INTEGRATED PEST MANAGEMENT

Unit 2 Section 1 Lesson 3
Friend or Foe?

Focus Areas: Pest Control Methods - Biological; Science, Language Arts

Focus Skills: Cooperative decision making, analyzing data, reading expository material, creating an oral presentation, scientific evaluation

Level of Involvement: MINIMAL

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INTEGRATED PEST MANAGEMENT

University of Connecticut
College of Agriculture and Natural Resources
Cooperative Extension System

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Dedicated to Reducing Pesticides

Objective

To understand the importance of carefully selecting natural enemies for use as introduced biological controls

Essential Question

What criteria must be evaluated prior to releasing non-native species as biological control agents?

Essential Understanding

Impact on native plants and animals must be considered prior to the introduction of non-native species into an ecosystem.

Background

Read articles Double Agents and Of Weevils, Thistles, and Biological Control.

In defense of biocontrol, it should be pointed out that in the case of the weevil feeding on not only the introduced thistle but some native thistles, researchers knew this biocontrol agent was not host specific, but weighed the risks and were more concerned about economic impacts of not controlling the introduced (problem) thistle. Today, biocontrol agents are screened much more thoroughly and new regulations are stricter.

Vocabulary

alternate host	An acceptable (substitute), but not preferred food source for parasitic organisms

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Vocabulary (Continued)

inoculative release — releasing a small number of natural enemies into an ecosystem for the purpose of long range reduction of pests

inundative release — the release of large numbers of natural enemies for the purpose of immediate reduction of pest populations

monoculture — only one species of plant growing in a habitat

non-native/exotic species — a species of plant or animal not found naturally as part of an ecosystem, but capable of successfully adapting to it

parasite — an organism that uses another plant or animal as a host during all or part of its life cycle

pathogen — an organism that causes disease in plants or animals

perennial — plants that bloom each year for several years without replanting

Unit 2 Section 1 Lesson 3: Friend or Foe?

Challenge

Choose the best fit for a natural enemy to combat the dreaded Purpleface Waterleaf

Logistics

Time: 60 minutes
Group size: 6 to 36
Space: comfortable group seating to allow individuals to work in teams of three

Materials

Article Double Agents *

Article Of Weevils, Thistles, and Biological Control *

Handout 1 Rules for Selecting and Releasing Biological Control Organisms *

Handout 2 Potential Natural Enemies of Purpleface Waterleaf *

Written Document Analysis Worksheet *

* single copy provided

Preparations

1. Prepare multiple copies of both handouts, one per individual
2. Introduce the vocabulary

Activity

Introduction

1. Review the concept of biological control, re-emphasizing that such natural enemies as predators, parasites, and diseases are used to help control pests.
2. Explain that pests are often introduced from other countries.

Activity

Introduction (Continued)

3. Predators, parasites, and diseases that control a pest in its native home are possibilities for use as biological control organisms.

4. These potential controls, however, must be studied with great care before they are introduced into the area now occupied by the non-native pest.

   * Distribute copies of Handout 1 Rules for Selecting and Releasing Biological Control Organisms.

   * Read and discuss them as a group. Develop the following scenario (**Note:** The plant is not a real species, nor are the potential natural enemies)

A perennial plant, the purpleface waterleaf, has been introduced into North America and is invading and destroying many wetlands by out-competing native vegetation. Purpleface waterleaf, while pretty to look at, has very little value as wildlife food and converts marshes and other wetland habitats into nonproductive monocultures (only one species of plant) in a very short time. A team of three scientists has been dispatched to Europe and Asia, where purpleface waterleaf is a native. Their mission is to find natural enemies to bring back and introduce to control this very severe pest.

Involvement

1. Divide the class into teams of three.

2. Give each team a set of Handout 1 and Handout 2.

3. Each team will function as a scientific unit.

Activity

Involvement (continued)

Each team of scientists reads and studies its material, thereby discovering potential diseases and predators (herbivores), natural enemies of purpleface waterleaf. Using Handout 1 Rules for Selecting Biological Control Organisms, each group should decide which of the organisms it will recommend to the United States Department of Agriculture for importation into the United States to be released as a natural enemy of purpleface waterleaf.

Follow Up

1. After completing the exercise, have each group discuss the organisms it chose and justify to the class why. Did all the participant groups agree?

2. An alternative to immediate release could also be that a species has potential, but we currently do not have enough information about it. What would participants suggest be done in this case?

Answer Key

Accept answers that can be justified by facts presented in the reading.

Assessment

Option #1 Cooperative teams are evaluated on their choice of natural enemy and explanation of that choice.

3 points. Justify their choice and explain why others were eliminated
2 points. Justify their choice, but do not explain weaknesses of other possibilities
1 point. Unsatisfactory justification of choice

Option #2 Individuals write a journal response: the dangers of indiscriminate selection of introduced species as biological controls .

Unit 2 Section 1 Lesson 3: Friend or Foe?

Follow Through

Case Reports: We Learn from Our Mistakes

Focus Areas: Same
Focus Skills: Comprehending a scientific article, determining main ideas

Activity: Individuals read article Double Agents and complete Written Document Analysis Worksheet.

Resources

Pests Have Enemies Too. Jeffords, M.R. and A.S. Hodgins. Illinois Natural History Survey Special Publication 18. July 1995.

Notes

Notes

Handout 1

Rules for Selecting and Releasing Biological Control Organisms

The rules listed below are applied by scientists when choosing organisms to be used for biological control. Make sure you read and understand each of these rules before beginning your search for biological control agents of purpleface waterleaf.

1. An organism that is to be introduced as a biological control agent must prey only (or mostly) on the target pest. Note that a pest is often an organism from another country that has become a problem because it was imported (usually accidentally) without its natural enemies. These natural enemies helped control it in its native home and can potentially be used to help control the pest in its new home.

2. The imported biological control organism should come from a climate and biological community similar to those into which it will be introduced. For example, if you want to control a pest of citrus trees, a biological control organism must be able to withstand the high heat of most citrus-growing areas in the U.S., and be able to grow and reproduce in its new environment. For example, an insect that required an extended cold period (winter) to complete its development would not be a suitable candidate.

3. An organism that is to be used for biological control must be easy to capture, be raised in large numbers for release (inundative release), or have a high enough reproductive potential in its new home so that its numbers will increase rapidly (inoculative release) after release. For most programs to succeed, thousands of individuals of a particular natural enemy must be released into the environment, an effort that may take several years. Such large-scale releases are the best way to ensure that enough males and females (in the case of larger organisms) find each other to mate and reproduce in their new home. In the case of disease-causing organisms, a release of large numbers may initially cause a wide-scale outbreak of the disease and establish it so that subsequent outbreaks also occur in future years and help control the unwanted organism.

4. An organism introduced to help control a certain pest must have little or no direct or indirect effects on other organisms in the environment (see rule 1) and must not become a pest itself.

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Handout 2

Potential Natural Enemies of Purpleface Waterleaf

A Scientific Adventure

(A) While traveling in northern Iran searching for populations of purpleface waterleaf (which you note are very rare), you encounter a small wetland with a few plants growing near the edge. Upon close examination, the leaves of one plant are riddled with insect feeding, so much so that the plant has failed to bloom and appears to be near death. After your excitement diminishes somewhat, a careful search of the plant reveals that the damage is being caused by a very small leaf beetle. No beetles can be found on the plant because when they are disturbed, they simply let go and fall off the plant. You collect several hundred beetles from around the plant and take them to the nearest laboratory facility in Tehran, where they are identified as the waterleaf beetle. A search of the literature reveals that relatively little is known about the species except that it feeds on several different kinds of closely related waterleafs, has two generations per year, and can be raised in captivity, but only on potted waterleaf plants. Female beetles lay between 100 and 400 eggs per generation, depending on the time of the season. In addition, for beetles to survive and reproduce, they must undergo a cold period (with winter temperatures near freezing) for at least 6-8 weeks.

