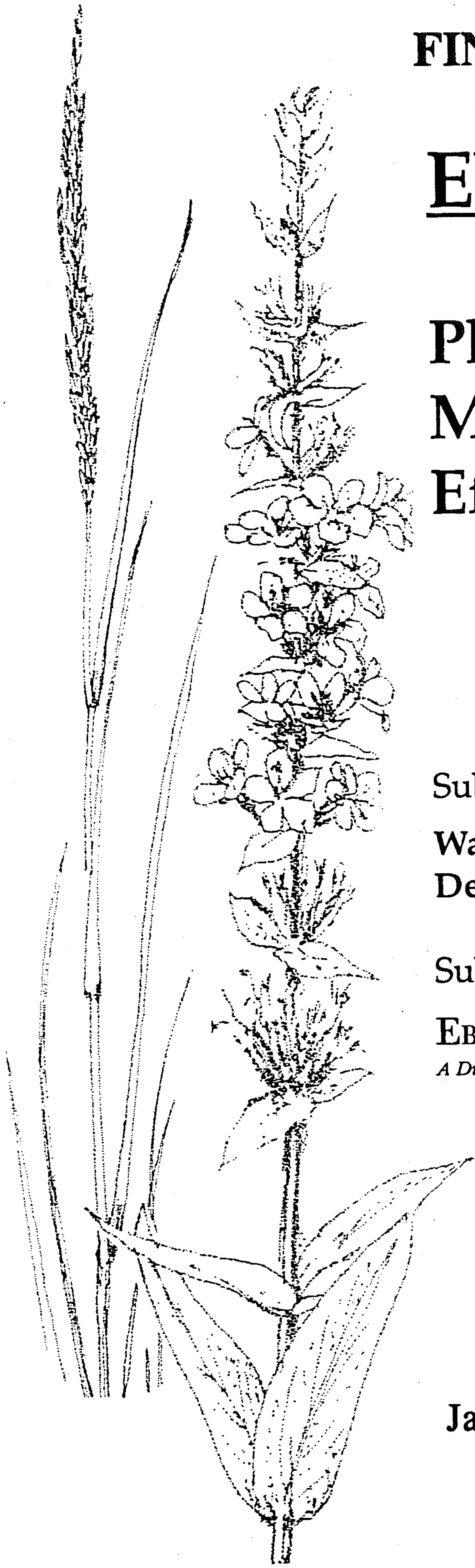

FINAL REPORT

Element D

Physical Control Methods: Efficacy and Impacts

Submitted to

Washington State
Department of Ecology

Submitted by

EBASCO ENVIRONMENTAL
A Division of Ebasco Services Incorporated

January 1993

FINAL REPORT

Element D: Physical Control Methods: Efficacy and Impacts

Submitted to:

Washington State Department of Ecology

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February 1993

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ABSTRACT

Physical methods for controlling (eradicating, containing, or preventing seed production) nine species of noxious weeds are discussed. Species of concern include three species of cordgrass (*Spartina patens, S. alterniflora,* and *S. anglica*), purple loosestrife (*Lythrum salicaria* and *Lythrum virgatum*), garden loosestrife (*Lysimachia vulgaris*), giant hogweed (*Heracleum mantegazzianum*), and indigo bush (*Amorpha fruticosa*).

Control methods addressed in this report include: digging, covering, dewatering/drainage, flooding/inundation, burning, and use of explosives. Most physical control methods are expensive and/or labor intensive when used to eradicate colonies. Prevention of seed production or slowing spread of individual infestations may be feasible uses of some methods. Control methods vary in application practicality depending on size of infestation, age of plants, topography, and proximity to agricultural, aquacultural, or built environments. Significant environmental impacts include soil erosion, sediment mobilization, non-target species mortality, noxious plant dispersal, soil compaction, and disruption of aquatic food webs. Mitigation measures can be used to reduce or eliminate potential impacts.

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 in the State of Washington. Species of concern include salt meadow, smooth, and common cordgrass (*Spartina patens, S. alterniflora,* and *S. anglica*, respectively), purple loosestrife (*Lythrum salicaria* and *Lythrum virgatum*), garden loosestrife (*Lysimachia vulgaris*), giant hogweed (*Heracleum mantegazzianum*), and indigobush (*Amorpha fruticosa*). These species are included on the Washington State Noxious Weed List (Chapter 16-750 WAC) because they are considered detrimental to the agricultural, aquacultural, and natural environments of the state. Their control (eradication, containment, or prevention of seed production) is mandated by inclusion on the Noxious Weed List. The effort required to control a noxious species varies according to its current distribution, likelihood of spread to uninfested areas, and other factors (WSNWCB 1991). 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 existing noxious species and new invaders.

