

FINAL REPORT

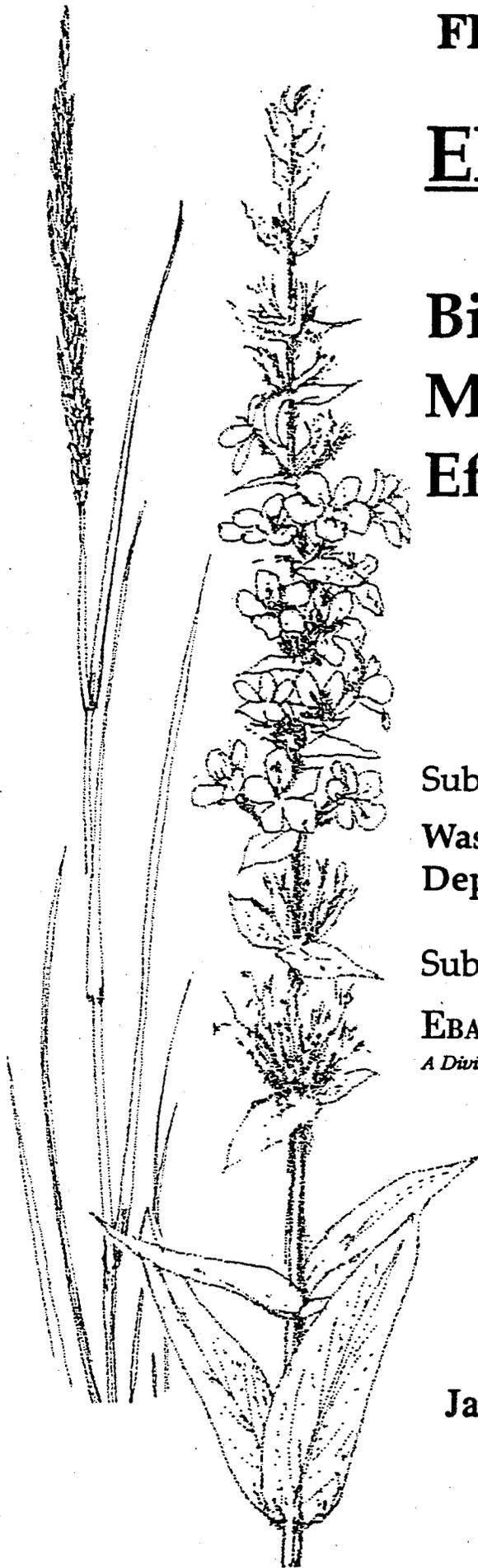
Element H

Biological Control Methods: Efficacy and Impacts

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FINAL REPORT

Element H: Biological Control Methods: Efficacy and Impacts

Submitted to:

Washington State Department of Ecology

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ABSTRACT

Infestations of several species of noxious emergent plant species in Washington are raising ecological and economic concerns. The Washington State Departments of Agriculture, Ecology, Fisheries, Natural Resources, and Wildlife, and the Washington State Noxious Weed Control Board have proposed to develop and implement a management plan for these species. One management alternative is to use biologically-based controls, such as pathogens, insects, livestock, genetic engineering, and competitive plant species, to limit the spread or aid in the eradication of noxious species. The potential efficacy and impacts of biological methods to manage infestations of noxious emergent plants in Washington are described in this report.

The planthopper, *Prokelisia marginata*, holds promise for large-scale control of seed production in *Spartina alterniflora*. Potential insect agents for control of *S. anglica* and *S. patens* have not been investigated. Several insect species have been released in Washington for control of *Lythrum salicaria*. Little information was found describing or evaluating potential biologically-based controls for the other noxious plant species of concern: *Lythrum virgatum*, *Lysimachia vulgaris*, *Heracleum mantegazzianum*, and *Amorpha fruticosa*.

1.0 INTRODUCTION

1.1 PURPOSE

The Washington State Departments of Agriculture, Ecology, Fisheries, Natural Resources, Wildlife, and the Washington State Noxious Weed Control Board, acting as co-lead agencies, have proposed to develop and implement a management plan for noxious emergent plant species occurring in Washington. Species of concern include three species of cordgrass or *Spartina* (*S. patens*, *S. alterniflora*, and *S. anglica*), purple loosestrife (*Lythrum salicaria*), wand loosestrife (*Lythrum virgatum*), garden loosestrife (*Lysimachia vulgaris*), giant hogweed (*Heracleum mantegazzianum*), and indigobush (*Amorpha fruticosa*). The lead agencies seek to determine which management alternative or combination of alternatives would provide the most effective management of noxious emergent plants with the least environmental impacts. The ultimate goal of this effort is to develop criteria and approaches for managing infestations of both new invader and established weed species.

The lead agencies have determined that management of these noxious emergent plant species could have probable significant adverse impacts on the environment. Thus, an environmental impact statement (EIS) is required under RCW (Revised Code of Washington) 43.21C.030(2)(c). The lead agencies, through a public scoping process, have identified topics to be discussed in the EIS, including biology and ecology of problem species, management alternatives, efficacy and impacts of alternatives, and mitigation strategies. Ebasco Environmental was contracted by the nominal lead agency, the Washington State Department of Ecology, to assemble and synthesize available information on the topics of interest for probable inclusion into the EIS. This report provides information on the use of biologically-based controls for managing infestations of noxious emergent weeds in Washington.

1.2 OBJECTIVES

The objectives of this report are to:

- (1) evaluate, based on available information, the efficacy of the use of biological controls to manage infestations of *Spartina alterniflora*, *S. patens*, *S. anglica*, *Lythrum salicaria*, *L. virgatum*, *Lysimachia vulgaris*, *Heracleum mantegazzianum*, and *Amorpha fruticosa* present in Washington; and
- (2) describe potential impacts of biological controls on natural, agricultural, and built environments and their associated human uses.

Information sources for this report included published journal articles, published and unpublished studies, and communications with knowledgeable individuals. Information was obtained from both national and international sources.

2.0 BIOLOGICAL CONTROL

Biotic interactions may affect the vigor, occurrence, or reproduction of plants. For example, naturally-occurring fungal infestations can prevent seed production in grasses and heavy grazing by waterfowl can reduce densities of wetland and aquatic plants. It may be possible to capitalize on such biotic interactions to manage infestations of noxious plant species in wetland environments.

The National Academy of Sciences research briefing panel broadly defines biological control "as the use of natural or modified organisms, genes, or gene products to reduce the effects of undesirable organisms, and to favor desirable organisms such as crops, trees, animals and beneficial insects, and microorganisms" (NAS 1987). Based on principles of population ecology, a realistic goal of a biological control program is to reduce noxious species abundance to an economically, aesthetically, or ecologically acceptable level within the control area, rather than eradicate the species from the control area (Goeden 1977, Schroeder 1983). Successful biocontrol of a dominant, undesirable plant species can cause increased community biodiversity (Harris 1986, 1988).

"Classical" or inoculative biological control involves the introduction of a biological agent, such as a predator, parasite, or pathogen to maintain another organism's population density at a lower average level than would occur in the absence of the biocontrol agent (DeBach 1964). The use of biological agents for noxious plant control is based upon two fundamental principles: natural enemies play major roles in regulating plant populations; and, some of these natural enemies have a limited host range. Excellent reviews of the procedures followed by practitioners of inoculative biological control are provided by Wilson (1964), Frick (1974), Andres et al. (1976), Schroeder (1983), and Harley and Forno (1992).

This report describes the efficacies and impacts of various biologically-based controls for managing infestations of introduced species of *Spartina*, purple loosestrife, and several other noxious emergent plant species occurring in Washington. The ability of naturally existing populations of organisms to control noxious species is evaluated in the report for Element C - No Action Alternative.

2.1 SPARTINA

Efficacies and impacts of various biological controls for managing infestations of noxious *Spartina* species in Washington are summarized in Table 1.

2.1.1 Microbial Pathogens

2.1.1.1 Efficacy

Several viruses and fungi have been identified that are naturally associated with *Spartina* populations outside and within Washington. Some do not appear useful as biological control

Table 1. Efficacies and major environmental impacts associated with the various biologically-based methods for controlling *Spartina*. Mitigation measures for impacts are discussed in text.