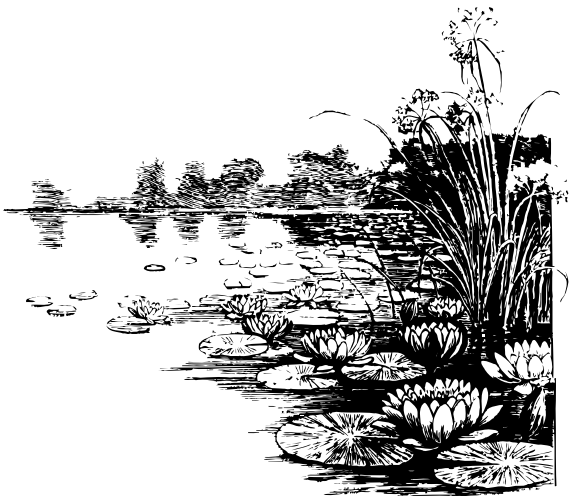
(B) In northern Germany, you encounter a small population of purpleface waterleaf that has wrinkled, curly leaves and very stunted plants. You immediately think that perhaps these plants have some sort of disease. After collecting a sample of the leaves and testing it in a local laboratory, the pathogen is determined to be a kind of virus that is unknown to scientists. You have discovered a new kind of pathogen and no information is available about it.

(C) In the same locality, you collect last year s seeds from several plants and bring them into the laboratory for examination. After they were put in a white enamel pan and left overnight, you notice that a large number of tiny, white maggot-like creatures with dark heads have emerged, apparently from the seeds. Each creature is placed in a small container of soil where it digs in and forms the pupa. After waiting very impatiently for a month, you notice one day that a small beetle, called a seed weevil, has emerged from the soil! The beetle is sent off to an entomologist in England, who identifies it as the miniature forb weevil. A search of the available information reveals that the weevil attacks seeds of a certain size, but is not very particular about the kind of seeds it attacks. You also note that rearing the weevil in large numbers is likely to be very labor-intensive.

Handout 2

Potential Natural Enemies of Purpleface Waterleaf

A Scientific Adventure (continued)



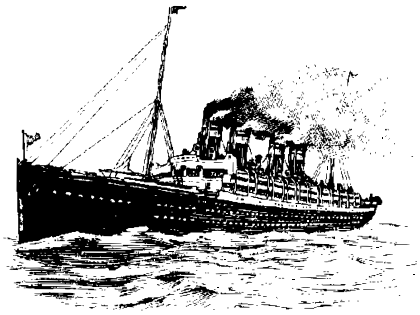
(D) While traveling through northern Italy, you notice that a large marsh has a narrow fringe of purpleface waterleaf around it. In one place you find several fairly large caterpillars that are defoliating the young plants. After collecting a quantity of the caterpillars and the purpleface waterleaf, you return them to a laboratory in Milan where you attempt to rear them into adult moths on the potted plants. Just before they are ready to form pupae, you notice that every caterpillar is covered with at least five fuzzy-looking egg-shaped structures. In about a week, the mystery is answered as tiny wasps emerge from these cocoons. This tells you that all the caterpillars have been parasitized by wasps and the wasp larvae spent the summer developing in the caterpillar. Even though these caterpillars continued to feed on purpleface waterleaf, they failed to develop into adults. Your curiosity aroused, you vow to return next season in an attempt to find more caterpillars that are not victims of these parasites. In addition, because no adults were produced, you are not able to identify the caterpillars.

(E) While rearing purpleface waterleaf plants in a greenhouse in Lisbon, you notice that several of the plants are wilting and dying. These plants are infested with tiny insects called aphids that suck the sap from the plants. After bemoaning the fact that they are killing your plants, you are struck by the idea that perhaps these insects might also be potential natural enemies. The aphids are identified and it turns out that they are a single species with two names, the purpleface waterleaf aphid and the cork oak aphid. Puzzled by this, you contact several aphid experts and discover that this insect has a very complicated life cycle. The aphids spend the winter as eggs on cork oak trees and when they hatch in the spring, they feed for a short time on new oak leaves before migrating to purpleface waterleaf. Here they spend the summer and reproduce in very large numbers. In the fall, the aphids produce winged offspring that must fly back to cork oak trees, feed for a short while, and lay the eggs that will spend the winter. Your curiosity leads you to investigate if this aphid will accept a substitute alternate host oak tree from North America. You spend several seasons doing this research and discover that white and bur oak are acceptable alternate host plants.

Handout 2

Potential Natural Enemies of Purpleface Waterleaf

A Scientific Adventure (continued)



(F) Before leaving Europe, you make one more short trip through Austria and discover a small patch of purpleface waterleaf that is covered with what appears to be a hairy white powder. Puzzled, you consult with a plant pathologist and find that the plant has a powdery mildew fungus that is almost always fatal to the plant. Searching the literature reveals that all members of the family to which purpleface waterleaf belongs are susceptible to this disease, but that it occurs only during extremely wet summers with high heat and humidity. In dry cool years the disease, while still present, does not appear to affect the plants. You also discover that the disease can be easily cultivated artificially in petri dishes in the laboratory. A search of the plant literature for North America shows that we have 49 species of the purpleface waterleaf family. Three of these species are considered rare and two are endangered, but occur only in California and Oregon.

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Unit 2 Section 1 Lesson 3: Friend or Foe?

Written Document Analysis Worksheet

1. Title of document:_____
2. Date of document: _____
3. Source of document: _____
4. Audience for whom document was written: _____
5. Main idea(s) of document: _____