The lead agencies have determined that management of these noxious emergent plant species could have 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 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 in the EIS.

This report provides information on physical methods of controlling *Spartina*, purple loosestrife, garden loosestrife, giant hogweed, and indigobush.

1.2 OBJECTIVES

The objectives of this report are to:

(1) evaluate, based on available information, efficacy of physical methods for controlling populations of *Spartina alterniflora, S. anglica, S. patens, Lythrum salicaria, Lythrum virgatum, Lysimachia vulgaris, Heracleum mantegazzianum,* and *Amorpha fruticosa* present in Washington;

(2) describe potential impacts and cumulative effects of physical control methods on natural, agricultural, aquacultural, and built environments; and

(3) discuss mitigation for environmental impacts.

Potential impacts of each control method to sediments/soils; water quality and movement; non-target plants and animals; wildlife, fish, and benthic habitat; trophic interactions; air quality; aesthetics, recreation, and cultural resources; and human health are discussed. The potential for spread of noxious species to unaffected areas is also presented. For this report, the natural environment includes areas not 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 included in this section. Other "open space" areas managed for recreation or other human use, such as state, county, or city parks, are addressed under the "built environment." Impacts to cultivated or domesticated species are described under "agricultural/aquacultural environment."

Sources of information for this report included published articles, published and unpublished studies, and communications with knowledgeable individuals. Information was obtained from both national and international sources. Little is known about the control methods discussed here and most available information is anecdotal or relates to limited studies, sometimes without adequate experimental design. Following discussions of control methods, research and information needs are presented.

2.0 PHYSICAL CONTROL METHODS

The goal of noxious weed control is to eradicate or contain populations of noxious weeds and to slow or stop habitat degradation. Methods using physical means that primarily involve hand labor are addressed in this report. Other reports address biological controls, chemical controls, and physical methods using heavy equipment, .

Physical control methods evaluated in this report include:

- Hand removal (hand digging and pulling);
- Covering (plastic, soil, etc.);
- Dewatering/drainage (ditching, diking);
- Flooding/inundation (diking);
- Burning; and use of
- Explosives.

These control methods may be used singly or in combination with other methods. For example, covering with black plastic is usually preceded by mowing to reduce biomass under the plastic mats or sheets. Some techniques, such as burning, are more practical for controlling spread of individual colonies while others, such as covering, are intended to completely eradicate clumps or colonies of plants.

2.1 *Spartina*

Efficacy and impacts of the various physical methods for controlling *Spartina* are summarized in Table 1.

2.1.1 Hand Removal

Hand removal by pulling or digging requires limited equipment, including shovels, hand clippers, and protective clothing. Bags, shoulder bags, wheel barrows, hand carts, boats, barges, and/or motorized vehicles may be required for transporting plants away from the treatment site. Workers walking on soft substrates may use "mudluks," which attach to boots to increase surface area contact with the substrate. These make walking easier and minimize soil compaction. Mudluks are made from tire innertubes attached to a support.

2.1.1.1 Efficacy

Hand pulling is a labor-intensive method that is impractical for controlling larger clumps of *Spartina*. Any portion of rhizome or root left behind can potentially sprout and re-establish the clone. This method was tried in England over several seasons at one site but was eventually abandoned because of difficulties in preventing reestablishment from underground parts left behind (Corkhill 1984). Hand pulling or digging may be used to supplement mowing or other control efforts.

Hand pulling accompanied by digging of underground parts can be an effective control method for small clumps of *Spartina* or low-density infestations of young plants, however (Way 1990). A one square-meter (10.8 ft^2) patch of *S. alterniflora* was effectively removed by hand pulling at the Niawiakum Natural Area Preserve (Friedman 1988, cited in Aberle 1990). Friedman estimated that about one cubic meter (35.3 ft^3) of wet mud weighing more than a metric ton (1.1 ton) was also removed. The operation required six person-hours to accomplish. She noted that rhizomes extended 0.5 m (1.5 ft) beyond the shoots at the edge of the clump. Way (1987) found rhizomes 1.2 m (4 ft) below the surface in Ribble Estuary, England. He suggested that seedlings and young plants (2-3 years old, with 3-10 shoots) could be effectively removed by hand pulling.

