) 734-8700;
plehtone@aphis.usda.gov

Erich Rudyj
USDA-APHIS-PPQ
National Biological Control Institute
4700 River Road, Unit 5
Riverdale, MD 20737-1229
(301) 734-4329;
erudyj@aphis.usda.gov

George P. Markin
USDA-FS, Forest Science Laboratory
MSU, Campus Building 278
Bozeman, MT 59717-0278
(406) 994-4892; fax (406) 994-5916

James G. Saulman
EPA, Office of Pesticide Programs (7503W)
401 M Street SW
Washington, DC 20460
(703) 308-8126; fax (703) 308-8090;
saulmon.james@epamail.epa.gov

David Sisneros
USDI, Bureau of Reclamation
P.O. Box 25007
Denver Federal Center
Building 56, Room 2000, D-8220
Denver, CO 80225
(303) 236-6007, ex. 241;
ax (303) 236-6008;
dsisnero@do.usbr.gov

Tom Roberts
USDI, Bureau of Land Management
(W0220)
1849 C Street NW (LS204)
Washington, DC 20240
(202) 452-7743; fax (202) 452-7709;
troberts@wo.blm.gov

Dan Hilburn
(represents the National Plant Board)
Oregon Department of Agriculture
63 5 Capitol Street NE
Salem, OR 97310-0110
(503) 986-4663; fax (503) 986-4786;
dhilburn@oda.state.or.us

Bryan Arroyo
USDI, Fish and Wildlife Service
4401 North Fairfax Drive, Suite 452
Arlington, VA 22203
(703) 358-2106, ex. 5475;
fax (703) 358-1735;
bryan_arroyo@mail.fws.gov

Thomas A. Bewick
(represents the Weed Science Society
of America)
Cranberry Experiment Station
P.O. Box 569
East Wareham, MA 02538
(508) 295-2212, ex. 13; fax (508) 295-6387;
cranweed@fnr.umass.edu

Michael Sarazin, Canadian contact
Eastern Cereal and Oilseed Research Centre
Central Experiment Farm, Room 3035D
K.W. Neatby Building
960 Carling Avenue
Ottawa, ON, Canada K1A 0C6
(613) 759-1885; fax (613) 759-1926;
sarazinm@em.agr.ca

Luis A. Aguirre Uribe, Mexican contact
Direccion de Regulacion Fitosanitaria
Guillermo Perez Valenzuela 127
Col. del Carmen Coyoacan
04100 Mexico, DF
(525) 554-5147; (525) 658-0696

Other Resource People

U.S. Fish and Wildlife Service
Integrated Pest and Weed Management
Washington Office

Linda Lyon, fish and wildlife biologist
Environmental Contaminants Division
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive
Arlington, VA 22203
(703) 358-2148; fax (703) 358-1800;
Linda_Lyon@fws.gov

Mary Henry, chief
Branch of Ecological Health
Environmental Contaminants Division
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive
Arlington, VA 22203
(703) 358-2148; fax (703) 358-1800;
Mary_Henry@fws.gov

Bryan Arroyo, Technical Advisory Group
Liaison
Endangered Species Division
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive
Arlington, VA 22203
(703) 358-2106; fax (703) 1735;
Bryan_Arroyo@fws.gov

Gordon Brown, Weed Coordinator
Division of Refuges
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive
Arlington, VA 22203
(703) 358-2043; fax (703) 358-1826;
Gordon_Brown@fws.gov

Howard Schlegel, Integrated Pest Management
Division of Refuges
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive
Arlington, VA 22203
(703) 358-2392; fax (703) 358-1826

Bob Peoples
Nonindigenous Species Coordinator
Fisheries, management assistance
U. S. Fish and Wildlife Service
4401 N. Fairfax Drive
Arlington, VA 22203
(703) 358-1718; fax (703) 358-2044;
Robert_Peoples@fws.gov

Jim Siegal, course leader, IPM Training Liaison
National Educational and Training Center
U.S. Fish and Wildlife Service
Route 3, Box 49
Kearneysville, WV 25430
(304) 725-8461, ex. 246; fax (304) 728-6772;
Jim_Siegal@fws.gov

Region 1
(*WA, OR, ID, N V, CA, HI, GU, Pacific Islands*)
Scott Stenquist, Refuges Program Specialist
(see list of authors for address)