Ecological Control Method	Most Practical Applications	Use Constraints	Significant Environmental Impacts
Microbial pathogens (seed fungi)	Prevention or reduction of seed set	Specificity to <i>Spartina</i> species not investigated; 8-12 years may be necessary to complete testing and gain regulatory approvals	Possible effects on native species or agricultural grasses; fungal infestations may reduce palatability of <i>Spartina</i> to waterfowl, livestock, or other animals
Phytophagous insects (<i>Prokelisia marginata</i>)	Prevention or reduction of seed set	Specificity to noxious <i>Spartina</i> species not investigated; 8-12 years may be necessary to complete testing and gain regulatory approvals	Possible effects on native species or agricultural grasses; high arthropod densities may reduce plant palatability to livestock
Grazing (livestock)	Eradication of plants or reduction of plant vigor in small, monospecific areas	Animal acquisition and care, fencing, and associated human labor costs high; intensive grazing probably required to effect control	Soil compaction; inputs of nutrients, sediments, and fecal coliform bacteria to surrounding waters; impacts to non-target plants and animals possible
Genetic engineering	None	---	---
Plant competition and forced succession	Limitation of landward <i>Spartina</i> spread in small areas	Expensive	Conversion of low salt marsh areas to high salt marsh

agents. For example, the *Spartina* leaf mottle virus, which appears distantly related to the agropyron mosaic virus, does not appear to cause dieback of *S. x townsendii/anglica* in Britain, since it occurs in both healthy and dieback stands (Jones 1980). Similarly, Sivansen and Manners (1970) determined that fungi are probably relatively unimportant, even as secondary parasites, in contributing to dieback of *S. x townsendii/anglica* in Britain.

Other pathogens may hold potential for biological control of *Spartina*. The Ascomycete fungus, *Buergenerula spartinae*, occurs commonly on the leaves and stems of growing, senescing, and dead stages of *S. alterniflora* in the eastern United States (Gessner 1976). It appears to invade *S. alterniflora* initially as a weak parasite. Although the parasitic habit of *Buergenerula spartinae* likely impacts *S. alterniflora* plants in some way, its utility for large-scale biological control of *Spartina* is unknown.

Gessner (1978) identified 15 species of seed fungi associated with standing *S. alterniflora* plants in North Carolina. One of these species, *Claviceps purpurea*, has been shown to impact *S. anglica* seed production (Thompson 1991). *Claviceps purpurea*, the ergot fungus, causes a destructive disease of grasses by infecting their flower parts and replacing the grain with the sclerotia of the fungus (Bold *et al* 1980). Sclerotia are stony bodies consisted of tightly cemented fungal hyphae. These bodies are known as ergot. Ergot has also been observed growing on *S. alterniflora* in Willapa Bay and infestations may have lowered seed viability (pers. comm., J. Friebaum 1992). Thus, *C. purpurea* could be a suitable biological control agent to limit or prevent the spread of *Spartina* by seed.

Based on available information, seed fungi appear most promising as a microbial control for *Spartina*. However, the feasibility of large-scale control efforts involving *C. purpurea* or other fungi has not been researched (pers. comm., D. Strong 1992). Several factors need to be investigated to make this determination, including verification of microbe specificity to noxious *Spartina* species, and appropriate method(s), timing, frequency, and environmental conditions for fungal applications. These studies may take considerable time (years) and funds to complete and would be required as part of the permitting process to institute a biological control program utilizing pathogens (Klingman and Coulson 1983). This permitting process is fully described in Section 2.1.2 - Insects.

2.1.1.2 Environmental Impacts

The following discussion of impacts focuses on seed fungi because they appear most promising as a microbial control agent for *Spartina*.

Natural Environment

For this report, the natural environment includes those areas that have not been directly modified by residential, commercial, or public works developments, or agricultural or aquacultural activities. Wildlife refuges, nature preserves, natural areas, etc., established to preserve ecosystems are considered in this section. Impacts to agriculture and aquaculture

are detailed in a separate section. Other "open space" areas that are intensively managed for recreation or other human use, such as state, county, or city parks, are addressed in the Built Environment section.

Sediments/Soils

Use of seed fungi to limit seed production in *Spartina* infestations would have no foreseeable detrimental impacts on the sediment composition and dynamics of natural environments.

Water Quality and Movement

Impacts to water quality from release of seed fungi have not been investigated. No significant impacts are expected to water movement in natural environments.

Susceptibility of Non-Target Biota

A requirement of the release of any pathogen would be demonstrated specificity to the exotic species of *Spartina* occurring in Washington. The fungus, *Claviceps purpurea*, has been shown to infect both *S. alterniflora* and *S. anglica*. Thus, its specificity appears to be at the genus rather than species level. The native *Spartina* species occurring in Washington, *S. gracilis* and *S. pectinata* (which occur in eastern Washington), may also be susceptible to *C. purpurea* and could be incidentally impacted by its release. In addition, *C. purpurea* also infects rye, wheat, barley, oats, and many other grasses. Thus any strain of *C. purpurea* introduced should not infect cereal grains (i.e., should be specific to *Spartina*).

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

A biological control program involving seed fungi would not significantly impact habitat for wildlife, fish, and benthic organisms. Infestations of some seed fungi may reduce the palatability of *Spartina* plants to waterfowl or other herbivores or be injurious to animal health.

Aesthetics, Recreation, and Cultural Resources

Large infestations of pathogenic microorganisms in a *Spartina* stand could be perceived as visually unappealing because of their impact on normal plant growth and development. Recreation and cultural resources would not be negatively impacted by the use of microbes.

Human Health

The alkaloids in ergot sclerotia are deadly to humans, who can contract a disease known as St. Anthony's Fire if they ingest the sclerotia (Bold *et al.* 1980).

Agricultural/Aquacultural Environment

Impacts of introducing seed fungi on the sediments/soils and water quality and movement of agricultural/aquacultural environments are similar to those in natural environments.

Agricultural/Aquacultural Species and Practices

Infestations of seed fungi may reduce the palatability of *Spartina* plants to livestock. The alkaloids present in ergot, *C. purpurea*, cause abortion in cows and gangrene of the hooves and tails in cattle (Bold *et al.* 1980). In addition, it is possible that seed or other types of fungi could impact some pasture grasses or other agricultural crops. Thus, specificity of the fungi to *Spartina* should be verified before introductions occur.

Built Environment

Impacts to built environments from the use of seed fungi to control seed production in *Spartina* are the same as those occurring in natural environments.

Maintenance Practices

Microbial control agents would not affect maintenance practices in parks, residences, or other managed landscapes.

Cumulative and Synergistic Effects

Positive cumulative effects would occur from the control of seed production in *Spartina* because establishment of new infestations would be limited or prevented. Limitation of seed set from fungal infections may impact the survivability of insects introduced for biological control purposes that feed upon the seeds of *Spartina*. In areas where livestock grazing may be applied to control *Spartina* spread, infestations of seed fungi may reduce plant palatability.

2.1.1.3 Mitigation

Studies are necessary to better determine the feasibility of seed fungi as biological control agents for *Spartina*. In particular, specificity to noxious *Spartina* species and effects of fungal releases on human health should be investigated.

2.1.2 Insects

Phytophagous insects have been used to suppress noxious plant species. Introduced plants have been the targets of most biological control projects using insects (Julien 1992). Insect bioagent use is restricted to situations where control or containment of noxious species is the desired objective; their use is not consistent with eradication efforts.

To entomologically control a noxious plant species, destructive natural enemies must be procured in the plant's native home and thoroughly tested to ensure that they damage only the noxious species and not any aesthetically, ecologically or economically important plants. Once judged safe by federal and state regulatory agencies, they are liberated against the plant in the invaded area. Oscillations in the populations of noxious species and their insect controls will occur over time in response to environmental conditions and the normal interactions between the host plant and its control agents. Ideally, the released bioagents build up large populations in time and bring the naturalized noxious plant species under control.

2.1.2.1 Efficacy

Phytophagous insects have been suggested as potential biological control agents for noxious *Spartina* species. Herbivorous insects have been shown to impact growth and seed production in eastern populations of *S. alterniflora* and *S. patens*. None of these insect species are present in Washington.