   _____

   _____

6. Three important points made in the document (should support main idea):

   1. _____

   2. _____

   3. _____

7. A question I still have regarding the topic of the document: _____

   _____

   _____

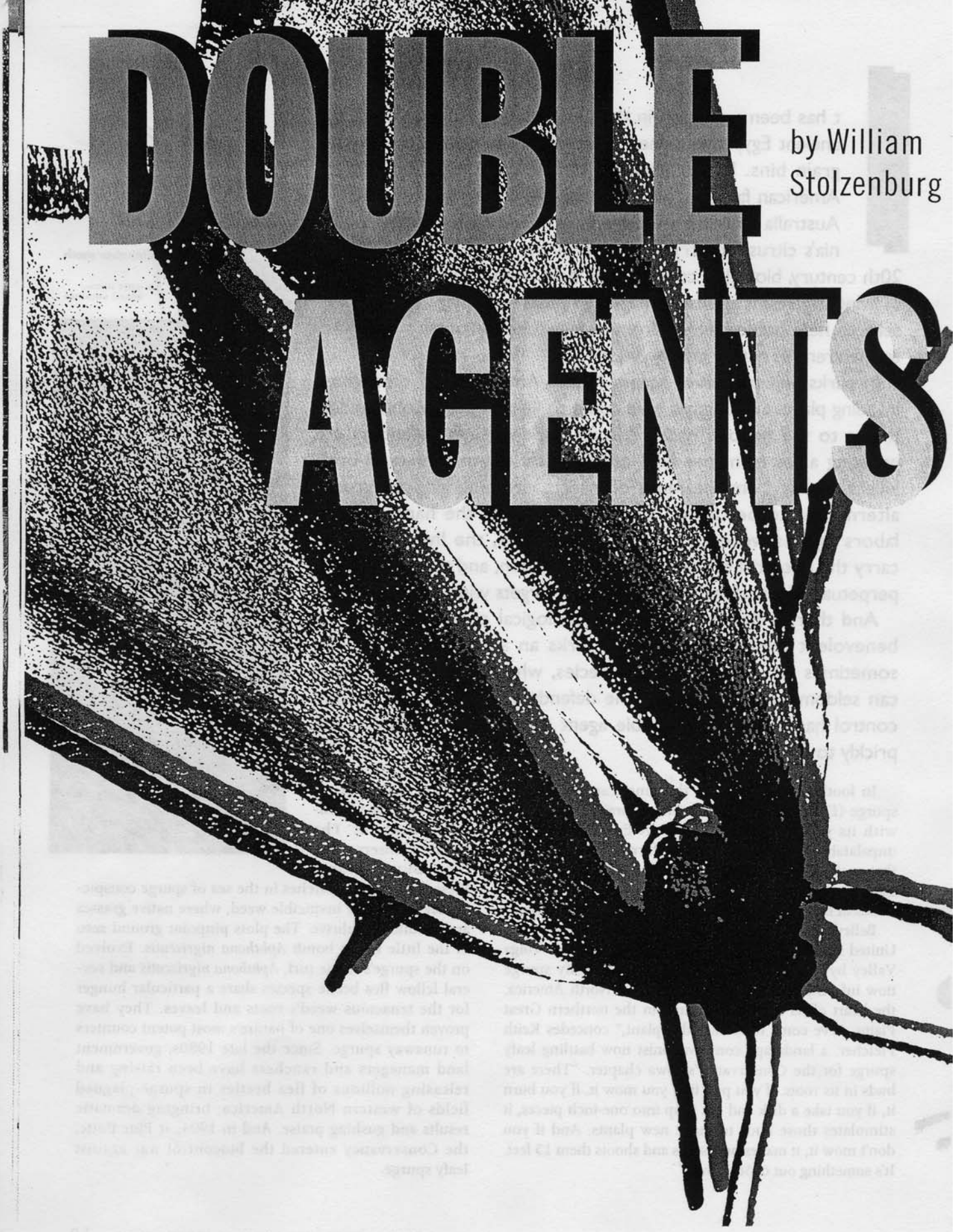
8. My thoughts/feelings about the topic of the document: _____

   _____

   _____

DOUBLE AGENTS

by William Stolzenburg



Cinnabar moth

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The Peril and Potential of Biological Control

It has been a weapon in the human arsenal at least since the ancient Egyptians turned their cats loose on rats raiding the grain bins. It was wielded with lethal impact in 1889 by American farmers, who brought the vedalia beetle from Australia to crush a foreign insect assault on California's citrus industry. And now at the close of the 20th century, biological control—the deliberate pitting of living organisms against humankind's pests—is being sent to new battlegrounds, from its agricultural roots to the arena of nature conservation.

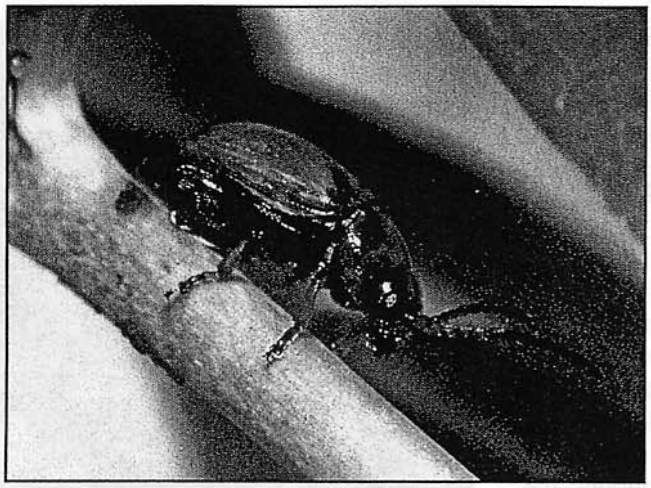
In parks and preserves across North America, at a time when invading plants and animals have come to light as the second-leading threat to the nation's native species, biodiversity's defenders are enlisting allies from the field of biological control. Natural-born killers, mainly from the ranks of insects, are emerging as "green" alternatives to pesticides, as blessed relief in the hand-to-hand labors against weed and pest. Upon release, the living weapons carry the potential to consume the opposition, and the capability to perpetuate themselves and pursue their targets without supervision.

And therein lies the paradox of biological control. Behind the benevolent bug-in-shining-armor lurks an alter ego, whose aim sometimes falls upon innocent species, whose attack once begun can seldom be called off. For the defenders of native species, biocontrol has become the double agent too potent to dismiss, too prickly to embrace.

In foothills and plains of the American West, leafy spurge (*Euphorbia esula*) has colored prairie landscapes with its yellow-green blossoms. A Eurasian invader unpalatable to cattle and rapidly forming dense stands that push aside the prairie's native plants, leafy spurge has established itself as one of the most feared and despised weeds of both western rancher and natural-area manager.

Believed to have been accidentally shanghaied to the United States in sacks of grass seed from Russia's Volga Valley by Mennonite immigrants in 1827, leafy spurge now infests about 5 million acres across North America, the heart of its invasion centered in the northern Great Plains. "I've come to admire this plant," concedes Keith Fletcher, a landscape conservationist now battling leafy spurge for the Conservancy's Iowa chapter. "There are buds in its roots. If you pull it, if you mow it, if you burn it, if you take a disk and cut it up into one-inch pieces, it stimulates those buds to make new plants. And if you don't mow it, it makes new seeds and shoots them 15 feet. It's something out of *Star Trek*."

Yet along Montana's Rocky Mountain Front, at The Nature Conservancy's Pine Butte Swamp Preserve, there are patches in the sea of spurge conspicuously free of the invincible weed, where native grasses and wildflowers thrive. The plots pinpoint ground zero of the little insect bomb *Aphthona nigriscutis*. Evolved on the spurge's home turf, *Aphthona nigriscutis* and several fellow flea beetle species share a particular hunger for the tenacious weed's roots and leaves. They have proven themselves one of nature's most potent counters to runaway spurge. Since the late 1980s, government land managers and ranchers have been raising and releasing millions of flea beetles in spurge-plagued fields of western North America, bringing dramatic results and gushing praise. And in 1994, at Pine Butte, the Conservancy entered the biocontrol war against leafy spurge.



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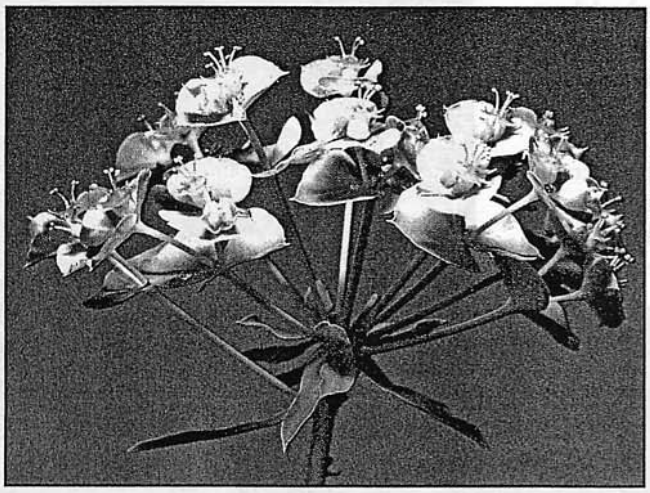

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▲ Flea beetles (top) are proving themselves worthy opponents against leafy spurge (middle), a Eurasian invader whose rampant displacement of native grasses and wildflowers forms a chain of threats extending all the way to the grizzly bear.

For decades leafy spurge had kept a low profile at Pine Butte beneath the solidarity of an unusually vigorous community of native plants. That all seemed to change in 1975, when one of the major floods of the century rolled through the preserve. In the patches swept bare by floodwaters, leafy spurge took hold. "It probably wasn't until 10 years after that people started seeing how really bad spurge had gotten," says Dave Hanna, manager of the preserve. "It took over hundreds of acres. Now you get up on a hill and you see solid leafy spurge, like having planted a crop of it. You can't see anything else."

