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CLASSICAL BIOLOGICAL CONTROL OF ENVIRONMENTAL PESTS

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ABSTRACT

Exotic species commonly invade areas of conservation concern. Such species may threaten native species or ecosystems, either attacking individual species, or changing ecosystem characteristics in ways that make them less suitable for the continued existence of one or more native species. Among the potential effects of exotic species are crowding, changes in water table levels, fire frequency or intensity, altered soil fertility or chemistry, and altered levels of predation or disease. Chemical, mechanical and biological methods each may be used to control exotic species in some cases. Chemical and mechanical methods are difficult to apply to large areas and must be repeated periodically to prevent pest resurgence. Classical biological control often has high initial costs but is permanent in nature and self propagating, such that large areas can be treated economically. Risks of biological control are minimal if agents are appropriately screened to determine host range prior to introduction and if introductions are conducted using appropriate quarantine procedures. Biological control is a useful approach for control of a variety of kinds of environmental pests that threaten the conservation of native species and ecosystems, including exotic plants, herbivorous and predacious arthropods, other invertebrates, and in some instance vertebrates.

Key Words: Biocontrol, nature conservation, exotic species.

RESUMEN

Especies exóticas frequentemente invaden las áreas de interés de conservación. Tales especies pueden amenazar o los ecosistemas o las especies nativas, o atacar especies particulares o cambiar caracteristicas del ecosistema en maneras que lo hacen menos apropiado para la existencia continuada de una o más especies nativas. Entre los efectos potenciales de las especies exóticas se incluyen densidad desfavorable de organismos, cambios en el nivel hidrostático o en la intensidad o la frequencia de fuegos, química o fertilidad alterada del suelo, y niveles alterados de predación o enfermedades. Métodos químicos, mecánicos o biológicos se pueden usar para controlar especies exóticas en unos casos. Métodos químicos y mecánicos son dificiles aplicar a areas grandes y tienen que repetirse periodicamente para prevenir resurgimiento de la plaga. El control biológico clásico frequentemente tiene costos iniciales altos, pero es de un caracter permanente y se propaga por si mismo, por eso, su pueden tratar economicamente a áreas grandes. Los riesgos de control biológico son mínimos si sé examinan los agentes adecuadamente para determinar el rango de organismos hospederos antes de introducirlos, y si se conducen las introducciones usando metodos apropiados de cuarentena. El control biológico es un enfoque útil para controlar una variedad de plagas ambientales que amenazan la conservación de especies y ecosistemas nativos, incluyendo plantas exóticas, artrópodos herbívoros y predadores, otros animales invertebratos, y animales vertebrados.

Biological reserves and other undeveloped lands and water of conservation importance are regularly invaded by exotic plant and animal species. Such invasions reflect the level of human activity in a region because many invasions are assisted by the movement of people and commercial trade in plants and other products. Aggressive exotic species may threaten native flora or fauna by competition or direct attack. In other cases, exotic species may alter basic properties of the ecosystems they invade, rendering them less suitable for the continued existence of broad sets of native species. Efforts to combat such invading species by chemical or mechanical means are often unsatisfactory, the former because of the risk of chemical pollution and cost, and the latter because of cost and the difficulty of applying mechanical remedies to any large undeveloped region. Additionally, neither chemical nor mechanical control provides a permanent solution and areas must be re-treated periodically to prevent pest resurgence. Biological control, through the introduction of natural enemies specialized to attack the undesired exotic species, offers a method to control some exotic pests, over wide areas, permanently. In this article, I discuss the kinds of impacts exotic species can have on native species and ecosystems and define the potential that classical biological control has to address this important conservation issue.

IMPACT OF EXOTIC SPECIES

Exotic species become environmental pests when they attack and threaten the continued existence of particular native species or alter ecosystems on a broadscale in ways that they threaten the continued existence of whole biological communities.