Five species of stem borers have been identified that are associated with *S. alterniflora* in the eastern United States: *Calamomyia alterniflorae*, *Mordellistena splendens*, *Languria taedata*, *Chilo plejadellus*, and *Thrypticus violaceus* (Strong 1990). The first three kill the developing seed head of the plant and the last two attack young shoots. Three species of sap-sucking leaf feeders have also been identified: *Hydrellia valida*, *Orchelimum fidicinium*, and *Prokelisia marginata*. Very high densities of the planthopper, *P. marginata*, can kill *S. alterniflora* plants. *Prokelisia marginata* also consumes flowers of *S. alterniflora*. The grasshopper, *Conocephalus spartinae*, feeds on flowers and seeds of both *S. alterniflora* and *S. patens* (Bertness *et al.* 1987). Several additional species of sap-feeders have also been found associated with eastern *S. patens* populations (Denno 1980). Two other species of grasshoppers and one species of leafhopper have also been found to feed on *S. anglica* in Britain (Payne 1972). The utility of these species to control *S. anglica* has not been investigated.

Prokelisia marginata, or a subspecies, is also associated with *S. foliosa* and *S. alterniflora* in California (pers. comm., D. Strong 1992). *Prokelisia marginata* occurs at low densities on *S. foliosa* within the plant's native range from Bodega Bay to Baja California. However, high densities of *P. marginata* were observed on the flowers of *S. alterniflora* in San Francisco Bay in 1991 and 1992. The insects may have reduced seed production in the bay in 1991 since few seedlings of *S. alterniflora* were found in 1992. Dr. Strong speculates that *P. marginata* is indigenous to California because it occurs with *S. foliosa* in areas where *S. alterniflora* has not been introduced.

Dr. Strong also suggests that the California *P. marginata* would be an excellent biological control candidate to limit the spread of *S. alterniflora* in Washington because it appears to reduce or prevent seed production. However, tests would need to be performed to determine threats to any native plant species and the insect density required to effect control.

Additionally, the susceptibility of *S. patens* and *S. anglica* to *P. marginata* or other species has not been examined.

Permitting

Procedures developed by scientists of the United States Department of Agriculture's (USDA) Agricultural Research Service (ARS) govern the introduction into the United States of biological control agents for noxious plant species. These procedures specifically address requirements for introducing bioagents non-native to the United States, but are also applicable to those microbial or insect agents native to the eastern United States or California being considered for introduction in Washington populations of *Spartina* (pers. comm., G. Piper 1992). The USDA would be the federal agency responsible for approving release of microbial or insect agents in Washington for *Spartina* control.

The process of introducing a microbial or insect biological control agent can be divided into four phases (Cofrancesco 1992). The first phase involves identification of potential biocontrol agents for noxious species. The second phase consists of the completion of preliminary studies evaluating the general specificity of the potential agents. Biological control agents being considered for import into the United States must be initially studied and undergo preliminary host-specificity screening at overseas laboratories. If preliminary studies indicate that an agent is "generally specific", a petition is made to the USDA Animal and Plant Health Inspection Service (APHIS) Technical Advisory Group (TAG) on the Introduction of Biological Control Agents of Weeds to have the agent introduced into a domestic quarantine facility. The TAG, which is composed of thirteen members from federal, state, and private agencies, reviews petitions for content, validity of experimental studies, and potential conflicts of interest. During the third phase, extensive host-specificity tests are conducted on the agent while in quarantine, under USDA permit, and the results of the studies are subsequently reviewed by the TAG (Lima 1990, Coulson 1992). Similar reviews are also conducted, as appropriate, by advisory groups in Canada and Mexico. Advisory groups reviews are then submitted to the Plant Protection and Quarantine (PPQ) division of the APHIS. If the APHIS-PPQ determines the proposed introduction will not adversely impact economically or ecologically important plants (including native flora that may be impacted by bioagent introduction) and animals, including threatened and endangered species, and approvals from the appropriate state regulatory agencies (e.g., Washington State Department of Agriculture and others) are obtained, a permit ["Application and Permit to Move Live Plant Pests and Noxious Weeds" (PPQ Form 526)] for the release of the agent can be issued following preparation of an Environmental Assessment (EA) to meet requirements set forth in the U.S. National Environmental Policy Act (NEPA). Once the release permit is received, the fourth phase is initiated and the biological control agent can be released. No permits are required for the intrastate redistribution of an approved biological control organism (pers. comm. G. Piper 1992).

The time to complete the four phases varies. A survey of biological control projects in the United States involving insects found that, in general, 8-12 years elapsed between the

initiation of the biocontrol project and release of agents into the field (Cofrancesco 1992). If an agent shows potential for control, two to four years of testing may be required to complete specificity tests in quarantine. One to two years may be necessary to complete the permitting process once a petition is submitted for release of an agent.

2.1.2.2 Environmental Impacts

Natural Environment

Sediments/Soils

The introduction of insect biological controls would not adversely impact sediments or soils in natural environments.

Water Quality and Movement

No detrimental impacts to water quality and movement in natural environments would occur from the release of insect bioagents.

Susceptibility of Non-Target Biota

Any insect agent released in Washington for *Spartina* control should be specific to cordgrass species non-native to the state. The planthopper, *Prokelisia marginata*, has been found associated with populations of *S. alterniflora* and *S. foliosa* in California. Specificity tests should be performed to determine whether the native *Spartina* species occurring in Washington, *S. gracilis* and *S. pectinata*, or other desirable plants could be susceptible to *P. marginata*.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

A biological control program for *Spartina* involving insects would not negatively impact habitat for wildlife, fish, benthic, or other organisms as long as insects were specific for *Spartina* and as long as no wildlife, fish, or invertebrate species have come to depend on *Spartina*.

Aesthetics, Recreation, and Cultural Resources

The control of *Spartina* infestations could be viewed positively or negatively, from an aesthetic point of view. The use of insect agents would not detrimentally impact recreation and cultural resources.

Human Health

No studies have been done evaluating the risks to human health of utilizing insects for *Spartina* control.

Agricultural/Aquacultural Environment

Based on available information, the use of insect agents to control *Spartina* would not adversely impact the sediments/soils and water quality and movement in agricultural/aquacultural environments.

Agricultural/Aquacultural Species and Practices

Insect infestations may reduce the palatability of *Spartina* plants to livestock. In addition, the specificity of insect agents to *Spartina* should be verified before introductions occur to prevent detrimental impacts to pasture grasses or other agricultural crops.

Built Environment

Impacts to built environments from the use of insects to control *Spartina* would be the same as those occurring in natural environments. Maintenance practices in managed landscapes would not be impacted by insect agents.

Cumulative and Synergistic Effects

The spread of *Spartina* could be slowed or stopped in treatment areas with a successful insect biological control program. Limitation of seed set from introduced fungal bioagents may impact the survivability of seed-feeding insect bioagents. In areas where livestock grazing may be applied to control *Spartina* spread, high densities of insects may reduce plant palatability.

2.1.2.3 Mitigation

Studies are necessary to better determine the feasibility of utilizing *P. marginata* or other insects as biological control agents for *Spartina* species. In particular, insect specificity to noxious *Spartina* species and effects of their introduction on human health should be investigated.

2.1.3 Grazing

2.1.3.1 Efficacy

Grazing by domestic livestock or other animals has been suggested as a potential control technique for *Spartina*.

Heavy grazing by the snail, *Littorina littorea*, appears to significantly limit *S. alterniflora* distribution on rocky beaches of the Atlantic Coast from Nova Scotia to Long Island Sound (Bertness 1984). The snail, introduced from Europe in the 1840s, feeds on the shoots and rhizomes of *S. alterniflora*. *Littorina littorea* has become the dominant herbivorous snail in the littoral zone (the area between mean high water and shallow subtidal waters) of protected, rocky beaches within its range and does not appear to have an ecological analog in the native community. Both direct grazing and associated habitat modifications (e.g., sediment removal) from *L. littorea* herbivory influence *S. alterniflora* distribution.

Two native species of *Littorina*, *L. scutulata* and *L. sitkana*, occupy rocky beaches along Washington's Pacific Coast (Kozloff 1983). The introduction of *L. littorea* to Washington as a potential control for *Spartina* is not recommended because of possible impacts to native *Littorina* species or native vegetation.

Introducing other exotic wildlife species that graze on a variety of wetland and aquatic plants, such as additional introductions of nutria (*Myocastor coypus*), is not recommended because of potential negative impacts to desirable vegetation.

Grazing by domestic livestock has also been suggested as a control method for *Spartina*. *Spartina alterniflora* and *S. patens* marshes along the Atlantic and Gulf coasts are used as pasture for livestock. *Spartina patens* was also historically cut for hay in some areas. *Spartina anglica* marshes in Britain have been used extensively as sheep and cattle pasture (Ranwell 1967). *Spartina alterniflora* marshes in New Zealand have been managed as green feed for cattle (Franko 1985).