Labor intensive methods are typically expensive, although inexpensive sources of labor may also be available. Prisoners, for example, may be potential sources of cheap labor. A supervisor, guard, and 10-person crew typically cost $500 to $700 (plus transportation and

Table 1. Efficacy and major environmental impacts associated with the various physical methods for controlling *Spartina*. Mitigation opportunities for impacts are described in text.

Physical Control Method	Most Practical Applications	Use Constraints	Significant Environmental Impacts
Hand pulling or digging	Eradication of small, isolated clumps, seedlings, or sparse infestations	Labor-intensive; multiple treatments may be required	Loss of substrate affixed to roots; increased potential for soil erosion; sediment mobilization; compaction of soils from foot traffic
Covering	Eradication of small colonies	Expensive and labor-intensive over a large area; treatment sites must be mowed or burned initially; wind or waves may dislodge covers; monitoring during treatment required	Desirable plants and infauna beneath covers impacted; compaction of soils from foot traffic; sediment mobilization
Dewatering/drainage	Eradication of medium size colonies	Expensive; not practical for large areas or gradual slopes near sea level	Sediment mobilization; non-target plants and animals will be affected; disruption of aquatic food webs; disturbances associated with construction
Flooding/inundation	Eradication of medium- sized colonies	Expensive; shoreline topography must be amenable	Non-target plants and animals will be affected; disturbances associated with dike construction
Burning	Prevention or reduction of seed set; enhancement of susceptibility of plants to other control methods	Treatment prior to seed set, during dry weather, and when wind blows smoke away from inhabited areas; smoke may be toxic to workers; flaming is labor-intensive	Non-target plants and animals may be impacted; air quality temporarily affected; water may be polluted
Explosives	Not recommended	Use may be prohibited in some areas	Dispersal of rhizomes and seeds; significant impacts on non-target plants and animals, and on soil and water resources

meal expenses) per day (D. Dolstad, pers. comm. 1993). Volunteer organizations may also become involved in community-sponsored activities and provide labor at minimal cost.

To restore a site to pre-invasion conditions, hand pulling of *Spartina* stems would need to be followed by removal of accreted sediments (either by digging or through erosion) to restore former elevations. In areas vegetated prior to invasion, plantings (eelgrass (*Zostera* sp.), salt marsh plants) may also be required to ensure rapid regrowth. Waterfowl use would not be restored in some areas unless the marsh was returned to an elevation that would support bulrush (*Scirpus* sp.) marshes (C. Iten, pers. comm. 1992).

Seasonal and Access Constraints

Removal of *Spartina* by hand may be hampered by high tides and stormy weather. The likelihood of rhizome dispersal is greater in these conditions, especially for *S. alterniflora* and *S. anglica*, which may occur in the lower intertidal zone.

2.1.1.2 Environmental Impacts

Natural Environment

<u>Sediments/Soils</u>

Sediments may be redistributed through wave or current action after *Spartina* plants are removed. Erosion would be more pronounced on slopes and along margins of stream banks and tidal channels. After removal of a *S. anglica* stand in New Zealand, significant movement of sediment occurred, especially along channel and creek banks, which collapsed and widened (Gillespie *et al.* 1990). In a *S. anglica* marsh in Great Britain, where *Spartina* was dying back and being eroded, Gray (1991) noted higher, possibly enhanced sediment accretion rates in higher tidal zones. He attributed these findings to increased mobilization of sediments in the lower zones and indicated that a steepening of the marsh profile was an inevitable consequence of the changing sediment dynamics.

Digging or hand pulling *Spartina* results in the loss of soil affixed to the removed root mass. Removing all underground plant parts requires digging up large amounts of soil surrounding each clump, which forms large holes. Removal of accreted sediments during plant removal may accelerate restoration of the original sediment/soil surface. Human foot traffic during digging and pulling operations and the weight of equipment used to remove dug plants would result in temporary compaction of wetland soils.

<u>Water Quality and Movement</u>

Pulled or dug plant biomass is typically carried away by workers. Oil and fuel from motorized equipment used to remove dug plants may enter waterbodies. Short-term increases in water turbidity would occur after digging. Water movement may be affected by channel reconfiguration resulting from changes in sediment dynamics and erosion patterns.