Tom O'Brien
Chief of Contaminant Prevention Branch
U.S. Fish and Wildlife Service
Eastside Federal Complex
911 NE. 11th Avenue
Portland, OR 97232-4181
(503)-231-6223; fax (503)-231-6243;
Thomas_OBrien@FWS.gov

Region 2
(*NM, AZ TX, OK*)

Steve Robertson
Environmental Contaminants Coordinator
(acting)
U.S. Fish and Wildlife Service
500 Gold Avenue SW., P.O. Box 1306
Albuquerque, NM 87103
(505) 766-2914; fax (505) 766-2289;
Stephen_Robertson@fws.gov

Ralph Bryant, Manager
U.S. Fish and Wildlife Service
Wichita Mountains Wildlife Refuge
Route 1, Box 448
Indiahoma, OK 73625
(405) 429-3019; fax (405) 429-9323;
R2RW_WM@fws.gov

Region 3
(*MN, WI, MI, MO, IL, IN, OH*)
Stan Smith
Assistant Environmental Contaminants
Coordinator
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, MN 55111
(612) 725-3536, ex. 231; (612) 725-3526;
Stan_Smith@fws.gov

Region 4
(*NC, SC, GA, FL, TN, AR, LA, AL, PR*)
Jerry O'Neal
Environmental Contaminants Coordinator
U.S. Fish and Wildlife Service
1875 Century Boulevard
Atlanta, GA 30345
(404) 679-7127; fax (404) 679-7081;
Jerry_O'Neal@fws.gov

Whit Lewis, Assistant Refuge Manager
Tennessee National Wildlife Refuge
U.S. Fish and Wildlife Service
810 E. Wood Street, Suite B
P.O. Box 849
Paris, TN 38242
(615) 535-2465; fax (615) 535-3974;
R4RW_TN.IPM@fws.gov

Region 5
(*ME, VT, NH, MA, NJ, DE, MD, WV, VA*)
Tim Fannin, Environmental Contaminants Coordinator
U.S. Fish and Wildlife Service
300 Wastage Center Drive
Haley, MA 0 1035-9589
(413) 253-8659; fax (413) 253-8482;
Tim_Fannin@fws.gov

Region 6
(*CO, UT, KS, NE, WY, MT, ND, SD*)
Linda Drees
U.S. Fish and Wildlife Service
315 Houston Street, Suite E
Manhattan, KS 66502
(913) 539-3474; (913) 539-8567;
Linda_Drees@fws.gov

Steve Berlinger
U.S. Fish and Wildlife Service
c/o Rio Grande National Forest Supervisor's Office
1803 West Highway 160
Monte Vista, CO 81144
(719) 852-6221; fax (719) 852-6250;
Steve_Berlinger@fws.gov

Region 7
(*A K*)
Tony DeGange, Ecological Services
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3492; fax (907) 786-3493;
Tony_deGange@fws.gov

Appendix 2. Web sites for weed biocontrol information

Alberta Research Council weed biocontrol site:

http://www.arc.ab.ca/crop/weed/Biocontrol.html

CABI BioScience:

http://www.cabi-bioscience.org/

Controlling weeds using biological methods (British Columbia):

http://www.for.gov.bc.ca/hfp/pubs/interest/noxious/noxtoc.htm

Cooperative Research Centre for Tropical Pest Management (Australia):

http:/www.ctpm.uq.edu.au/biocontrol/biocontrol/html

Commonwealth Scientific and Industrial Research Organization (CSIRO) Entomology: Weed Management Program (Australia):

http://www.csiro.au/

Cornell University biological control site:

http://www.nysaes.cornell.edu/ent/biocontrol/weedfeeders/wdfdrintro.html

Endangered and threatened species, including candidate species:

http://endangered.fws.gov/wildlife.html

Endangered Species Act of 1973 (Federal Act):

http://www.fws.gov/~r9endspp/esa.html

Exotic plant species: What are they and why we should be concerned? U.S. Geological Survey-Biological Resources, Division, Colorado Plateau Field Station, Flagstaff, AZ:

http://www.nbs.nau.edu/FNF/Vegetation/Exotics/concern.html

Federal Interagency Committee for Management of Noxious and Exotic Weeds (FICMNEW):

http://refuges.fws.gov/FICMNEWFiles/FICMNEWInformation.html

Germplasm resources information network (GRIN):