Grazing by livestock would potentially affect *Spartina* in several ways: direct grazing or trampling could impact the health and vigor of individual plants, and soil compaction from livestock trampling could prevent seed germination or vegetative propagation. Intensive grazing has been reported to kill *Spartina* in some areas (Aberle 1990). Seedlings and young shoots would be particularly vulnerable to grazing pressure. Grazing may also produce effects similar to those observed after cutting or mowing *Spartina*, specifically reduction or prevention of seed set. Trampling by livestock may kill individual plants or affect *Spartina* spread in an area. Ranwell (1967) found that *S. anglica* seedlings or rhizomes could not establish in areas near sheep-paths where soil had been trampled.

Intensive grazing may be effective in killing or severely impacting the vigor of *Spartina* over small, monospecific areas. However, grazing of livestock would probably not be feasible over large areas of salt marsh because of impacts associated with intensive grazing. In particular, substrate trampling and erosion, and additions of nutrients and fecal coliform bacteria to surrounding waters would be incompatible with shellfish aquaculture. Grazing in mixed salt marsh (*Spartina* and native species), however, may be beneficial to *Spartina*. Reimold *et al.* (1975) studied the effects of grazing on *S. alterniflora*-dominated salt marshes in Georgia. In an ungrazed marsh, *Salicornia virginica* predominated during some months of

the year. However, in a grazed and formerly grazed marsh, *S. alterniflora* was the dominant emergent plant during all months of the year.

Sayce (pers. comm., 1992) noted a suspected case of nitrogen toxicity involving *S. alterniflora* in Willapa Bay. Several cows owned by a local resident died after grazing on *S. alterniflora* which froze the night before. In some C₄ grasses, freezing temperatures convert naturally-occurring nitrogen compounds to toxic forms (pers. comm., K. Sayce 1992).

The use of livestock to manage *Spartina* in most situations would typically not be an inexpensive undertaking. Monies would be expended for animal acquisition, sheltering, supplemental feed, health care, transportation, and fencing. A considerable investment of labor would also be involved in treatment site stocking and destocking operations.

2.1.3.2 Environmental Impacts

This discussion focuses on impacts from livestock grazing.

Natural Environment

Sediments/Soils

Trampling by livestock would compact wetland soils. Sediments would also be transported on the hooves of livestock. Soil chemistry would be altered by fecal and urine deposition.

Water Quality and Movement

Grazing of salt marshes by livestock may result in the transport of sediments, nutrients, and fecal coliforms to surrounding waters. Surface water flow patterns could be altered by soil compaction.

Susceptibility of Non-Target Biota

Grazing would selectively affect *Spartina* if livestock were confined to monospecific stands. However, impacts to non-target plants would occur in mixed stands.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Some animals that feed, hide, or nest in salt marsh vegetation could be displaced as a consequence of the physical presence of livestock or through their grazing. Soil compaction may affect infauna. Water quality for fish species could be affected by high levels of nutrients, increased suspended sediments, or reduced dissolved oxygen levels.

Aesthetics, Recreation, and Cultural Resources

Presence of livestock in salt marshes may be unappealing to some viewers. Recreational activities may be disrupted in areas where livestock are present. Public access may be restricted to insure both human and animal safety. Archaeological resources at or near the soil surface could be damaged by livestock trampling.

Human Health

Human health could be endangered if microbes harmful to humans increased in nearby surface waters from livestock presence.

Agricultural/Aquacultural Environment

Effects on sediments/soils and water quality and movement in agricultural/aquacultural environments would be similar to those occurring in natural environments.

Agricultural/Aquacultural Species and Practices

Shellfish beds would be negatively impacted by increased levels of fecal coliform bacteria in overlying waters.

Built Environment

Impacts to built environments from the use of livestock would be the same as those occurring in natural environments. Pasturing of livestock may be prohibited in some areas by zoning codes or other regulations.

Cumulative and Synergistic Effects

Use of livestock to manage *Spartina* infestations would not be practical on a large scale. Prolonged or repetitive use of intensive grazing could negatively impact desirable plant and animal populations and water quality.

If insect bioagents are released to control *Spartina*, high arthropod densities may reduce plant palatability to livestock.

2.1.3.3 Mitigation

Surveys for non-target biota, especially threatened, endangered, and sensitive plant and animal species, and cultural resources should be conducted prior to introducing livestock at a site. Steps should be taken to avoid or minimize adverse impacts. Fencing may be required to prevent livestock entry into some sensitive areas. Sites should be grazed

only once or twice a year to minimize impacts to non-target plants and animals, and soil and water resources.

2.1.4 Genetic Engineering

No information was found on the application of genetic engineering to control *Spartina* species.

2.1.5 Plant Competition and Forced Succession

Once sediment in a *Spartina* marsh accretes to the level of the higher marsh areas, *Spartina* stands may be naturally invaded and displaced by native high marsh species such as *Salicornia virginica* and *Distichlis spicata*. Competition from native high marsh species may ultimately reduce the landward extent of *Spartina* infestations in some areas. Plantings of native vegetation have not been previously tried to control exotic *Spartina* species. Because of the cost and labor associated with extensive planting efforts, this approach does not appear feasible as a large-scale control.

2.2 PURPLE LOOSESTRIFE

Efficacies and impacts of biologically-based controls for purple loosestrife are summarized in Table 2.

2.2.1 Microbial Pathogens

The use of exotic phytopathogenic microorganisms for the biological control of purple loosestrife is not currently viewed as a viable approach. There are no reports in the American and European literature of significant pathogens being recovered from *L. salicaria* (Schroeder and Mendl 1984). The few species of endemic fungi reported as incidental and minor pathogens of purple loosestrife in North America were from other species of plants, including native *Lythrum* spp. and *Oenothera* spp. (Farr *et al.* 1989). Field surveys conducted in Europe (Blossey and Schroeder 1986) and in Washington (G. L. Piper, unpublished data) did not reveal any damaging pathogens attacking purple loosestrife.

2.2.2 Insects

Surveys for purple loosestrife biological control agents, conducted between 1979 and 1981 in northern and central Europe by scientists from the USDA Beneficial Insects Laboratory, and the Commonwealth Institute of Biological Control (CIBC), revealed 120 phytophagous insects associated with the plant (Schroeder and Mendl 1984, Batra *et al.* 1986, Blossey and Schroeder 1986). Follow-up investigations by CIBC entomologists indicated that 14 species exhibited excellent potential as control agents. From this group, six species were selected as the most promising for biocontrol. Three of these insects, *Hylobius transversovittatus*, *Galerucella californiensis*, and *G. pusilla*, were approved for release by federal and state

Table 2. Efficacies and major environmental impacts associated with the various biologically-based methods for controlling purple loosestrife. Mitigation measures for impacts are discussed in text.

Biological Control Method	Most Practical Applications	Use Constraints	Significant Environmental Impacts
Microbial pathogens	None	---	---
Phytophagous insects	Eradication; reduction of seed set; reduction of plant vigor	Releases of several insect species will be necessary to effect control	Honey production in managed apiaries may be impacted
Grazing (livestock)	Eradication of seedlings or reduction of seedling vigor	Older, woody plants not highly palatable; intensive grazing probably required to effect control	Soil compaction; inputs of nutrients, sediments, and fecal coliform bacteria to surrounding waters; impacts to non-target plants and animals possible
Genetic engineering	None	---	---
Plant competition and forced succession	Undetermined	Expensive and labor intensive; treatment sites must be burned, mowed, etc. before planting/seedling; multiple plantings/seedlings may be required	Non-target plants and animals may be impacted

regulatory agencies in 1992 and limited releases were begun in Washington (pers. comm., G.L. Piper 1992). It is not known when the remaining bioagents will be available for release. Insect biologies and impacts on *L. salicaria* are summarized below.

Hylobius transversovittatus (Coleoptera: Curculionidae)

The biology and ecology of this species has been chronicled by Schroeder and Mendl (1984), Blossey (1991), and Blossey and Schroeder (1991a). In early May, overwintered adults appear and feed on the leaves of purple loosestrife causing insignificant damage. Egg laying soon commences and can continue into September, with each female being capable of producing 300 eggs during her lifetime. About 70% of the eggs are deposited in the soil near the roots; the remainder of the eggs are inserted into the stem just above the soil surface. Feeding, mating and oviposition occur at night. Upon hatching, larvae enter the root and consume the vascular and cortical tissues over a one or two year period. Pupation occurs within the damaged root and adults emerge during mid to late summer. The beetle may overwinter as an egg, larva, pupa, or adult; adults may live three years. The insect completes a single generation annually. Larval feeding impacts on individual plants are dependent upon rootstock size, and attack intensity and duration (Blossey and Schroeder 1991a). Small roots can be destroyed within two years if infested by several larvae; larger roots will perish from higher attack rates or after low to moderate infestation over several consecutive years.