There are no particularly rare plants at Pine Butte to worry its managers over the spurge's spread. What concerns them most is the bear. Pine Butte is the last place in North America—probably the world—where grizzly bears still wander the native prairie. They're particularly drawn to the prairie wetlands with their cow parsnip, angelica, roots, grasses and sedges—the same wetlands that the leafy spurge had begun to invade.

Weed pulling and herbicide spraying had failed against the leafy spurge. Backed to the wall, Dave Carr, Hanna's predecessor, finally considered biocontrol. Carr and Hanna began two painstaking years assessing the risks and costs of releasing this new alien to fight the old. In a sense, the bug was already proven. Ranchers near the preserve had already begun employing flea beetles, with happily devastating results. But a heavy stigma remained, weighted by an infamous history of biocontrol agents turned traitor.

Over the past 40 years, *Euglandina rosea*, known by some as the cannibal snail, had been deliberately loosed on more than 20 islands and archipelagos in the Pacific and Indian oceans. It was meant ostensibly to dispatch an introduced garden pest, the giant African snail. Instead it has helped itself to the islands' native mollusks, eliminating more than 50 species of land snails. *Bufo marinus*, a giant toad from Latin America, was sent to Australia in the 1930s to save farmers from the sugar cane beetle. The cane beetle remains. The toad—now infamously known as the cane toad—quickly multiplied to nearly plague proportions, swarming over lawns and roads and swallowing a wide range of native wildlife.

Holding respect for these and other occasional biocontrol backfires, the Conservancy has maintained a cautious prohibition against biological control on lands it owns or manages. But at Pine Butte Swamp, the time had come to make an exception. In 1994, with hard-fought approval from leading Conservancy scientists and its Board of Governors, Carr and Hanna released a thousand flea beetles into a cordoned patch of leafy spurge.

Five years later, the beetles are performing as advertised, moving slowly and eating thoroughly, devastating dense stands of leafy spurge and leaving its native neighbors alone. The beetles have demonstrated, in the

language of the trade, selectivity—the quality that often separates biocontrol's beauties from its beasts. It is a quality that may cost its seekers two to three years of overseas odysseys and extensive feeding experiments to find the bug that eats only what it is hired to eat. It is a prerequisite for release that in the past has not always been meticulously applied.

The semaphore cactus (*Opuntia spinosissima*) is known to exist in one, maybe two, places in the world. One for sure is Torch Wood Hammock, in the Florida Keys, which The Nature Conservancy acquired in 1989 for the sake of the semaphore cactus. Soon after, a local botanist noticed among the semaphores a related cactus riddled with insect holes. Inside, she found the striped black-and-orange caterpillar of *Cactoblastis cactorum*—the same Argentinian moth that in the 1920s had been famously successful at clearing alien cactus from millions of acres in Australia. And here was the moth again, a short crawl away from a native cactus species represented by 12 wild specimens.

Cactoblastis's transformation from Australian hero to American pest began with a costly nonchalance toward the moth's rather predictable mobility. Following its Australian victories—in a continent with no native cacti—the

Running wild: Introduced to eat insect pests, ▲ the cane toad is devouring native wildlife in Australia. ▼ Deployed to control the giant African snail in the Pacific Islands, the carnivorous rosy wolfsnail, from the mainland of the Americas, has decimated scores of the islands' native land snails.

moth was introduced in 1957 for similar eradication duty in the Caribbean. Again it did the job—and then some. From the island of Nevis, by human hands and its own wing power, the moth island-hopped its way up the Lesser Antilles, through Puerto Rico, the Dominican Republic and the Bahamas. By the late 1980s, it was found helping itself to rare cacti in the Florida Keys.

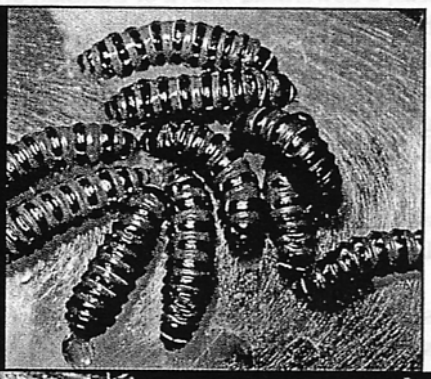
At Torch Wood Hammock, most of the few remaining semaphore cacti were quickly shielded under screens. The cactus has tentatively dodged the *Cactoblastis* bullet, but word is that the semaphore may be only the first in line to be threatened by the cactus moth. Biologists forecast the mobile moth trucking its way across the Gulf states and into the cactus-rich environs of the American Southwest.

"In my opinion, the moth's introduction [to the Caribbean] was ill-advised," says the U.S. Department of Agriculture's Robert Pemberton, a specialist in biocontrol on natural areas. There was never any secret that *Cactoblastis*'s tastes ran to at least 15 cactus species of the genus *Opuntia*, says Pemberton, even among those who set the moth loose within range of native and rare *Opuntia*. "But native plants weren't valued," he explains.

Another who took serious note of *Cactoblastis*'s latest leap was biologist Daniel Simberloff, a leading authority on population biology. Upon hearing of the near miss at Torch Wood Hammock, Simberloff began looking deeper into the practice of biological control. In 1996, he and colleague Peter Stiling published a paper in the journal *Ecology*, asking, "How risky is biological control?" Stiling and Simberloff, at the time a member of the Conservancy's Board of Governors, answered their question by labeling government regulations of biocontrol agents as insufficient, and outlining a string of ill-planned introductions and disastrous get-aways, including that of *Cactoblastis*. Even as they wrote, there were biocontrol mishaps in the making.

In 1993, Svata Louda, a biology professor at the University of Nebraska, was at work in the Conservancy's

▼ Down to just 12 individual plants in the wild, the semaphore cactus was shielded under mesh cages to offer protection from ► the *Cactoblastis* caterpillar, an escaped cactus-killer introduced in the Caribbean in the 1950s to control more common species.



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Arapaho Prairie and Niobrara Valley preserves in Nebraska's sandhills, examining the interactions between thistle flowers and their native insect predators. Twelve years into her study, a strange new weevil quietly arrived on the scene. The next year Louda noted a few more. By 1995, Louda reported with alarm that the new weevil was taking a substantial bite out of three native thistles. One of them, the Platte thistle (*Cirsium canescens*), was a sandhills prairie specialty. The seed-eating weevil was cutting the seed production of the Platte thistle by 86 percent.

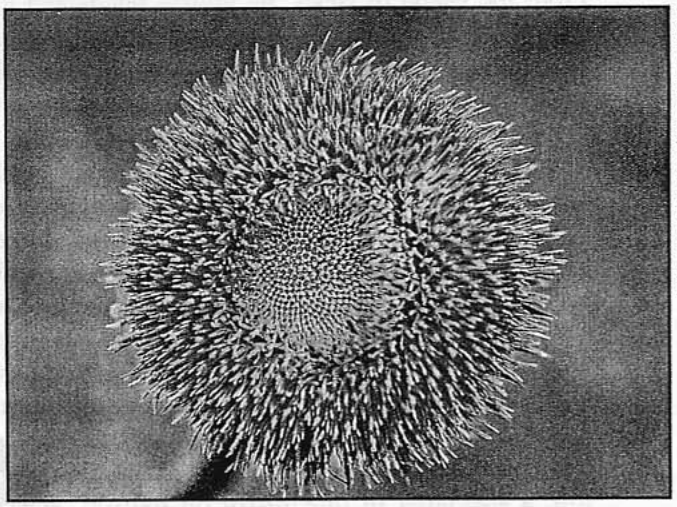
The mystery bug would turn out to be *Rhinocyllus conicus*, a flowerhead weevil of Eurasian origin. Since 1968, it had been widely released by Canadian, U.S. and state agencies, intended to control several alien thistle species, all of them rangeland weeds. Though its résumé suggested the weevil was anything but finicky, feeding on a host of thistle species, the scientists behind its release concluded that native thistles would not be seriously attacked. "But they made the wrong conclusions," says Louda.