http://www.ars-grin.gov/npgs/tax/index.html

Integrated pest management plan for leased lands at Lower Klamath and Tule Lake National Wildlife Refuges, OR/CA(includes discussion of noxious weeds), DRAFT:

http://refuges.fws.gov/NWRSFiles/H/KBasin/index.html

International organization for the Biocontrol of Weeds working group:

http://www.gnv.ifas.ufas.ufl.edu/~iobcweed/

National Wildlife Refuges, U.S. Fish and Wildlife Service:

http://refuges.fws.gov/NWRSHomeP.html

Pacific Northwest 1998 weed control handbook, to order in Washington (state):

http://caheinfo.wsu.edu

Plant list of accepted nomenclature, taxonomy, and symbols (PLANTS):

http://plants.usda.gov/

Proceedings: Saltcedar management and riparian restoration workshop, Las Vegas, NV, September 17 and 18, 1996:

http://refuges.fws.gov/NWRSFiles/SaltcedarWorkshopSep96/wkshpTC.html

Pulling together: National strategy for invasive plant management, U.S. Fish and Wildlife Service:

http://bluegoose.arw.r9.fws.gov/FICMNEWfiles/NatlWeedStrategyTOC.html

Status of weed-biocontrol organisms in Canada:

http://res2.agr.ca/lethbridge/weedbio/index.htm

Tree of life (phylogeny; for determining clades down to family):

http://phylogeny.arizona.edu/tree/phylogeny.html

USDA, APHIS, PPQ:

http://www.aphis.usda.gov/ppq/bats

USDA, APHIS, PPQ, National Biological Control Institute:

http://www.aphis.usda.gov/nbci/nbci.html

USDA, APHIS, PPQ–Technical Advisory Group:

http://www.aphis.usda.gov/ppq/ss/tag/

USDA, European Biological Control Laboratory:

http://www.ars-ebcl.org/

Vascular plant family nomenclature, James L. Reveal, University of Maryland, College Park, MD 20742-5825. This web site includes individual, fully annotated treatments for Cronquist, Dahlgrent, Takhtajan, and Thorne:

http://www.inform.umd.edu/PBIO/fam/revfam.html

Weeds on the public lands: A bulletin of the California Interagency Noxious Weed Coordinating Committee:

http://www.ca.blm.gov/weeds

Wyo-Bio: Biocontrol News and Views for Wyoming:

http://www.uwyo.edu/AG/PSISCI/Newsletter/index.html

Appendix 3. Common and scientific names of all taxa mentioned in text

PLANTS

Alligatorweed	*Alternanthera phylloxeroides*
Bindweed, field	*Convolvulus arvensis*
Broom, French	*Genista monspessulana*
Broom, Scotch	*Cytisus scoparius*
Cactus, prickly-pear	*Opuntia* spp.
Gold-wire	*Hypericum concinnum*
Gorse	*Ulex europeaus*
Halogeton	*Halogeton glomeratus*
Houndstongue	*Cynoglossum officinale*
Ivy, Cape	*Senecio mikanioides*
Klamath weed	*Hypericum perforatum*
Knapweed, diffuse	*Centaurea diffusa*
Knapweed, Russian	*Acroptilon (Centaurea) repens*
Knapweed, spotted	*Centaurea maculosa*
Loosestrife, purple	*Lythrum salicaria*
Paperbark tree	*Melaleuca* spp.
Peppertree, Brazilian	*Schinus terebinthifolius*
Pine, ponderosa	*Pinus ponderosa*
Poison-hemlock	*Conium maculatum*
Poppy, Arizona	*Kallstroemia grandiflora*
Puncture vine	*Tribulus terrestris*
Ragwort, tansy	*Senecio jacobaea*
Sage, Mediterranean	*Salvia aethiopis*
Saltcedar	*Tamarix ramosissima*
Skeletonweed, rush	*Chondrilla juncea*
Spurge, leafy	*Euphorbia esula*
Tamarisk	*Tamarix pentandra*
Starthistle, yellow	*Centaurea solstitialis*
Thistle, Canada	*Cirsium arvense*
Thistle, Italian	*Carduus pycnocephalus*
Thistle, milk	*Silybum marianum*
Thistle, musk	*Carduus nutans*
Thistle, Russian	*Salsola iberica*
Thistle, Scotch	*Onopordum acanthium*
Toadflax, Dalmatian	*Linaria dalmatica*
Waterhyacinth	*Eichornia crassipes*