Galerucella californiensis and *G. pusilla* (Coleoptera: Chrysomelidae)

Detailed information on the biologies of these species is provided by Blossey and Schroeder (1986, 1991a) and Blossey (1991). Adults appear in May and chew holes in young leaves of purple loosestrife. Females lay eggs in clusters of 2-6 on the lower stem, leaves, and in leaf axils. The average number of eggs per female is 500. Upon hatching, early stage larvae feed on leaf and flower bud tissues; older larvae consume leaves. Mature larvae pupate in the soil and F1 generation adults appear in early summer. These adults feed until September, and mated females may lay a limited number of eggs. Adults spend the winter in the soil.

At high population densities, adult and larval feeding may result in complete defoliation and plant mortality (Blossey 1992). Feeding by the larvae also reduces shoot growth and may inhibit flower and seed production (Blossey and Schroeder 1991a).

Nanophyes marmoratus (Coleoptera: Curculionidae)

According to Schroeder and Mendl (1984) and Blossey and Schroeder (1991b), adult weevils emerge in late May and initially feed on young, unfolding leaves near the shoot tips. They later move to flower spikes and feed upon unopened flower buds. Oviposition occurs from June to September, during which time a female will produce 60-100 eggs. Eggs are laid individually in immature flower buds. Upon hatching, a larva consumes the petals, stamens,

and ovary. Infested buds do not open and drop from the plant. Pupation occurs within the bud and adults emerge in late summer. Overwintering occurs as an adult in the soil.

In Europe, up to 60% of the flower buds on a spike have been destroyed by the weevil larvae (Batra *et al.* 1986), thereby decreasing seed production (Blossey and Schroeder 1991b).

Nanophyes brevis (Coleoptera: Curculionidae)

The biology of this univoltine curculionid has been discussed by Schroeder and Mendl (1984) and Blossey and Schroeder (1991b). Overwintered adults begin to emerge in late May and feed on young leaves near shoot apices. Once flower spike development commences, adults become concentrated on the lower half of the spike where they attack the receptacles of opened flowers. In contrast to *N. marmoratus*, *N. brevis* oviposits exclusively in opened flowers, i.e., those that escaped attack by *N. marmoratus*. A larva is capable of consuming nearly 50% of the developing seeds within the ovary. Pupation occurs within the attacked ovary which remains attached to the spike; adult exit is via a hole chewed through the ovary wall.

In Europe, nearly one-third of the ovaries examined are infested by the weevil. The infestation rate should be higher in North America since the insect is released in parasite- and predator-free environments. Larval feeding results in substantial reductions in seed crop size (Blossey and Schroeder 1991b).

Bayeria salicariae (Diptera: Cecidomyiidae)

An account of the biology of *B. salicariae* is provided by Blossey and Schroeder (1991b). This midge has three or four generations a year. First generation adults appear in June and females soon lay between 80 and 120 eggs into leaf buds on rapidly growing shoots. Galls develop which enclose the feeding larvae. Pupation occurs within the galls, and newly formed adults exit from openings at the top of the galls. Egg to adult development requires one month. Larvae from subsequent generations form galls in flower bud tissue. Last generation larvae exit their galls and overwinter in the soil within cocoons they produce.

Batra *et al.* (1986) reported that leaf gall formation can reduce foliage production by 75%. Flower bud gall development results in spike growth deformities that consequently can diminish seed production by 80%.

2.2.2.1 Efficacy

There is great potential for the use of classical biological control against purple loosestrife in Washington and elsewhere in the United States (Thompson *et al.* 1987, Hight and Drea 1991). Purple loosestrife possesses many of the attributes of other plants that have been controlled by biotic agents. It is (1) an introduced species, (2) a perennial plant, (3) host to

a variety of effective biotic agents in its area of origin, (4) restricted to a specific and relatively stable habitat, (5) relatively isolated taxonomically from economically valuable and ecologically important plants, and (6) offers feeding niches that are unfilled in North America by natural enemies (Hight 1990; Hight and Drea 1991; G. L. Piper, unpublished data).

Natural enemy effectiveness depends upon the time of attack in relationship to the plant's growth cycle, the number of enemies infesting the plant, the amount of damage produced, and the plant tissues or organs impacted. Based upon previous biological control successes, it may be necessary to establish four to six insect species on *L. salicaria* before control is achieved (Harris 1979).

Because of the high level of host-specificity exhibited by insect natural enemies and their ecoclimatic preadaptations, all the introduced arthropods are expected to be highly effective and reliable in controlling populations of purple loosestrife. Based upon European research studies, the insects proposed for introduction into Washington readily accept and develop upon the *L. salicaria* biotypes that occur within the state (Blossey and Schroeder 1991a). This observation has subsequently been confirmed following initial releases of *H. transversovittatus*, *G. californiensis*, and *G. pusilla* in Washington in 1992 (G. L. Piper, unpublished data). Blossey and Schroeder (1991a) also state that a 90% reduction in *L. salicaria* stand density will likely eventually be realized upon the successful establishment of the European phytophages in North America.

The only labor requirements associated with the use of insects involve their initial release and, upon establishment, their subsequent redistribution to other sites within an infested region to enhance rapidity of further colonization. An expenditure of human labor may also be required to assess the impacts produced by the natural enemies on noxious species over time. The amount of time required to collect sufficient numbers of insects needed for relocation efforts will depend on the densities and accessibilities of the various species and on available labor force. It is preferable to release maximum quantities of all available insect species on *L. salicaria* in order to impose the highest level of stress as quickly as possible. Bioagent establishment will not immediately result in the disappearance of the plant. The amount of time required for control of purple loosestrife to be effected is not known nor can it be readily predicted. Based upon other biological weed control program successes achieved throughout the world, five to ten years may be required before significant plant population density reductions are realized (Harley and Forno 1992).

Barring unanticipated events that might result in the localized decimation of bioagent populations (e.g. insecticides applied for insect pest control or weed elimination by herbicides), a single release of each natural enemy at a site should be sufficient to effect permanent establishment. Insects are self-perpetuating and will remain in an area year after year as long as the target weed is present.

Natural enemy activity is intimately linked to plant phenological events. Bioagents for purple loosestrife, depending on the particular insect species involved, are prevalent between May and September. Most of the adult and larval insect feeding damage inflicted upon the plant would occur at this time. Releases and/or redistributions of insects would also be made during this time period.

Permitting

Permitting requirements for release of insect biological control agents for purple loosestrife are the same as those outlined in Section 2.1.2

2.2.2.2 Environmental Impacts

Natural Environment

Sediments/Soils

Insect bioagent utilization will not have a detrimental effect on sediment/soil stability and chemistry. The roots of plants killed as a consequence of the attack by *H. transversovittatus*, *G. californiensis*, or *G. pusilla* will remain in the soil and contribute to soil stability. Sediment trapping will decrease as *L. salicaria* density is lowered.

Water Quality and Movement

No adverse impacts will be produced on the quality of surface water supplies and groundwater by the insects themselves. Flow rates in streams and rivers and flow patterns in impounded waterbodies will be enhanced by the biological control of purple loosestrife.

Susceptibility of Non-Target Biota

Insect natural enemy utilization is a very selective form of plant control. In no instance has an insect introduced against an exotic weed in North America become a pest itself or endangered a native plant species (Harris 1988). Procedures followed in the host-specificity screening of bioagents to insure their safe introduction have been reviewed by Harris and Zwolfer (1968), Zwolfer and Harris (1971), Wapshere (1974), Goeden (1977), Schroeder (1983), and Harley and Forno (1992).

In host-specificity tests involving *H. transversovittatus*, *G. californiensis*, and *G. pusilla*, 50 APHIS-PPQ-TAG recommended plant species believed to be at risk were evaluated to determine if the insects could feed and/or reproduce on them. The majority of the tests were conducted by CIBC between 1988 and 1990 (Blossey and Schroeder 1989, 1991a); additional testing was conducted in the Virginia Polytechnic Institute & State University quarantine laboratory in 1989 and 1990 (Kok and McAvoy 1990, Kok *et al.* 1992). The screening tests

confirmed that all three species are highly host-specific for *L. salicaria*. No non-target plants will be impacted by the release of these beetle species.