Single Species

Exotic species affect individual native species either because they are pre-adapted to attack them or they simply heighten the competition for resources in ways that are damaging to native species. Rare species, which by virtue of their precarious small populations or limited distributions, may not be resilient to additional competition or mortality. The Bermuda "cedar" (*Juniperus bermudiana* L.), for example, once widespread on Bermuda, has been nearly eliminated following the invasion of the island by two exotic scales, *Carulaspis minima* (Targ.) and *Insulaspis pallida* (Maskell) (Cock 1985) (Figs. 1,2). Similarly, the introduction of the European starling, *Sturnus vulgaris* L., to North America caused a serious decline in the eastern bluebird, *Sialia sialis* (L.), through competition for nesting cavities. Also, the arrival of the exotic pathogen *Cryphonectria parasitica* (Murr.) Barr which caused a blight of the American chestnut, *Castanea dentata* (Marsh.), all but eliminated this tree, which once dominated forests throughout much of eastern North America. In Florida, native bromeliads are currently threatened by the arrival in Florida (via importation of bromeliads from Central America or Mexico) of weevils in the genus *Metamasius* (Frank, in press) (Figs. 3,4).

Communities

In many cases, exotic species do not directly attack native forms but, rather, outcompete or dispossess them for space and resources by various broad effects that alter the ecosystem or preempt their living space (Vitousek 1986). Among these effects are: (1) crowding and smothering, (2) changes in water tables, (3) altered fire frequency or intensity, (4) changes in soil fertility or chemistry, and (5) enhanced predation or disease.

Crowding. One of the more common effects of introduced environmental plant pests is the formation of dense stands of single species that cover a high percentage of the available habitat. The floating fern *Salvinia molesta* D. S. Mitchell, for example, was spread as an aquarium plant by Europeans to the Old World tropics (from a homeland in southern Brazil). The mats of this plant have covered hundreds of square kilometers

Fig. 1. Bermuda cedar (*Juniperus bermudiana* L.) stands damaged by exotic scales (photo by F. D. Bennett).

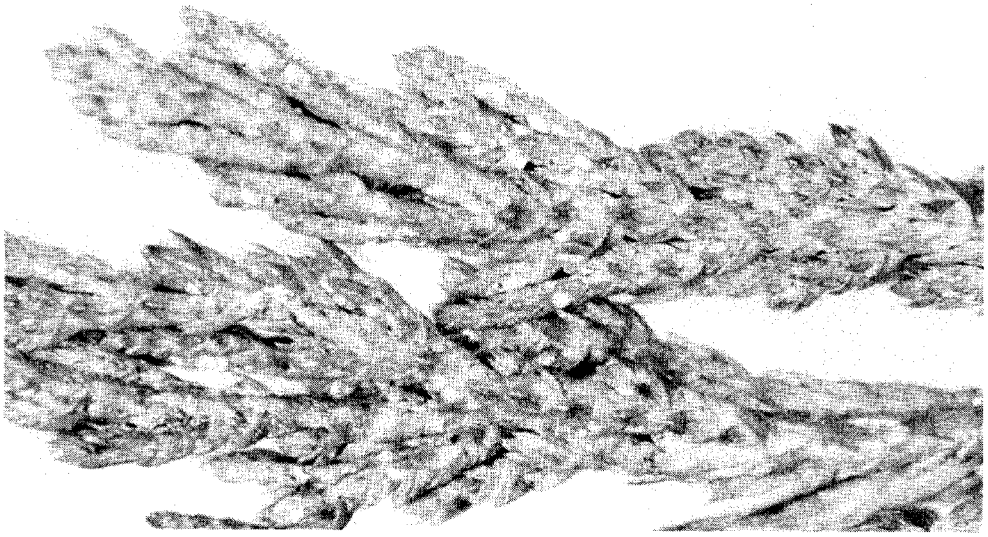

Fig. 2. *Carulaspis minima*, one of two exotic scales attacking Bermuda cedar (photo courtesy of Division of Plant Industry, Florida Dept. of Agriculture & Consumer Services).

Fig. 3. Bromeliad in Florida damaged by immigrant weevil, *Metamasius callizona* (Chevrolat) (photo by J. L. Castner).