INSECTS

Coleoptera

Beetle, Klamath weed	*Chrysolina quadrigemina*
Flea beetle, alligatorweed	*Agasicles hygrophila*
Flea beetle, black-dot spurge	*Aphthona nigriscutis*
Flea beetle, tansy ragwort	*Longitarsus jacobaeae*
Weevil, thistlehead	*Rhinocyllus conicus*
Weevil, puncture-vine stem	*Microlarinus lypriformis*

Diptera

Flies
Fruit flies, seed-head
Midges

Lepidoptera

Moth, cinnabar	*Tyria jacobaeae*
Moth, stem-boring	*Coleophora parthenica*

Appendix 4. Glossary

APHIS–Animal and Plant Health Inspection Service.

Area of introduction or introduced range–Area, outside its native range, into which a plant has accidentally or deliberately been introduced by human activity.

ARS–Agricultural Research Service.

Arthropods–Animals with external skeletons and jointed legs; includes insects, mites, spiders, millipedes, and crustaceans.

Biocontrol–See classical biocontrol.

Candidate agent–An organism proposed for use as a biocontrol agent that has not yet been fully tested or approved for release.

Center of origin–Area in which a plant species or group originally evolved.

CEQ–Council on Environmental Quality.

Classical biocontrol–Introducing exotic natural enemies, generally self-sustaining, to reduce populations of an introduced pest.

Collection and distribution–Gathering insect biocontrol-agents from established field sites and releasing them in weed-infested sites.

Collection threshold–A sampling result that determines when the population is large enough to permit collecting.

Conflicts of interest–Disagreement about whether an introduced plant is a noxious weed.

Decision threshold–The set of conditions when information acquired during sampling indicates that a decision is needed.

EA–Environmental assessment.

EIS–Environmental impact statement.

EPA–Environmental Protection Agency.

ESA–Endangered Species Act of 1973.

Fecundity–Number of offspring produced by an organism over the course of its life.

Field insectary–A weed-infested site selected for propagating a biocontrol agent.

FIFRA–Federal Insecticide, Fungicide, and Rodenticide Act of 1947.

FONSI–Finding of no significant impact.

FPPA–Federal Plant Pest Act of 1957.

FWS–United States Fish and Wildlife Service.

GPS–Global positioning system, a satellite-based navigation system designed to provide real-time location information on portable receivers.

Host plant–Any plant on which a biocontrol agent can feed and develop.

Host range–The set of species on which a biocontrol species can feed and develop in nature.

Host specificity–The limitation of a biocontrol agent to feeding and developing on a particular plant or set of plants.

Monitoring, plant–Observing, measuring, or both to evaluate changes in plant attributes.

Monitoring, insect Biocontrol-agents–Observing, measuring, or both to evaluate the abundance of insect biocontrol-agents to understand their interactions with host plants.

Multiple-choice tests–Determining host range of biocontrol agents by allowing them to select from an array of potential host plants for feeding and ovipositing.

Native range–Area in which a plant grows naturally without having been introduced by human activities.

NEPA–National Environmental Policy Act of 1969.

No-choice tests–Confining candidate biocontrol agents to a single host plant species to determine its ovipositing behavior; sometimes called a "starvation" test.

Phylogeny–An organism's evolutionary history.

Phylogenetic reconstruction–A method of reconstructing the evolutionary relations among a group of organisms by analyzing their patterns of shared and unique characters.

Potential host–A plant on which a control agent can complete its life cycle.

PPQ–Plant Protection and Quarantine (part of APHIS).

PQA–Plant Quarantine Act of 1912.

Safety (of a biocontrol agent)–Originally, not a danger to plants of importance to agriculture, horticulture, forestry, or wildlife. Now, includes plants related to endangered and threatened species; other related, nonlisted native plants; and native habitats.

Qualitative estimates for monitoring–Techniques–such as using a sweep net, timed counts, or visual ratings of abundance or damage–that produce relative abundances of biocontrol agents from one sampling date or site to another with no direct relation to land surface area.

Quantitative estimates for monitoring–Techniques that produce abundances of biocontrol agents per plant, per plant part, or per unit area.

Sampling–Collecting and analyzing a small part of a population to gather reliable information about the population as a whole.

TAG–Technical Advisory Group for Biological Control Agents of Weeds

USDA–United States Department of Agriculture.

USDI–United States Department of the Interior.