Host-specificity testing is still in progress for *N. marmoratus*, *N. brevis*, and *B. salicariae* but preliminary results suggest that all species exhibit a high degree of host-specificity (Blossey and Schroeder 1991b).

The bioagents released to date and those species whose release is pending for control of purple loosestrife are incapable of injuring domesticated or undomesticated animals. Biological control will improve animal utilization of infested sites by facilitating the entry of plants that are better food, nesting, and shelter species. Some of the introduced insects may serve as food themselves for some wetlands animals, e.g. birds, small mammals, amphibians, and predatory arthropods.

Honey bee use of *L. salicaria* as a nectar and pollen source could be impacted by its biological control. However, honey bees survived on other plants prior to the invasion of purple loosestrife and now survive in areas not yet invaded by it. Furthermore, not all purple loosestrife plants will be eliminated by bioagent attack. Surviving *L. salicaria* will still provide nectar and pollen. It is conceivable that other bee forage plants will occupy sites vacated by purple loosestrife.

Native insects associated with purple loosestrife will not be significantly impacted. These insects have moved from indigenous and/or exotic plants onto *L. salicaria* upon its invasion into an area, and would readily survive in the weed's absence (Hight 1990; G. L. Piper, unpublished data).

Any endangered and threatened biota occurring in purple loosestrife-infested sites will benefit from its biological control by insects. There are no sensitive, threatened, or endangered plant species in the family Lythraceae in Washington (Washington Natural Heritage Program 1990). The insects would not adversely affect the survival of any listed threatened or endangered wildlife species in Washington (Washington Department of Wildlife 1991).

Loss/Alteration of Wildlife, Fish and Benthic Habitat

Densities of purple loosestrife seedlings and older plants should decline following the establishment of damaging bioagent populations. The loss of the plant will not negatively affect most animal populations, with the possible exception of the honey bee. However, this impact is not expected to be great because honey bee survival is not linked to the presence of *L. salicaria*. Additionally, vegetation having a greater wildlife value will eventually reoccupy sites from which *Lythrum* has been eliminated.

Aesthetic, Recreation, and Cultural Resources

The biological control of *L. salicaria* will have either a positive or negative impact on aesthetics, depending upon the attitude of the observer. Noxious weed control and wildlife management personnel may consider the absence of the plant to be most desirable whereas a beekeeper may consider purple loosestrife to be a welcome addition to the environment. Biological control will not result in the short-term elimination of the plant; some *L. salicaria* will continue to exist but its occurrence will be much reduced following successful biocontrol.

Biological control of purple loosestrife on lands and waters utilized for recreation will not impact access to, use of, or the quality and quantity of available sites. Insect-induced reductions in plant density will contribute to marked improvements in hunting, fishing, wildlife watching, and other opportunities conducted in natural environments.

Human Health

Human health will not be endangered from the use of insect biological control agents. The insects are not capable of biting or stinging humans, producing toxic secretions, or transmitting pathogenic microorganisms.

Agricultural Environment

Insect bioagent use will not adversely affect sediments/soils or water chemistry and movement in agricultural environments.

Agricultural Species and Practices

Insect-induced density reductions in purple loosestrife-infested wetland pastures and wild hay meadows should increase livestock forage plant availability and quality. Biocontrol may diminish honey bee visitation opportunities. Honey production in managed apiaries might be reduced as a consequence.

Where bioagents are attacking irrigation ditchbank infestations of *L. salicaria*, some mortality to insects could occur from insecticide drift onto plants when applications are made to nearby crops. In riparian pastures, bioagent population development could also be negated or impeded by livestock feeding and trampling activities.

Built Environment

No adverse impacts to soils or water quality and movement are expected from insect use in built environments. Impacts to aesthetics, recreation, and cultural resources would be similar to those occurring in natural environments.

Maintenance Practices

Insect-induced reductions in *L. salicaria* density may greatly diminish the frequency of herbicide use for purple loosestrife control in some managed landscapes.

Cumulative and Synergistic Effects

With the establishment of each biotic agent, incremental reductions in *L. salicaria* vigor, growth rate, and reproductive success will be evidenced. As natural enemy populations increase and expand their distributions, either through their own powers of dispersion or by human intervention, impacts on purple loosestrife will be intensified. These impacts will continue into the foreseeable future as long as environmental conditions favor survival of natural enemies and as long as plant populations persist.

In areas where livestock may be used as a biocontrol, insect population development could be negated or impeded by livestock feeding and trampling activities.

2.2.2.3 Mitigation

Pre-introduction regulations mitigate concerns about non-target plant impacts. Thus, no measures to mitigate the effects of introduced bioagents would be necessary or desirable. Natural enemy population densities are regulated by the abundance of purple loosestrife. As plant densities decline, corresponding decreases also will occur in control organism populations.

To maximize biological control organism survival, releases should be avoided in sites that might receive synthetic organic insecticide treatments directed against certain pest arthropod populations. Release would also be unwise in purple loosestrife infestations specifically targeted for control by the unilateral use of herbicides or certain physical methods (burning, mowing, flooding), or in areas subjected to heavy livestock grazing.

Initial bioagent release sites should be isolated from human activities that might interfere with organism establishment success but sites should be reasonably accessible for monitoring purposes.

2.2.3 Grazing

2.2.3.1 Efficacy

Vertebrate animals such as cattle, horses, goats, and sheep have often been used for weed control. However, control by domesticated animals differs in its mode of operation from that of insects. Insect numbers are reciprocally regulated by the abundance of their hosts whereas livestock numbers are not dependent upon plant densities. Furthermore, ungulate grazers are

usually oligophagous or polyphagous and lack the high degree of host specificity possessed by many insect herbivores.

There are no published studies available that indicate that livestock grazing can effectively control purple loosestrife. Although animals will consume the plant during the early growth stages, it apparently is not a highly palatable plant (Thompson *et al.* 1987, Parker and Burrill 1992). It is not known what kinds of livestock might most efficiently graze the plant in wetland sites. Sheep and goats have been used with success against certain rangeland weeds (Johnston and Peake 1960, Scifres 1981, Fay 1990, Wallander *et al.* 1992) and may possibly be of some value in controlling *L. salicaria*.

Forced browsing on *L. salicaria* seedlings or shoot regrowth during the spring may adversely impact survival or seed production potential. As the growing season progresses, plant palatability would decrease as the stems become woody.

Effective suppression of *L. salicaria* could possibly result from short-duration high-intensity grazing of seedling plants during the spring and/or early summer. It is also quite probable that livestock feeding impacts plants in much the same way that cutting or mowing does.

The use of livestock to manage purple loosestrife in most situations would normally not be an inexpensive undertaking. Monies would be expended for animal acquisition, sheltering, supplemental feed, health care, transportation, and fencing. A considerable investment of labor would also be involved in treatment site stocking and destocking operations.

2.2.3.2 Environmental Impacts

Natural Environment

Sediments/Soils

Heavy grazing may result in soil compaction and short-term increases in soil erosion, particularly along stream banks and shorelines. Soil chemistry will be altered by fecal and urine deposition.

Water Quality and Movement

Animal grazing activities may result in sediment and nutrient infusion of adjacent surface waters. Temporary increases in turbidity and phytoplankton growth and a decrease in dissolved oxygen content might occur. Surface water flow patterns could be altered by soil compaction.

Susceptibility of Non-Target Biota

If grazing is confined to monospecific stands of *L. salicaria*, it could be a very selective form of control. However, if stands of mixed species vegetation are browsed, the possibility exists that non-target plants could be injured or killed. Damage to some plant species, especially those with poor regenerative capabilities, could be significant. Plant habitat availability could also be diminished by extensive fecal deposition.

Some animals that feed, hide, or nest in target site vegetation could be displaced as a consequence of the physical presence of the livestock or through their feeding activities. Any of the *L. salicaria* insect bioagents would be highly susceptible to injury.

Loss/Alteration of Wildlife, Fish and Benthic Habitat

Habitat for benthic infauna would be impacted by trampling. Water quality for fish species could be affected by high levels of fecal coliform bacteria or nutrients.