In the 1980s, USDA scientists came to new conclusions, experimentally rearing the weevils on 12 native species of thistle from California, three of them already candidates for listing under the federal Endangered Species Act. And as Louda followed her own thread of the runaway weevil, she found scenarios similar to hers across the West. In Rocky Mountain, Mesa Verde and Wind Cave national parks, fellow botanists were documenting damage to native thistles by the Eurasian weevil. In 1997, three months after Louda's results were published, the Suisan thistle of California was federally listed as an endangered species. The announcement mentioned, among other concerns, that the thistle was being fed upon by *Rhinocyllus conicus*.

Louda now fears for the Platte thistle, and in time for its closest relative, the imperiled Pitcher's thistle of the Great Lakes dunes. "We do know that the densities of those thistles is determined by seeds, and the weevil is reducing [Platte thistle] seeds by 86 percent. If you're already sparse, you increase the vulnerability to extinction."

"I don't think the loss of Platte thistle is going to be dramatic," says Louda. "But it's like pulling a thread. There's a whole suite of species that at some point in their life cycles each season rely on that plant. Maybe they won't all starve to death, but there will be one less resource on which to raise the children."

Louda's findings, published in a 1997 issue of the journal *Science*, came as harsh medicine for some of biocontrol's champions, for reasons earlier expressed by her colleague Simberloff: "After all, biological control has been advanced for many years as a green alternative to chemical control, and the great majority of its practitioners surely entered the field as idealists, seeking to stem



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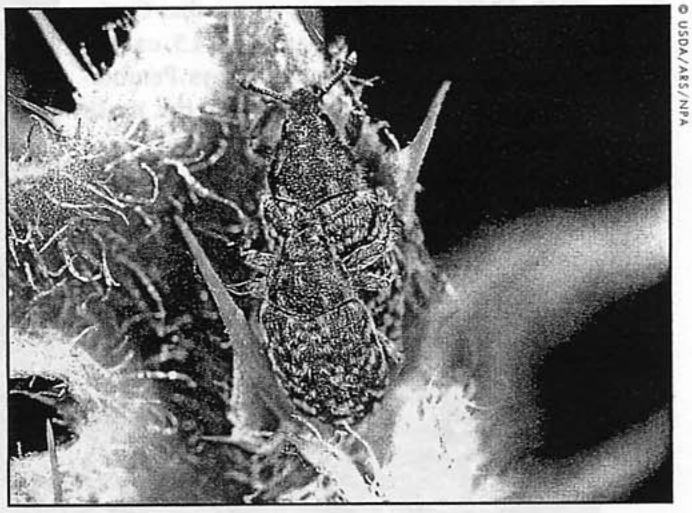

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Introduced to control weeds such as the musk thistle (top), a weevil (center) is now attacking several native thistles, including the Platte thistle (bottom).

environmental destruction. To then be tarred with the same brush as the pesticide 'nozzleheads' must be a cruel blow." Nonetheless, Simberloff now says, "Biocontrol should be viewed as a method of last resort rather than first resort."

Last resort is where certain Conservancy stewards now find themselves. At the Broken Kettle Grasslands Preserve, in Iowa, harboring some of North America's last tallgrass prairie, landscape conservationist Keith Fletcher has run out of answers to leafy spurge. "It's too big to properly handle with chemicals at this point," he says. "It's expensive and you would lose the prairie community you're trying to protect. Kill the spurge with chemicals, you kill the prairie."

Last July, encouraged by the promising precedent of biocontrol at Pine Butte and by nearly two years of his own thorough background research, Fletcher released a batch of flea beetles on the leafy spurge of Broken Kettle. Now he waits.

"I agree we need to be very cautious," says Fletcher. "And with these beetles we were. We consulted the best scientists in Iowa. We looked forward and backward. Yes, I'm nervous, but we're definitely going to lose much of the prairie unless we do something now."

Fletcher's concerns are backed by the numbers. In a poll of national park superintendents, 61 percent of 246 respondents ranked non-native plant invasions as moderate or major problems in their parks. One in 10 Conservancy stewards have judged weeds to be their number-one headache. "What we're seeing is a tremendous pressure to do new [biocontrol] projects from land management people," says USDA's Pemberton. To the nation's guardians of biological diversity, alien species are in dire need of worse enemies.

"My sense is that there are two extremes," says John Randall, the Conservancy's weed specialist and primary consultant on its biocontrol projects. "At one end, folks see biocontrol as a panacea. It seems so natural. It offers a chance to get away from pesticide dependence. At the other end, there are those who are really leery of releasing any non-natives. We've screwed up enough, they say; another exotic would just add fuel to the fire. Where most of the Conservancy's stewards fit is in the middle. At times, it's the best option we're likely to have."

Since the encouraging initiation to biocontrol at Pine Butte Swamp, a handful of Conservancy stewards across the country have come forward with similar dilemmas and requests to give biocontrol a try. They have been cautiously regarding the apparent successes of neighboring ranches and parks pitting foreign bugs against leafy spurge and a wetland counterpart, purple loosestrife. As chemicals and weed-pulling fall short, the beetles, they think, may be their only hope.

"Unfortunately, every weed control technique carries some risks with its potential benefits," says Randall. "But we're being called on to do something now. We always seek to do more good than harm. If we can't assure ourselves of doing that, then we have to do something else. Our goal is not killing weeds; it's protecting natives."

As biodiversity's stewards struggle to come to terms with the two faces of biocontrol, weighing a legacy of alliances gone bad with the enticements of new potential saviors, perhaps only the oldest of adages still applies. For those battling the threat of advancing aliens, there still are no silver bullets.

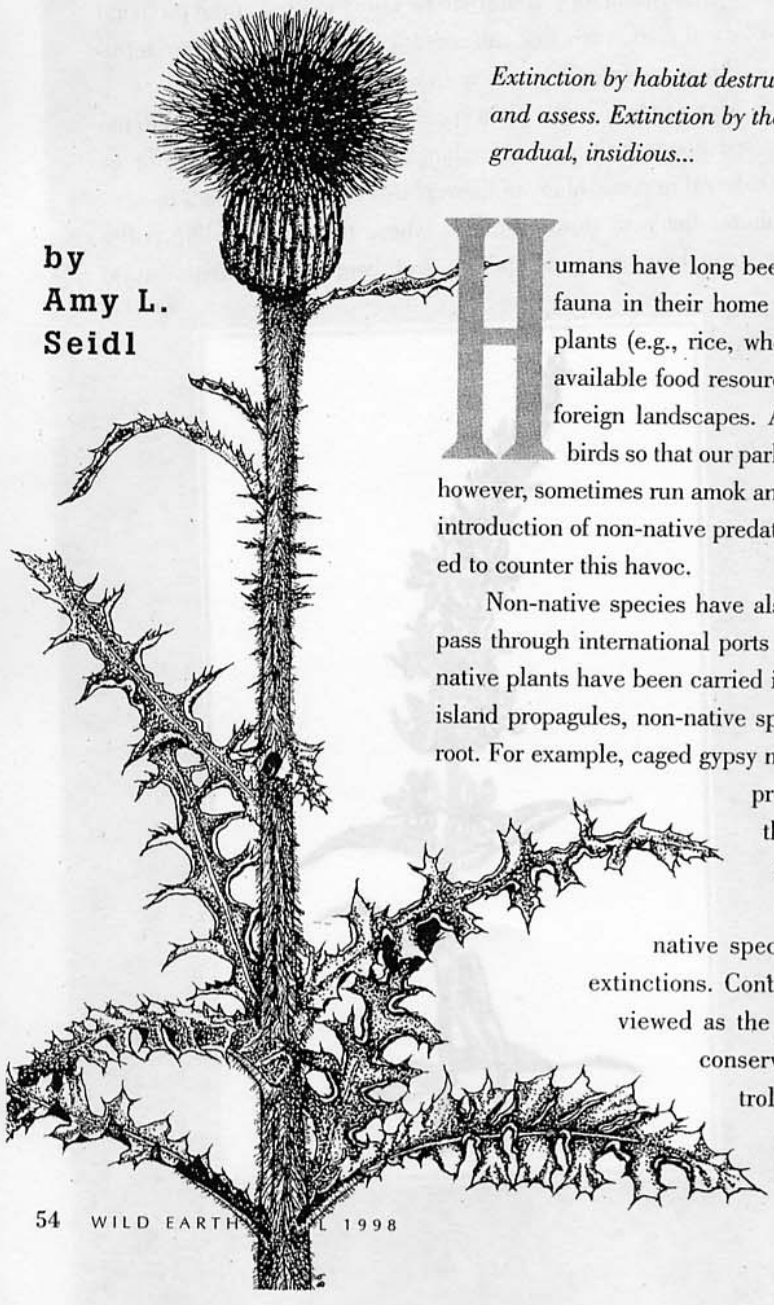
WILLIAM STOLZENBURG *is science editor of* Nature Conservancy.