Mortality of Non-Target Biota

Hand pulling and digging are highly selective control methods that should have minimal impacts on non-target plant and animal species. However, some species including threatened, endangered, or sensitive (TES) species intermingled with *Spartina* in mixed colonies or in surrounding areas, could be impacted by hand removal methods. *Spartina anglica* often has a diffuse pattern of growth and tends to co-occur with other plant species. Thus, the likelihood of mortality of non-target biota is greater in stands of this species. TES species include threatened, endangered, or candidate threatened species listed by the U.S. Fish and Wildlife Service and endangered, threatened, or sensitive species listed by the Washington Natural Heritage Program. TES plant species documented or suspected to occur in salt marshes in Washington include Alaska alkaligrass (*Puccinellia nutkaensis*), thickglume reedgrass (*Calamagrostis crassiglumis*), and sharpfruited peppergrass (*Lepidium oxycarpum*) (J. Gamon, pers. comm. 1992). Soil compaction and trampling may kill infauna. Infauna and epifauna populations would be temporarily affected by changes in sedimentation and erosion, both within the area treated and at lower elevations. Sediment transported away from the site could smother infauna, epifauna, and algae. Animals and plants adhering to *Spartina* plants and in the mud removed from the site would perish.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Animal and plant populations may be temporarily diminished or displaced during control treatments. Soil compaction could delay reestablishment of infauna or native vegetation. In a preliminary study, Allard (1991) found no statistically significant differences in total number of fish or species composition between *S. alterniflora* clones and mudflats in Willapa Bay. She concluded that *Spartina* eradication at the site would not have permanent adverse impacts on native fish or crab species. The only waterfowl species that regularly utilizes *S. patens* plants for food is the black duck (*Anas rubripes*), but this species is rarely observed in Washington (S. Iten, pers. comm. 1992).

Trophic Interactions

Following digging and exportation from the treatment site, reductions in *Spartina* aerial and subterranean biomass would cause reductions in organic matter available for detritivore processing. In salt marsh areas, decomposer population levels would likely be depressed until revegetation is complete. In mud flats, decomposer population levels may quickly return to pre-infestation levels. Increased turbidity would temporarily reduce light penetration in the water and consequently, reduce primary productivity.

Potential for Spread of Noxious Species to Unaffected Areas

Hand removal methods may contribute to the spread of *Spartina*. It is spread by dispersal of seed, rhizome fragments, and entire plants. Dislodged rhizomes may float to new sites and establish new colonies. It is essential that pulled plants be disposed of away from estuarine habitats to prevent vegetative regrowth and/or seed dissemination. Seeds or rhizome fragments may inadvertently be redistributed within the treatment site or transported to new sites in mud attached to the footwear and clothing of workers, or on vehicles and boats entering the treatment area. *Spartina alterniflora* and *S. anglica* seeds overwinter but do not persist to the following year and, therefore, do not form long-lived seed banks (Sayce and Mumford 1990; Hartman 1988).

Air Quality

Air quality would not be affected by hand pulling or digging *Spartina*. Emissions would be produced by the combustion of gasoline and diesel oil used to power transport machinery. The small amounts produced, however, are not likely to significantly impact air quality. Rotting *Spartina* waste hauled away from tidal areas could emit odors.

Aesthetics, Recreation, and Cultural Resources

Manual removal may have either a positive or negative impact on aesthetics, depending upon the attitude of the observer. *Spartina* clumps or larger colonies would be replaced by mud patches, which would temporarily have uneven, possibly unattractive surfaces. The patches would either blend in with continuous mud flats or contrast with vegetated marshes. The visual appeal of sites currently infested with *Spartina* would be increased for those people who prefer appearances of natural settings.

Removal of *Spartina* colonies may interrupt recreational use while treatments are in progress. Beach areas would ultimately be improved for walking, bird watching, hunting, and shellfish harvesting. In areas where *Spartina* colonies have accreted sediments to the extent that boating is curtailed, *Spartina* removal may eventually result in reestablishment of boating areas.

Subsidence has submerged archeological sites in some areas. Some of these areas may currently be vegetated with *Spartina*. Manual control measures could potentially disturb or destroy unidentified cultural resources on or near the soil surface.

Human Health

The eradication of *Spartina* colonies would have no adverse impacts on human health. However, hand pulling exposes workers to the hazards of physical contact with the plants. Ungloved hands may become irritated or blistered from sustained periods of uprooting the plants. Chronic back problems, arthritis or other such ailments may be exacerbated in some workers engaged in pulling operations; others may develop such ailments. Falls may occur when traversing uneven terrain or upon contact with slippery soils. Mudlucks require the user to walk with legs spread more widely than customary and may stress leg joints after prolonged use. Workers may become stuck in deep, soft sediments if improperly equipped and be exposed to cold temperatures or incoming tides. Certain individuals may experience allergic reactions upon contact with pollen produced by *Spartina* or other plants in the habitat.