Aesthetic, Recreation, and Cultural Resources

The biological control of *L. salicaria* will have either a positive or negative impact on aesthetics, depending upon the attitude of the observer. Presence of livestock in some wetland areas may be unappealing to some viewers. Recreational activities in areas where livestock are being utilized may be disrupted by their presence. Public access may be restricted by control authorities to insure both human and animal safety. Hunting and wildlife/wildflower viewing activities could be impacted because of reductions in or the elimination of some animal and plant populations.

In the long-term, *L. salicaria* removal by grazing should enhance fishing, hunting, boating, swimming, and other activities conducted in natural aquatic environments.

Trampling by livestock or other animals could potentially disturb or destroy unidentified resources on or near the soil surface.

Human Health

Human health could be endangered if bacteria counts in nearby surface waters were to increase as a direct consequence of livestock defecation. Such contamination probably would be infrequent because of the limited amount of time animals would be maintained and grazed at a site. Some grazers such as cattle and goats, if provoked, could physically injure people.

Agricultural Environment

Effects on sediments/soils and water quality and movement in agricultural environments would be similar to those occurring in natural environments.

Agricultural Species and Practices

Early season, high intensity livestock grazing may eliminate or reduce purple loosestrife competition with desired forage plants. This would benefit commercial livestock producers.

Built Environment

Impacts to built environments from the use of livestock to control purple loosestrife in built environments would be the same as those occurring in natural environments. Use of livestock in many human-managed landscapes may be prohibited by zoning codes or other regulations. The use of other forms of weed suppression may be more cost-effective and ecologically appropriate in such sites.

Cumulative and Synergistic Effects

Prolonged and/or repetitive use or the inappropriate use of intensive grazing could negatively impact plant and animal species abundance and richness and water quality in natural, agricultural, or built environments.

Grazing may not be compatible with use of insect bioagents for purple loosestrife control.

2.2.3.3 Mitigation

Cultural resource and threatened and endangered species surveys should be undertaken in purple loosestrife-infested sites targeted for control prior to the introduction of any livestock. Steps should be taken to avoid or minimize impacts to these resources.

Fencing would be necessary to confine grazing animals to specific treatment sites since unconfined animals may extensively damage non-target plants. Sites should only be grazed one or two times annually to minimize impacts to non-target plants and animals, and soil and water resources. Grazing stands of purple loosestrife that are partially submersed is not recommended.

2.2.4 Genetic Engineering

New techniques of molecular and cellular biology, including recombinant DNA, electroporation, projectile insertion, nuclear microinjection, and cell fusion, have emerged as powerful research tools in biology. As the foundations of modern biotechnology, these techniques hold great promise for the development of genetically engineered organisms (also termed transgenic organisms) that may benefit humans in various ways. The novelty of biotechnology is its ability to exploit the universality of the genetic code to combine, in a single organism, major adaptive traits developed by organism that have evolved along separate phylogenies.

Genetic engineering is still in its infancy. At this point in time, no biotechnological discoveries have been made that would be of immediate value in alleviating impacts resulting from purple loosestrife domination of natural, agricultural, and human-managed environments in Washington or elsewhere. The role genetic engineering may play in the future improvement of noxious plant control technologies has not yet been fully envisaged by weed scientists or others.

2.2.5 Plant Competition and Forced Succession

Competition can be defined as an interaction between individuals brought about by a shared requirement for a resource in limited supply that leads to a reduction in the survivorship, growth, and/or reproduction of the individuals concerned (Bergon *et al.* 1986). There are two major mechanisms of plant competition: resource competition and interference (allelopathic) competition. Resource competition can be further subdivided into competition for soil resources (nutrients and water) and competition for light (Aldrich 1984). Purple loosestrife, upon entering a site, can replace existing vegetation because it is capable of depleting site resources more efficiently than can those species it displaces. *Lythrum* seedlings appear during the spring and quickly develop an extensive root system to facilitate nutrient and water acquisition (Shamsi and Whitehead 1974a, 1977a). Rapid shoot and leaf development deny understory vegetation access to light (Shamsi and Whitehead 1974b). It is not known if the plant is capable of allelopathic competition.

Purple loosestrife control may be effected by using plants that possess competitive superiority, i.e., plants that are effective resource assimilators and/or interceptors (Shamsi and Whitehead 1974b, 1977b). This particular form of weed suppression is known as replacement control (Piemeisel and Carsner 1951). Replacement control is a component of forced succession or succession management (Luken 1990). Pickett *et al.* (1987) maintained that there are three basic causes of succession: site availability, differential species availability, and differential species performance. These components contributing to natural succession can be modified for application in resource management situations. To manage succession, three components are required: designed disturbance, controlled colonization, and controlled species performance (Luken 1990). Designed disturbance includes activities initiated to create or eliminate site availability (e.g. burning, flooding, drainage, herbicide application). Controlled colonization includes methods used to decrease or increase availability and establishment of specific plant species (e.g. seeding, direct planting, water manipulation, herbivory). Controlled species performance includes methods used to increase or decrease growth and reproduction of selected plant species (e.g. burning, grazing, mowing, herbicide application). All components result in changes in resource availability (light, water, nutrients) that influence plant survival during the successional process.

2.2.5.1 Efficacy

The use of competing vegetation to manage purple loosestrife has been attempted in several wildlife refuges. Rawinski (1982) planted Japanese millet (*Echinochloa crus-galli* var.

frumentacea) among purple loosestrife and noted that the millet seedlings out-competed those of *Lythrum*. He indicated that the millet had to be planted immediately after marsh drawdown in order to be effective. Rapid germination and growth of the millet enabled it to establish and usurp available space. Balough (1986) reported that *Echinochloa* does not regenerate well and would have to be replanted each year. He seeded pale smartweed (*Polygonum lapathifolium*) and found it also out-competed purple loosestrife. However, the effect was only of short-term duration as *L. salicaria* shoots produced from rootstocks of established plants the following year negated the effect of the competitive planting. Malecki and Rawinski (1985) also demonstrated that certain other early germinating plant species can outcompete purple loosestrife seedlings by monopolizing available sunlight. The Washington Department of Wildlife is investigating the abilities of several phreatophytes (cottonwood and willow species) to shade out or suppress purple loosestrife (Beckstead *et al.* 1991). University of Minnesota weed scientists are also exploring replacement planting utilization (Anon. 1990). Further research on *L. salicaria* replacement control plants is needed before the technique can be extensively used in succession management programs.

A substantial investment of labor and money may be required to initiate and maintain forced succession in a purple loosestrife-infested waterbody. Intentional disturbances (burning, flooding, cutting, herbicides) will be required to initiate the successional pathway at the control site. Since controlled colonization is the manipulation of plant species availability and establishment, many of the designed disturbance methods can also be used to control colonization. The rate at which colonization proceeds will be influenced by site floristics and the propagule pool. In controlled succession, management activities must be directed at the propagules, at the factors that disperse them, or at the establishment of seedlings from propagules. Labor inputs will be required for direct planting and seeding to effect site colonization. After desired plant species are established and colonization is complete, additional human involvement may be required to modify the growth and reproduction of the plants in the successional pathway (Luken 1990). Such measures might include cutting, burning, herbicide use, and encouraging or excluding grazers. Depending on the life cycles, reproductive capacities, and survivorship abilities of the plants selected, it may be necessary to periodically supplement their population densities to maintain a sufficient level of competitiveness against *L. salicaria*.

Due to the paucity of research studies on the use of replacement control against purple loosestrife, statements addressing its short- and long-term effectiveness cannot be made. Forced succession is but just one of the component tactics available for use and consideration when designing an integrated management program against *L. salicaria*.

2.2.5.2 Environmental impacts

Natural Environment

Sediments/Soils

Controlling purple loosestrife infestations will decrease the amount and rate of sediment and debris deposition attributable to the plant's occupation of a site.

Water Quality and Movement

Surface water and groundwater quality and quantity will not be significantly adversely impacted by competitive plant species. Replacement vegetation may slow surface water flow but this could be viewed as being desirable since soil erosion potential would be diminished. Flow rates in streams and rivers and current patterns in large impoundments will be enhanced by the replacement of purple loosestrife with other non-environmentally disruptive plants.

Susceptibility of Non-Target Biota

Plants introduced into a site will compete with previously established species. If the competitive abilities of established species are poorer than those of introduced species, some displacement or loss of established plants may occur. In particular, undetected populations of sensitive, threatened, and endangered plants could be displaced through competition with replacement plant species.