Unwelcome beauty: Deadly to native plants throughout the northern Great Plains and here in North Dakota ▼, leafy spurge is slowly coming under control at places such as The Nature Conservancy's Pine Butte Swamp Preserve in Montana, thanks largely to the big appetite of the tiny flea beetle.

Of Weevils, Thistles, and Biological Control

Is the Introduction of Non-native Predators a Sustainable Practice?

by Amy L. Seidl



Extinction by habitat destruction is like death in an automobile accident: easy to see and assess. Extinction by the invasion of exotic species is like death by disease: gradual, insidious...

—E.O. Wilson, 1997[1]

Humans have long been enticed by non-native species and desired exotic flora and fauna in their home places. As agriculturalists, we have intentionally introduced plants (e.g., rice, wheat, potatoes) and animals (e.g., pig, goat, ostrich) to expand available food resources. As horticulturists, we have planted ornamentals to mimic foreign landscapes. And as literary connoisseurs, we have introduced non-native birds so that our parks resemble a favorite author's landscape. These exotic species, however, sometimes run amok and create havoc with native ecosystems. Biological control—the introduction of non-native predators and herbivores that control introduced species—is intended to counter this havoc.

Non-native species have also arrived unintentionally. Marine invertebrates, for instance, pass through international ports in the ballast water of shipping vessels, and seeds from non-native plants have been carried in the pockets and shoe heels of tourists and immigrants. Like island propagules, non-native species unwittingly transported into foreign territory often take root. For example, caged gypsy moth larvae brought to the United States for their potential silk production escaped and established a population that spread throughout the Northeast, defoliating enormous tracts of forest and drastically changing the landscape.[2]

Whether by intent or accident, the introduction of non-native species threatens regional distinctiveness and promotes local extinctions. Controlling introduced species with natural enemies has been viewed as the most ecological approach to curbing invasives. Yet many conservationists have begun to debate the merits of biological control. This debate addresses whether the introduction of non-native predators and herbivores further disrupts native

thistle by Gary Eldred

ecosystems. How much more ecological is biological control than the use of herbicides or pesticides? How good is evolutionary theory in predicting the outcome between pests and their predators, plants and their herbivores? Ultimately, we have begun to ask: Is biological control a sustainable practice?

The Science of Biological Control

Biological control is a scientific discipline whose central premise maintains that natural enemies, taken from the region where the non-native originated, can control invasives. In effect, biological control is applied population dynamics: a species' natural enemy controls its prey (or host) at low levels, and is maintained in a regulated fashion. In turn, the prey acts as the limiting resource for the predator and thus controls the predator's own population dynamics.

The practice behind biological control is based on ecology, evolution, taxonomy, ethology, and physiology, and predicts self-sustaining relationships between nonindigenous plants and animals (primarily invertebrates) and their specialized herbivores and predators. Successful biological control programs are based on the assumption that the pest and predator have coevolved—that predator and prey have acted as reciprocal agents of selection such that the predator now specializes on the prey. Because the predator is a specialist, it is predicted to search for its recognized target as efficiently in a foreign environment as in its native habitat. A fundamental premise of biological control, and of population dynamics, is that the predator will *not* eradicate its prey but will control them at noninjurious levels. Eradication of the pest or host would result in its local extinction, thus risking the extinction of its natural enemies and permitting reinvasion of the habitat by the pest.

However, a recent approach to biological control claims that the introduction of any antagonistic predator, one which is naive to the prey and has no evolutionary ties with it, can be as effective as using a specialist. This method, termed *neoclassical biological control,* increases the chance that non-target species will be negatively affected. For instance, a generalist predator may find non-target species more attractive, easier to capture, and with higher nutritive value than the target pest, resulting in adverse effects on non-target species.

An Invasion of Plants

by Ana Ruesink

"The greatest service which can be rendered any country is to add a useful plant to its culture." So declared Thomas Jefferson more than 200 years ago as he gratefully acknowledged a gift of rice seeds from Africa. Jefferson would never have heard of invasive plant species such as purple loosestrife (*Lythrum salicaria*), cheatgrass (*Bromus tectorum*), or hydrilla (*Hydrilla verticillata*), and in his enthusiasm for global trade he failed to predict the profound ecological disruptions that can occur when exotic species are introduced into ecosystems in which they did not evolve.

Thousands of exotic plant species have been introduced to the United States for crop production, as ornamental species, or as accidental imports. Many of these plants remain quiescent in agricultural fields or flower gardens where they behave like polite guests in their new landscape. Some of them—approximately 4000

continues

purple loosestrife by Rebecca Merrilees

The introduction of non-native species to control pests began centuries ago: domesticated cats were introduced to medieval Egypt to protect grain reserves from rodents, and Linnaeus himself introduced predaceous beetles and ants to citrus groves to control fruit pests.[4] Successful biological control has been and remains an attractive option to agriculturalists and others interested in a chemical-free and strategic approach to controlling invasives.

One of the most successful biological control initiatives involved a vadalia beetle, *Rodolia cardinalis*, that successfully controlled the cottony-cushion scale, *Icerya purchasi*, a citrus pest of California's orange crop.[4] The scale insect had been inadvertently introduced to California from Australia where ecologists determined one of its native enemies to be *R. cardinalis*. In the 1940s, a population of fewer than two hundred vadalia beetles was introduced to control the scale pest in California. The beetle population quickly spread, since both larvae and adults feed on the immobile scale, and within a year the orange harvest was free of the pest. In the 1950s, as chemical pesticides became the *modus operandi*, DDT was sprayed to control citrus pests but simultaneously eradicated the beneficial beetle predator. The scale insect returned post-spray and agriculturalists, dismayed by the failure of DDT, re-introduced the beetle.

Another biological control success story is the suppression of Klamath weed, *Hypericum perforatum*, by two species of Chrysomelid beetle.[4] Klamath weed is native to Europe and north Africa and was introduced to rangeland along the Klamath River in the northwestern United States. Its weedy characteristics make it a good colonizer, and after its introduction, the plant quickly spread through overgrazed rangelands, outcompeting native grasses. Klamath weed is noxious to cattle and to most insect herbivores due to its constitutive phototoxic ingredient, hypericin, a compound that initiates blistering and open sores in nonadapted herbivores, including cattle. Chrysomelid beetles in the genus *Chrysolina*, however, have adapted to Klamath weed and are able to break down hypericin into innocuous compounds. Once introduced, the beetles fed voraciously on *H. perforatum* and brought a halt to the weedy scourge.