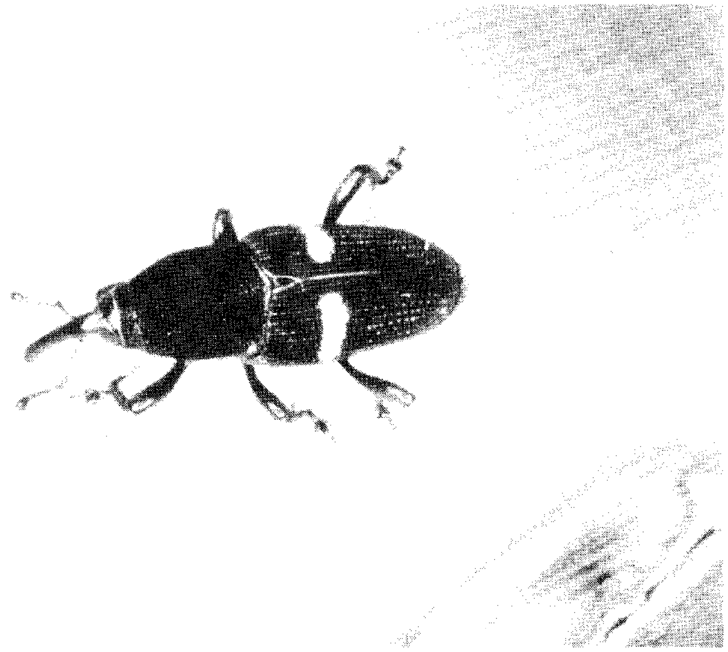

Fig. 4. *Metamasius callizona*, an immigrant weevil damaging native bromeliads in Florida (photo by J. L. Castner).

of rivers and lakes with a continuous layer up to a meter thick in spots (Mitchell et al. 1980). Herbivorous arthropods were sought in the native range of the plant and their subsequent importation caused dramatic reductions in weed densities in India, Papua New Guinea and Namibia (Figs. 5, 6) (Thomas & Room 1986, Forno 1987). Reduction of floating fern densities has allowed environmental conditions to revert to ones favorable for the pre-existing, largely native, vegetation in many areas. In the northeastern U.S., wetland ecosystems have been significantly altered in many states by an invasion of the garden flower purple loosestrife (*Lythrum salicariae* L.) (Fig. 6). This plant displaces the native vegetation in such habitats as cattail (*Typha* spp.) marshes, to the detriment of muskrats, ducks and native plants (Thompson et al. 1987). In Hawaii, interest is strong in maintaining the integrity of the native forest habitats upon which much of the endemic bird fauna depends. Introduced plants, such as the banana poka [*Passiflora mollissima* (Humbolt, Bonpland & Kunth)], are currently degrading the quality of the forest. Banana poka aggressively envelopes native trees in bags of foliage, leading to tree death (Fig. 7, LaRosa 1992). Biological control projects are currently under way against both purple loosestrife and banana poka, but are in their early stages and have not yet controlled the pest. In both cases, funding for the projects has been obtained specifically because of the environmental benefits of the projects, rather than for economic reasons.

Altered Water Tables or Fire Characteristics. In addition to physically taking possession of space, exotic species, especially plants, may alter the physical character of the habitat. Among these alterations are changes in the depth of the water table and the propensity toward fire. Salt-cedars (*Tamarix* spp.), for example, have invaded the riparian areas in the southwestern United States from their original home in Asia (Fig. 8). Because the plant is deeply rooted and does not restrict its evapotranspiration rate, it draws heavily on soil water reserves causing the water table to fall (Vitousek 1986). This