Some animal mortality may result from various physical control methods utilized at a site preparatory to revegetation efforts. If the replacement vegetation out-competes other plant species already established at the site, death or displacement of certain animal species (e.g. insects) utilizing the out-competed plants as hosts could occur.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Most wildlife species will benefit from purple loosestrife's removal and replacement by other plant species. Food web complexity will increase and the ability of the wetlands ecosystem to resist external perturbations should be improved (Odum 1971).

Aesthetic, Recreation, and Cultural Resources

Vegetative restoration of purple loosestrife-infested waterbodies will enhance their aesthetic appeal to some viewers. Any increase in the abundance and diversity of desirable plants will facilitate improved occupation of wetlands by wildlife species which will in turn benefit consumptive and non-consumptive users of these sites.

Effecting forced succession through the use of competitive plantings will positively benefit the quality and quantity of recreational activities conducted at waterbodies undergoing rehabilitation. Purple loosestrife removal and its replacement with more ecologically desirable forms of vegetation will improve hunting, fishing, boating, swimming, wildlife and wildflower viewing, and other related activities carried out in the natural environment.

Cultural resources would not be negatively impacted by the use of competitive plants.

Human Health

Existing infestations of *L. salicaria* are often diminished by the use of various physical or chemical control methods prior to planting competitive, replacement species. All human health hazards associated with the use of such techniques would be applicable. No significant human health problems should result from contact with those desired plant species selected to compete with and exclude purple loosestrife from affected sites.

Agricultural Environment

Soil movement and chemistry and water quality and movement would not be adversely affected by the use of competitive plants in the agricultural environment.

Agricultural Species and Practices

The use of competing plants in wild hay meadows and riparian pastures should not harm non-target biota. Rapidly growing, non-poisonous, broadleaved plants with good palatability characteristics and high livestock forage values should be grown in pasture areas to out-compete purple loosestrife. The control of *L. salicaria* with competing plants in riparian meadows is a relatively inexpensive method available for livestock producer use. However, areas in which competitive plants are grown should not be overgrazed or else purple loosestrife may soon regain its dominance of a site.

Built Environment

Impacts on sediments/soils, water quality and movement, and aesthetics, recreation, and cultural resources resulting from use of competitive vegetation would be similar to those occurring in the natural environment. The use of competitive plantings should not adversely impact maintenance practices in managed landscapes.

Cumulative and Synergistic Effects

For best results, competitive plantings should be used in conjunction with chemical, physical, and/or insect biological control methods.

2.2.5.3 Mitigation

Prior to the introduction or augmentation of indigenous or exotic vegetation, each targeted site should be examined for sensitive, threatened or endangered species. Impacts to these species should be avoided or minimized.

It is important to curtail *L. salicaria* growth and development as early as possible in the growing season to negate the plant's competitive ability. Competitive plantings should be initiated during the spring and summer months when adequate moisture will be available to insure germination and growth. Depending upon the life cycle and seeding/vegetative reproduction characteristics of the competitive species grown, it may be necessary to replant or augment returning plant populations annually to insure that a sufficient level of competitive pressure is maintained against the weed.

Since human intervention is necessary to initiate and maintain the process of forced succession, treatment sites must readily lend themselves to access by people and/or equipment. Once the successional pathway has been developed, the process will probably best proceed in a natural environment not subjected to repetitive human- and/or animal-induced disturbance. However, this needs to be determined through experimentation.

Since physical (hand removal, covering, water level manipulation, trampling/crushing, burning) and/or herbicidal control methods typically will be used preparatory to the planting of competitive vegetation, all mitigative measures described in the report for Element D-Physical Control Methods should be in effect.

This form of biological suppression should be incorporated into existing maintenance and beautification programs in order to keep such landscapes free of this undesirable plant or to minimize its continued spread within the system under consideration.

2.3 OTHER SPECIES

2.3.1 Giant Hogweed

Giant hogweed occurs along river and stream banks, and on drier, disturbed sites such as fill areas, and roadsides. It is a perennial herb with large tuberous roots, rapid growth, and abundant seed production.

Little information is available on the potential for insect biocontrol of giant hogweed. The plant has been reported as a host to the carrot fly, *Psila rosae* (Hardman and Ellis 1982). The insect's feasibility as a control agent for the plant is unknown. Several species of native herbivores have colonized introduced giant hogweed in Britain (Fowler *et al.* 1991).

Cattle and pigs can apparently eat the plant without harm (Wright 1984). In Europe, effective control of the plant has been obtained by allowing cattle to graze where plants are

growing. Trampling by livestock knocks down leaves and stems and crushes crowns or rootstocks of plants, preventing further growth (Morton 1978). However, goats may be sensitive to the toxins produced by giant hogweed. Andrews and Giles (1985) reported a suspected case of a goat poisoned after grazing upon the plant.

Possible impacts to natural, agricultural, and built environments from the use of livestock as bioagents include soil compaction, injury or death of non-target plants, displacement of animals by the presence of livestock, and increases in bacteria and nutrient levels of surface waters.

2.3.2 Other Loosestrife Species

Garden loosestrife (*Lysimachia vulgaris*) and wand loosestrife (*Lythrum virgatum*) are deciduous perennials that inhabit moist habitats such as marshes, wet woods, lakeshores and river banks.

Little information is available on possible biological control methods for these species. Braverman and Provvidenti (1977) reported a cucumber mosaic virus attacking a plot of *L. vulgaris* introduced to the United States from South Korea. Two strains of the virus were found which, individually or in combination, caused severe stunting, malformed leaves, prominent veinal chlorosis, green vein-banding, chlorotic spotting, and diffuse mottling of plants. Flower panicles were also reduced in size, but corolla color was not affected.

In Japan, the fly, *Tabanus chrysurinus* has been reported to lay its eggs on the underside of *L. vulgaris* leaves (Hayakawa and Yoneyama 1985). Impacts to the plant from this insect have not been fully investigated.

It is possible that biocontrol agents for *L. salicaria* may feed on *L. virgatum*. More studies are needed to determine the feasibility of microbial and insect or other animal controls for *L. vulgaris* and *L. virgatum*. A Lake Washington resident reported that hand pulling of *L. vulgaris* plants followed by spring planting of Japanese millet prevented new *L. vulgaris* growth. The natural summer drawdown of the lake killed the millet (S. Taylor 1992, pers. comm.).

2.3.3 Indigobush

Indigobush occurs in a wide variety of habitats, including river, creek, and lake shorelines, wet meadows, swamps, and floodplain depressions. It may form monospecific colonies that effectively displace native vegetation.

In China, larvae of the beetle, *Acanthoscoioides plagiatus*, have been reported to consume seeds of indigobush (Fan 1981). A heavy infestation of the beetle, *Acanthoscelides collusus*, impacted seed production of an indigobush infestation in Texas (Rogers and Garrison 1975).

More studies are needed to determine the viability of these or other insect species for control of indigobush.

This weed is reportedly used as forage for cattle and sheep in Italy (Bnciarelli and Santilocchi 1980), although no information is available on the efficacy of livestock for control of the plant.

3.0 RESEARCH AND INFORMATION NEEDS

Additional information on the use of biologically-based control methods in natural, agricultural, and human-managed environments is required. In particular, more studies are required to determine the feasibility of *Prokelisia marginata* as a bioagent for noxious *Spartina* species. In addition, basic research identifying potential insect or microbial species and the effectiveness of livestock for control of giant hogweed, garden loosestrife, wand loosestrife, and indigobush is needed.

The most information exists on biological controls for *Lythrum salicaria*. However, research could be undertaken to address the following questions:

What is the optimal number of insect bioagents that should be released at a site to effect colonization/establishment?

Research in progress: This question will be addressed by G. Piper, Department of Entomology, Washington State University, once larger quantities of the various bioagents become available for release during 1993 and in succeeding years.

What livestock species are the most efficient grazers of purple loosestrife?

Can purple loosestrife be controlled by grazing? If so, when should grazing be implemented, and what stocking rates and amounts of time are required to produce the effect?

At what point during the plant's phenological development does its palatability to livestock diminish?

Is *L. salicaria* allelopathic?

Which endemic or introduced plant species of value to wildlife will out-compete purple loosestrife?

Research in progress: Washington Department of Wildlife personnel have begun an assessment of the competitive abilities of several phreatophyte species (Beckstead *et al.* 1991). University of Minnesota weed scientists are also exploring competitive planting utilization (Anon. 1990). Additional wetlands plant species needed to be identified and subjected to evaluation by agency personnel and plant ecologists.

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