These examples of successful biological control are often cited in ecology textbooks and in lectures on integrated pest management and agroecology. They are instructive in several ways: 1) they illustrate how *specialized* herbivores and predators that regulate their hosts and prey are the most effective biological control agents, and 2) they illustrate that when predator and prey exist at low but stable levels, their population dynamics become linked such that both are maintained but neither explodes.

These are the conventional lessons—and yet they do not address the ecological unpredictability of introducing non-natives or the unintended disruptions of native communities that have resulted from biological control. How will a predator evolve once introduced? Is evolution towards generalism and away from specialization a possibility for the predator? How do shifts in host by the herbivore or predator affect non-native and non-target species? Will the target organism itself evolve evasive behaviors (e.g., feeding at night, leaf rolling, or dispersal into refugia) that will make it less visible to its predator? How then will the predator respond to these changes?

The situations where biological control initiatives have disrupted ecosystems are numerous. One of the best examples is

It is the complexity and unpredictability of ecological systems that throws a wrench into the sustainability of biological control.

that of the Indian mongoose, *Herpestes auropunctatus.* In the nineteenth century the mongoose was introduced to the Hawaiian islands to control rats rampant in the sugarcane fields.[5] Unfortunately, the mongoose is a diurnal animal, whereas the Norwegian rat is strictly nocturnal, and never did the two meet. Instead, the mongoose, an effective predator, began to decimate the islands' flightless birds and ground-dwelling mammals.

In the case of the mongoose, biological control had profoundly negative consequences due to unintended effects; the species' biology was not well known and the potential effects on the island community were inadequately considered. Rarely do we find that the disruption of an ecosystem stops at a single non-target species. Ecosystems are complex entities with unclear boundaries and cascading effects. For instance, a European tachinid fly, *Compsilura concinnata,* was introduced to parasitize gypsy moths in the United States, one of several attempts to control what has become a national problem.[6] Tachinid flies lay their eggs in a host on which the larvae feast and ultimately kill. Tachinid parasites were intended to biologically control the exotic gypsy moth; unfortunately, the flies were later reared not only from the moth, but from several hundred species of butterfly, non-target organisms often in need of protection.

A second example illustrates how the use of biological control against *native species* can interfere with highly evolved ecological roles. In the 1800s *Myxoma* virus was released to control the rabbit population in Great Britain.[7] The rabbits, confined to increasingly smaller spaces, were making quick work of the lush English landscape. As the virus infected the rabbits, plants grew back and open spaces became densely vegetated. At the same time, researchers noticed that the Lycaennid butterfly *Maculina arion,* a pale blue butterfly found in southern Great Britain, was becoming increasingly rare. Like many Lycaennid butterflies, *M. arion* is part of an ant-butterfly mutualism: the butterfly-loving ant, *Myrmica sabuleti,* carries *M. arion* larvae into its underground nests where the larvae develop and are fed by the ants. In turn the larvae provide a sweet secretion to the ants, creating a positive relationship for both species. The ants, however, prefer to inhabit open areas with exposed soil, conditions that are maintained by the presence of rabbits feeding on the vegetation. By eliminating the rabbit population, managers had inadvertently brought about the extirpation of the ant and its Lycaennid mutualist.

species, botanists claim—have become naturalized, settling in as regular components of the native ecosystem. But some invasive plants can seriously upset natural processes. According to a recent report by the US Office of Technology Assessment, one out of every seven plant introductions results in severe harm to this nation's economy or ecology.

Many of the economic costs of plant invasion accrue as non-natives compete with plants in cultivation. Half of all agricultural weeds are foreign to the United States, and introduced weeds cost Americans between $3.6 and $5.4 billion every year due to lost production and herbicide use.

Consider the case of tropical soda apple (*Solanum viarum*), an impenetrable South American nightshade that entered Florida with a shipment of contaminated grass seed in the mid-1980s. Control efforts cost the Florida cattle industry more than $10 million annually. One of the most well-publicized plant invaders is kudzu (*Pueraria lobata*), an Asian vine that was propagated by the US Soil Conservation Service and planted widely during the 1930s and 1940s for erosion control. As it spread throughout the Southeast, "miracle vine" grew thickly in fields and forest understories, disrupted electrical service, and covered houses and gardens with a blanket of vegetation. Today this federally listed noxious weed costs farmers and woodlot owners more than $100 million a year.

Most invasive plants flourish in areas such as plowed fields, fragmented forests, expanding cities, and overgrazed pastures where human impact is heavily felt. But wildlands are threatened as well. One estimate suggests that our public natural areas are being lost at a rate of 4600 acres per day to invasive plants.

Biodiversity—comprising wild genes, species, and ecosystems—is also under siege. A recent publication by the World Conservation Union identified non-natives as one of the single greatest threats to biodiversity worldwide, second only to the

continues

Morrow's honeysuckle by Rebecca Merrilees

Thistles, Weevils, and Complexity

It is the complexity and unpredictability of ecological systems that throws a wrench into the sustainability of biological control. Ecological communities are evolving entities and their components (species) are subject to natural selective pressures that may be abiotic, such as climate and weather, or biotic, such as competition and predation. A nonindigenous component thrust into an ecological community may become problematic, interrupting the relative balance between species that has been maintained through ecological time. An introduced predator can easily alter this balance and displace a native predator. Similarly, an introduced herbivore can displace native plant feeders. The European ladybird beetle, for instance, introduced to control the Russian wheat aphid in the Midwest, has now displaced its American counterpart.[7] And the honey bee, having colonized the majority of the Americas, has displaced native bees to near obscurity.

An introduced species may also evolve. Although biological control agents are often thought of as evolutionarily static organisms, they are as animate as native species. They experience mutations and undergo natural selection, processes that allow them to tolerate abiotic factors and expand their range by acquiring new hosts. Introduced species, like all living organisms, have some level of genetic variation that allows them to adapt to changes in their environment. As environments change and as non-native species disperse into new habitats, they may encounter different hosts, prey, and plants. The ability to utilize novel environments will be favored and selected for, and the non-native species may evolve and shift, often expanding their host range or taking a wider variety of prey.

Host range expansion can cause considerable disturbance in communities. Recently the range expansion of the flowerhead weevil, *Rhinocyllus conicus,* has threatened native plant communities.[3] *R. conicus* was released in Ontario in 1968 to control a species of European musk thistle, *Carduus nutans,* a plant thought to have been accidentally introduced to the United States with the importation of grain. The weevil larvae feed on thistle seeds, reducing the thistle's reproductive output by making the seeds either inviable or nonexistent. Biological control advocates had screened the insect for years before its introduction and found that although the weevil would oviposit on other thistle genera, including *Cirsium,* a genus for which the United States has several native species, its preference was for *Carduus.* Based on this evidence, the weevil was introduced to the United States in the 1970s and has since spread or been formally introduced to twenty states. By 1978, the weevil had infested native *Cirsium* species. Three of six native *Cirsium* species in Rocky Mountain National Park were found to be infested, some as high as 70%. The weevil was also found in the flowerheads of *Cirsium* in Mesa Verde and Wind Caves National Parks. Recently, the weevil has been documented on Platte thistle, *Cirsium canescens,* an endemic species restricted to the Sandhills prairie of western Nebraska. Platte thistle is closely related to Pitcher's thistle, *Cirsium pitcheri,* an endemic restricted to the Great Lakes sand dune ecosystem and federally listed as Threatened. Although the weevil has not been found on Pitcher's thistle, the pattern of infestation on native *Cirsium* and the thistle's susceptibility to the weevil leaves little doubt that it will be colonized soon.