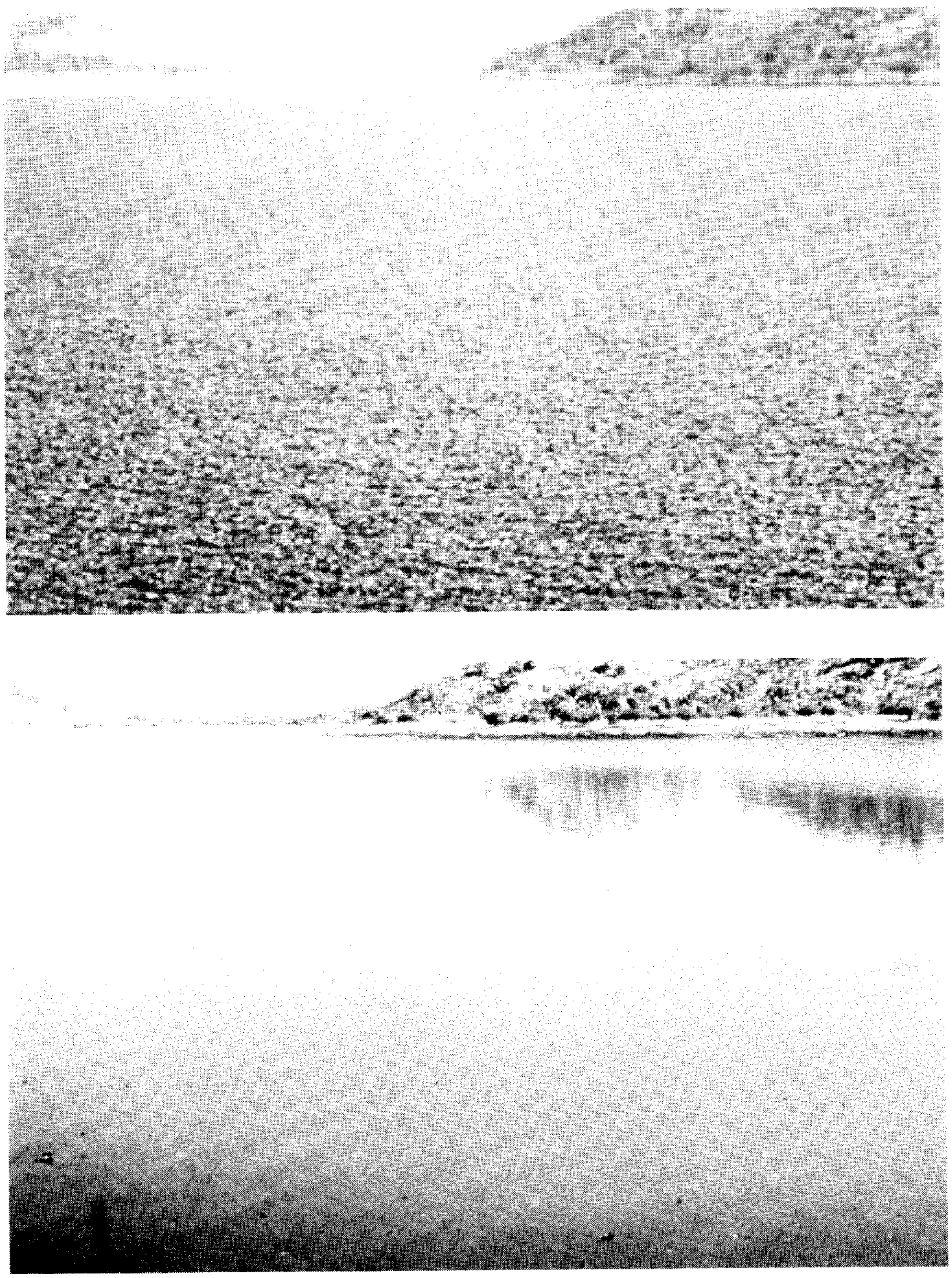

Fig. 5. Mat of the floating fern *Salvinia molesta* (a) before and (b) after biological control by the weevil *Cyrtobagous salviniae* (photo courtesy of CSIRO, Australia).

significantly affects shallow-rooted native riparian species that otherwise flourish in seeps and wet meadows. In areas with heavy concentrations of *Tamarix*, these native riparian communities have largely disappeared. In addition, *Tamarix* is more prone to fire than the native vegetation, and its dominance in an area increases the effects of fire. In South Africa, invasion of native fynbos habitat by the woody shrub *Hakea sericea*

Fig. 6. Stand of purple loosestrife, *Lythrum salicariae*, invading North American temperate wetlands (photo by Richard Malecki).

Schrader has caused a 60% increase in fuel loading at study sites (Versfeld & van Wilgen 1986), increasing fire intensity and perhaps frequency.

Altered Soil Fertility or Chemistry. Soil fertility, salinity and other chemical characteristics are important factors in determining a site's suitability as habitat for plants.

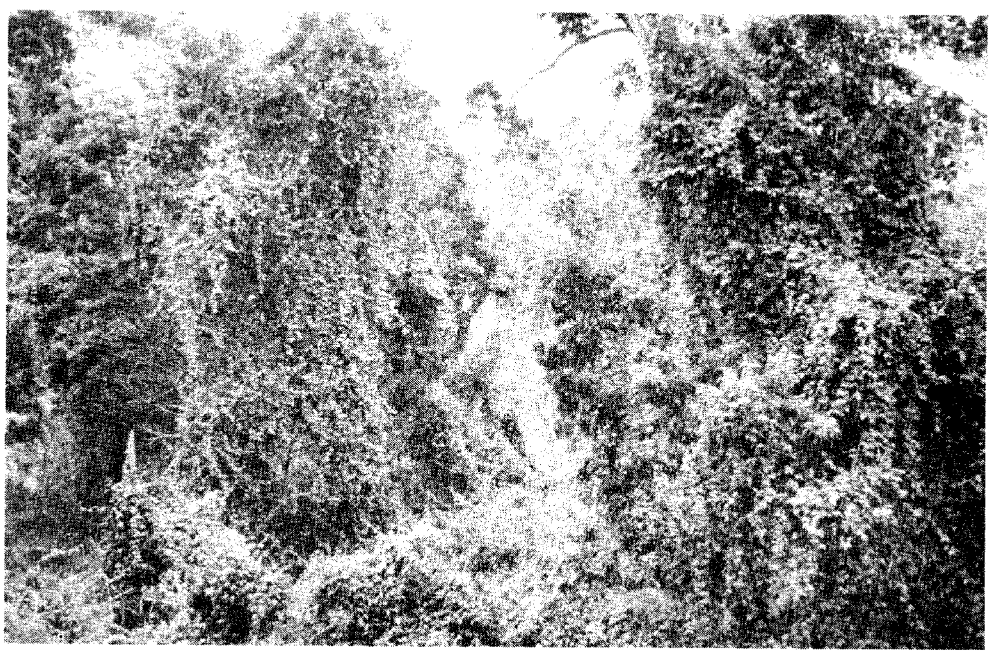

Fig. 7. The exotic vine banana poka (*Passiflora mollissima*) smothering native forests in Hawaii (photo by Clinton Campbell).

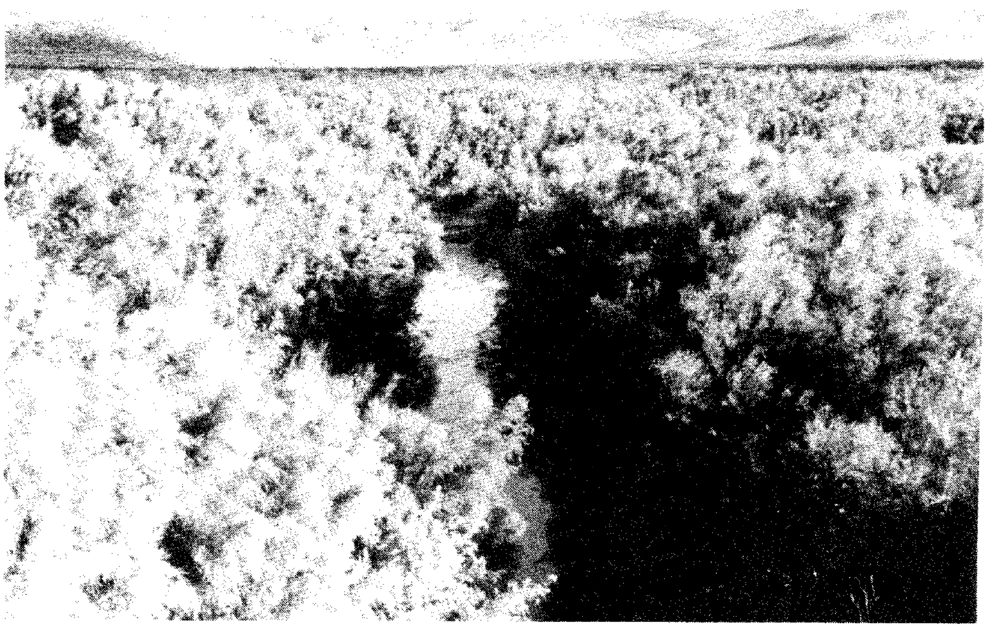

Fig. 8. Stands of salt-cedar (*Tamarix* sp.) in riparian areas in the southwestern United States (photo by Jack DeLoach).