It is apparent that even careful research on the diet limitations of biological control agents may fall short in predicting how introduced insects will act in the field. Although this flowerhead weevil's preference for *Carduus* may be strong in European habitats, its preferences have broadened in North America, and it clearly acts as a generalist in the United States. But this isn't the end of the story: Like many plant-insect interactions, thistles and weevils are enmeshed in a complex trophic structure that involves numerous other players.

Picture-winged flies with patterned wings and shiny metallic bodies also feed on thistle. *Paracantha culta,* a native picture-winged fly, has decreased in the Sandhills prairie ecosystem, and *Orellia occidentalis* has disappeared from thistles found in Mesa Verde National Park.[3] The decline of picture-winged flies illustrates how introductions may have unintended and unpredictable repercussions. How will their absence affect the Sandhills prairie and Mesa Verde ecosystems? Does the absence of picture-winged flies have an effect on other species? These questions are unanswerable because we do not know all the ecological details of picture-winged flies, weevils, and thistles, or their evolutionary trajectories. What we do know is that the human introduction of an exotic plant—followed by release of an exotic insect to control it—has clouded the fate of these native fly species. Like toppling dominoes, these changes have begun to reverberate through the landscape.

Recommendations & Conclusion

Although the harmful effects of biological control have been illustrated here, some recommendations can still be made for its future use.

1) *Specialist predators and herbivores are the best organisms for biological control.* Coevolved adaptations essentially limit an organism's ability to use alternate hosts. By using specialists as biological control agents, we can employ what natural selection has fine-tuned to our advantage.

2) *Rigorous ecological and evolutionary research on the biological control agent is essential prior to its release.* Although we cannot predict all of the consequences of introducing non-native species, rigorous research can test some basic questions of host use, dispersal distance, and life history, research which can help us assess the ecological risks of introduction.

3) *Neoclassical control methods should be severely questioned.* Aggressive predators and herbivores may appear to be an immediate remedy for controlling invasive species, and their voracious appetites and reproductive success contribute to this perception. Yet these are the same traits which make them destructive agents in novel environments, out of check and out of control. Their use should be limited if not abandoned.

Biological control once appeared to be a panacea in our fight against invasive species. For all intents and purposes, this method was the ecologically sound alternative to chemical sprays and their adverse effects on beneficial non-target organisms. In principle, biological control is simple and elegant: predator follows prey, herbivore forages on plant, species' interactions are two-way affairs. In practice, we have learned how truly complex ecological communities are and how plastic species' response to novel environments can be. Thus, prudence and caution are warranted when biological control methods are contemplated. ❙

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destruction and degradation of natural habitats. Considering plants and animals together, exotics have contributed to the decline of 42% of Threatened and Endangered species listed under the US Endangered Species Act.

Many consequences of plant invasion are more difficult to quantify than management costs, lost recreation areas, or imperiled species. By substantially altering community composition, structure, and function, invasive aliens can change the very fabric of the natural world. For example, through its dense light-capturing canopy and chemical effects, Norway maple (*Acer platanoides*) can eliminate native herbaceous species in forest understories of the eastern US, while invasive woody honeysuckles such as Morrow's honeysuckle (*Lonicera morrowii*) can create dense shrub layers where none previously existed.

Tamarisk (*Tamarix spp.*), a Eurasian tree introduced by western settlers in the 1800s, has contributed to major hydrological alterations in the desert southwest by guzzling water from deep within the ground.

Although the most successful invasive plant species are few in number, they are enormous in impact. Invasions can spread over wide areas and engulf a range of habitats. The most insidious effect of plant invasion may be biogeographic breakdown—a process by which landscapes are becoming increasingly homogenized, losing their biological distinctiveness and their deep legacy of evolutionary and geographic separation. The introduction of alien invasive plants is not a service, as Jefferson would have us believe, but an outrage, leading to a biological world that is simpler—and poorer. ❧

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RESOURCES

The National Association of Exotic Pest Plant Councils (8208 Dabney Avenue, Springfield, VA 22152) is an umbrella organization that oversees a handful of nonprofit organizations operating in Florida, Tennessee, California, and the Pacific Northwest that are dedicated to building public awareness about the invasive plant problem and developing support for the control and management of exotic plants.

The Animal and Plant Health Inspection Service (US Department of Agriculture,12th and Independence Avenue, SW, Washington, DC 20250; http://aphisweb.aphis.usda.gov/) is charged with preventing the importation of noxious weeds and designated foreign pests into the United States.

Seventeen federal land management agencies have pledged to coordinate the government's approach to managing exotic weeds on federal lands via the **Federal Interagency Committee for the Management of Noxious and Exotic Weeds** (1849 C Street, NW, Washington, DC 20240; http://refuges.fws.gov/FICMNEWFiles/FICMNEWHomePage.html).

A partnership of federal agencies and other public and private organizations, the **Native Plant Conservation Initiative's Exotic Plant Working Group** (4598 MacArthur Boulevard, NW, Washington, DC 20007; http://www.aqd.nps.gov/npci/epwg/) works to promote awareness of invasive exotic plant management issues.

The Nature Conservancy's Wildland Weeds Management and Research Program (Weed Sciences Program, Robbins Hall, University of California, Davis, CA 95616; http://tncweeds.ucdavis.edu/) promotes the sound management of pest plants on Nature Conservancy-managed lands and other lands with significant biological diversity.

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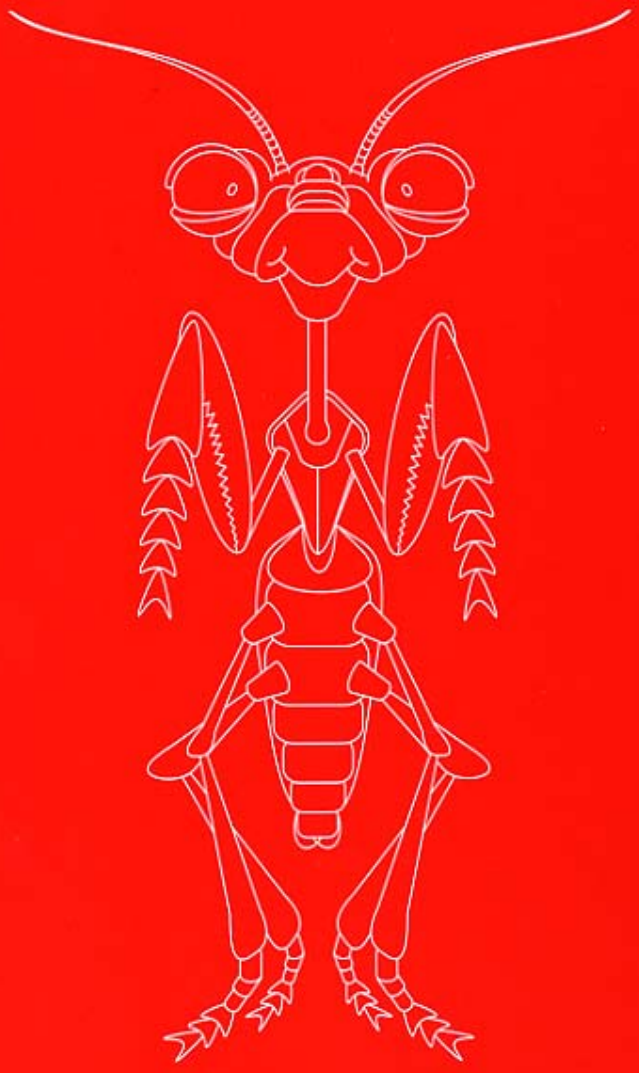

"Of Weevils, Thistles and Biological Control"
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"Pests Have Enemies, Too"
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