If these are altered by an invading plant species, some former occupants of the site may disappear. For example, rare native plants in the nutrient poor soils of the volcanic caldera of Hawaii depend on their ability to survive under such harsh conditions in order to mediate competition with more aggressive plants which require higher fertility levels. The exotic plant *Myrica faya* Ait. is a nitrogen-fixing species that has invaded this habitat and is raising soil nitrogen levels, with the likely outcome that the native species will lose their competitive advantage.

Annual iceplant, *Mesembryanthemum crystallinum* L., which was introduced to California for use as an ornamental, invades grasslands in various coastal areas in California, for example, Santa Barbara Island. The plant accumulates salt which is released upon death of the plant. Important native species in these dune communities are less salt tolerant than annual iceplant, which benefits from the altered soil chemistry allowing it to invade and hold its ground in competition with native species (Vivrette & Muller 1977, Kloot 1983). Exotic species that produce high concentrations of allelopathic chemicals in their root zones also may alter soil chemistry in ways that suppress native plants.

Altered Levels of Predation or Disease. Predacious (or parasitic) species that exhibit high densities and broad host ranges can have important indirect impacts on the densities and species evenness of herbivores or other organisms in the communities which they invade. Adding a dominant predator to a system formerly without one, or removing one from a system shaped by the presence of such a predator, can lead to major changes in competitors and lower trophic level organisms. Invasions of fynbos communities in South Africa, for example, by the Argentine ant, *Iridomyrmex humilis* (Mayr), displaced most of the indigenous ant fauna (Breytenbach 1986). Similarly, introduction of new species of predacious fish, such as the Nile perch (*Lates* sp.) in Lake Victoria, has had vast impact on fish communities, causing extinctions of many species and making many other once common species rare (Goldschmidt et al. 1993). Similarly, diseases can shape communities. Introduction of avian malaria, for example, is believed to be a significant factor in the narrowing of the distributions of native birds in Hawaii (van Riper et al. 1986).

METHODS FOR THE CONTROL OF EXOTIC SPECIES

Depending on the physical extent of the area affected by an exotic species, mechanical, chemical or biological controls may be employed successfully. When areas infested are small, it may be feasible to destroy the colonizing organisms mechanically or chemically (especially larger plants of species that have limited seed production) (e.g., Santos et al. 1992). Such controls are likely to require periodic repetition, increasing their cost and limiting the size of area which may be cleared of an exotic organism. When large areas are infested, extensive seed banks exist, or the organism is too small or hidden from attack by mechanical or chemical methods, biological control should be considered.

Biological control is limited in its environmental pest applications because developmental costs for new projects, especially against plants, are large and most expenses occur at the beginning of the project during exploration for, and host specificity testing of, new agents (Markin et al. 1992). Harris (1979), for example, estimates that in Canada a complete biological control program for one weed species could cost as much as 1.5 million Canadian dollars. These costs, however, are very low compared to those for developing new pesticides, or long term herbicide weed suppression projects. Also, when a biocontrol agent of a given weed has been employed successfully in one location, its use in similar projects in other countries or locations can be repeated at a much lower cost.

Another important feature of biological control is that the release of biological control agents is a permanent change. It is difficult, if not impossible, to "take back" a released organism once it has been liberated. Sufficient pre-release screening must, therefore, be done to ensure that only suitable organisms are approved for release. Given these constraints, biological control has great application for the control of widespread environmental pests because the natural enemies once released, if effective, remain effective permanently at no further annual cost. Because natural enemies do not need to be released repeatedly, and because they are able to spread to additional areas, the method can be applied even when infested areas are large (thousands to millions of hectares).

Risks from release of properly screened biological control agents are minimal, but each case must be carefully considered because actions that may be safe in one habitat may be undesirable in another (Harris 1990, Gould 1991, Howarth 1991). Rigorous efforts should be made to identify local biological resources of special significance so that these rare, local or unusual life forms are not threatened. Different types of natural enemies vary in the degree of risk that they may pose, and some groups, such as vertebrates, are generally unsuitable for introduction beyond their historical ranges without compelling circumstances (Legner 1986). While some environmental risks may remain in any natural enemy introduction program, even following careful host-range testing, these small, often conjectural, risks must be balanced against the risk of doing nothing. In many cases, uncontrolled populations of environmental pests have had, and continue to have, important impact on native species and ecosystems, including a threat to endangered forms that might contribute to their extinction.

EXAMPLES OF BIOLOGICAL CONTROL OF ENVIRONMENTAL PESTS

Biological control efforts have either been made, are in progress, or have future potential, for many kinds of environmental pests. In the following section I present some examples of biological control of environmental pests. These have been selected from a wide range of organisms in order to demonstrate the scope of biological control.

Aquatic Plants

Several species of tropical or subtropical plants growing in freshwater habitats have invaded other parts of the world. Often they are being spread as ornamental plants for use in ponds or aquaria. One of these is *Salvinia molesta*, a major pest in Africa, India, Papua, New Guinea and Australia. It has recently been controlled successfully, and impressively, with *Cyrtobagous salviniae* Calder & Sands (Forno 1987). Water hyacinth, *Eichhornia crassipes* [Martius (Solms-Laubach)] is another aquatic plant that has created problems around the world following its deliberate spread (for ornamental purposes) from its native Brazil (Gopal 1987). Mats of this plant may be so thick that in addition to economic damage to dams, navigation and fisheries, native fauna and flora are severely affected by reduced levels of dissolved oxygen and increased eutrophication (Harley 1990). Many biological control agents have been assessed for water hyacynth control. The weevils *Neochetina bruchi* Hustache and *Neochetina eichhorniae* Warner and the moth *Sameodes albiguttalis* Warner have been found to be the most effective (Harley 1990). Other important aquatic weeds which have been controlled through biological control, or which have high potential to be controlled, include alligator weed, *Alternanthera philoxeroides* (Martius) Grisebach; water lettuce, *Pistia stratiotes* L.; and Eurasian watermilfoil, *Myriophyllum spicatum* L. (Harley et al. 1990, Madsen et al. 1991).

Terrestrial plants

More than 87 species of terrestrial plants have been targets for biological control (Julien 1992). Most of these were selected because of the damage they caused to grazing and forest lands. However, many of these plants invaded extensive areas of natural habitat and, through the formation of dense, highly competitive weed stands, reduced the value of the habitat for native species, for example, klamath weed (*Hypericum perforatum* L.) in California and prickly pear cactus (*Opuntia stricta* Haworth) in Australia (DeBach et al. 1976).

In other instances, projects have been undertaken specifically for conservation purposes, as for example the control of weeds in the native forests of Hawaii (Markin 1982, Markin et al. 1992). Important terrestrial weeds of environmental concern against which biological control is being attempted or has potential are: banana poka (*Passiflora mollissima*), a forest weed in Hawaii (Waage et al. 1981); giant sensitive plant (*Mimosa pigra* L.), a woody shrub rapidly forming vast monospecific stands in northern Australia (Braithwaite et al. 1989); gorse (*Ulex europaeus* L.) in New Zealand; kudzu [*Pueraria lobata* (Willd.)] in the southeastern United States; and *Sesbania punicea* (Cav.) Benth. in South Africa (Hoffmann & Moran 1991).

Herbivorous Arthropods

Herbivorous arthropods are the most common organisms against which biological control has been employed (e.g., Laing & Hamai 1976, Clausen 1978). Relatively few of these projects, however, have been directed against pests attacking native plants that are not themselves economically valuable as crops, timber or forage. Exceptions include efforts to control scales damaging to the Bermuda cedar (Cock 1985), and weevils attacking native Floridian bromeliads (Frank, in press). Insect damage to native plants is not lacking, but rather, until recently, such ecological damage has not created sufficient public concern to generate funding of control projects.

Predacious or Parasitic Arthropods

Some species of predacious, social Hymenoptera such as the Argentine ant, *Iridomyrmex humilis*, several fire ants (*Solenopsis* spp.) and vespids [e.g., *Vespula pensylvanica* (Saussure)] have invaded various parts of the world. Because of their aggressive, generalist feeding habits and high numbers per ha, they often exert significant impacts on native invertebrates (e.g., Gagne & Howarth 1982, Gambino et al. 1990, Beggs & Wilson 1991). For such species, in forests or conservation lands, biological control holds some potential. Few past efforts, however, have been made against this class of pests.

Non-Arthropod Invertebrates

Relatively little use has been made of biological control for non-arthropod invertebrates, with the exception of molluscs that are herbivorous crop pests, or aquatic species that are intermediate hosts of liver flukes that attack man or domestic animals. No projects against this class of organism have been attempted solely for conservation purposes. Serious environmental pests do exist in this category, however. The zebra mussel, *Dreissena polymorpha* Pallas, has recently invaded North American fresh waters and is spreading rapidly (Ram et al. 1992). While this species is of great economic concern because of its ability to clog water intake pipes, it also is likely to cause significant environmental damage. Densities of this species are extraordinarily high and its presence is likely to place at risk much of the rich North America fresh water clam fauna once the major river systems of the continent are colonized.

Vertebrates

Options for the biological control of vertebrates are limited because their natural enemies are less specific and comprised of fewer species than those of arthropods and plants. Vertebrates that prey on other vertebrates are generally inappropriate for introduction outside of their historical range as the specificity of this group of agents is not usually sufficient to ensure safety to other species. Pathogens may be one group of organisms that may be sufficiently specific for such use. Myxoma virus has been used in several countries to reduce densities of the European rabbit [*Oryctolagus cuniculus* (L.)] (Ross & Tittensor 1986). Context can determine the degree of specificity needed. For example, the feline panleucopaenia virus has been used against feral house cats on Marion Island in South Africa to reduce numbers of seabirds killed by offspring of cats released by a lighthouse keeper (Rensburg et al. 1987). This project was feasible because the island was uninhabited and isolated from populated areas where domestic cats would be at risk. Dobson (1988) suggests that the damage from feral goats on oceanic islands - one of the worst environmental pests in the world - could be reduced by employing a highly specific venereal disease of goats caused by a protozoan in the genus *Trichomonas*. Again, this would be feasible only on islands lacking domestic goat populations.

Conclusion

Biological control, unlike mechanical or chemical control, offers a potential mechanism for controlling environmental pests which occupy large ranges in the country of invasion. While initially expensive, results are cost effective over the long term because control, if achieved, is permanent. Biological control has been employed with safety in the vast majority of cases. An adherence to quarantine and host-range testing procedures, a knowledge of locally rare or unique species that might be affected, and a thorough understanding of the biology of the agents to be introduced, should provide the means to ensure safe application of the method. It is broadly applicable to many types of environmental pests, but has been used so far mainly against plants. Other categories of organisms against which the method has potential application include arthropods, other types of invertebrates and, to a limited degree, vertebrates. Environmental pest creation is a function of the volume of human travel and commerce and should be expected to increase. It is well documented that not controlling such environmental pests puts native species and ecosystems at risk. Organized programs to identify and implement biological control projects against environmental pests are currently lacking with few exceptions. Such an approach is needed if the integrity of native ecosystems is to be protected around the world in the coming century.

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BIOLOGICAL CONTROL OF THE TWO-SPOTTED SPIDER MITE (ACARINA: TETRANYCHIDAE) ON COMMERCIAL STRAWBERRIES IN FLORIDA WITH *PHYTOSEIULUS PERSIMILIS* (ACARINA: PHYTOSEIIDAE)

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ABSTRACT

Biological control of *Tetranychus urticae* Koch in Florida's commercial strawberry fields is possible by use of the predacious mite *Phytoseiulus persimilis* Athias-Henriot. A low and stable population of both species is maintained after about 2 months. Immigration of local parasitoids and predators contributes stability. The cost is likely to be lower than that of chemical control, and strawberry yields are not reduced.

Key Words: Biocontrol, *Tetranychus urticae*, predacious mites.

RESUMEN

Control biológico de *Tetranychus urticae* Koch en campos comerciales de fresas en la Florida se logra con el uso del ácaro predador, *Phytoseiulus persimilis* Athias-Henriot.