Agricultural/Aquacultural Environment

Total eradication of *Spartina* populations would eliminate potential agricultural uses of the plants in Washington. Spartina is grazed by livestock in parts of the world (Doody 1990). *S. x townsendii*, and probably other species as well, have potential for cropping as silage (Hubbard and Ranwell 1966). In England, *S. anglica* has been studied for use in methane generation or production of gases, tars, or char (Scott *et al.* 1990). It has also been used locally for making paper. In Willapa Bay, Andrew Wiegardt (pers. comm., 1992) has been experimenting with producing hand-made paper from *S. alterniflora*. Aerial portions of plants are harvested with a line trimmer, shredded, and boiled to produce a pulp suspension. Tests conducted by Georgia Pacific showed that pulp content and fiber quality of *S. alterniflora* are comparable to or better than most wood pulp (A. Wiegardt, pers. comm. 1992). The Quillayute Tribe has used *Spartina* as a binder and as decoration in making baskets (K. Hansen, pers. comm. 1992). Other potential products include mats for erosion control, room dividers, flooring, and baskets (A. Wiegardt, pers. comm. 1992; Stiles undated).

Components of the aquacultural environment potentially adversely impacted by *Spartina* infestations or control measures include oyster beds and clam beds. Measures for *Spartina* control or eradication may also have impacts on the aquacultural environment. Floating aquaculture, such as red algae (nori) cultivation should not be adversely affected by either *Spartina* infestations or measures for their control.

Sediments/Soils

Sediment redeposition on oyster or clam beds may have detrimental effects. Way (1987) reported a case in which oyster beds were smothered by sediments that may have come from mudbanks of recently eradicated *Spartina*. Other effects would be similar to those occurring in the natural environment.

Water Quality and Movement

Water quality may be temporarily diminished by suspension of fine sediments during digging. Other effects would be similar to those occurring in the natural environment.

Agricultural/Aquacultural Practices

Spartina colonies used for grazing, sources of paper fiber, or other agricultural purposes would be harmed by control measures. In addition, Spartina has detrimental effects on oyster and clam beds because of accretion of fine sediments and formation of dense root mats. Therefore, removal of *Spartina* could increase available habitat for aquaculture.

Built Environment

The built environment includes any area constructed, and often managed, by humans. Examples of built environments include inhabited areas, industrial areas, harbors, and parks. Impacts of physical control methods in built environments would be similar to those occurring in the natural environment. They are discussed in this section only when there are additional concerns.

Sediments/Soils

Areas in which *Spartina* aids in shoreline stabilization and protection of structures or managed landscapes would be adversely affected by colony removal. However, this does not appear to be an important function of *Spartina* in Washington.

Recreation

Access to, use of, or quality of recreation sites would not be permanently impacted, although access to beaches and mudflats may be temporarily restricted. Manual removal of plants on beaches and around watercraft launching facilities would improve , boating and other water-related sports. Noise from use of motorized vehicles could annoy local residents.

Maintenance Practices

Hand pulling and digging *Spartina* typically should not adversely impact maintenance practices in built environments. If *Spartina* is providing beach stabilization, alternative shoreline stabilization measures would be required upon its removal. Practices could be incorporated into existing maintenance and beautification programs to help prevent *Spartina* establishment or spread.

Cumulative Effects

Significant cumulative affects of hand pulling or digging extensive *Spartina* colonies in bays or enclosed waterways include negative impacts to non-target biota, especially TES species (if present), whose populations may suffer long-term declines. Recreation and tourism could be impacted due to noise from motorized devices used for removing plants, and exclusion from areas undergoing control treatments. Sediment dynamics may be altered, with positive or negative affects. Eelgrass beds and associated plants and animals may be smothered by sediments. Repeated entry by workers and repeated pulling or digging treatments could produce substantial habitat disturbance and lead to increases in water turbidity and soil compaction.

Positive cumulative effects of controlling *Spartina* by hand pulling or digging would occur from the on-site reestablishment of desirable habitats. Wildlife habitat, scenic vistas, and recreational opportunities would be benefitted by site rehabilitation.

2.1.1.3 Mitigation

Potential negative impacts caused by hand removal methods include *Spartina* dispersal to new sites, adverse changes in sediment dynamics, death of non-target species, temporary degradation of water quality, temporary loss of habitat, adverse impacts to human health, and loss of cultural resources. Before initiating control measures, surveys should be done in the project area to determine potential impacts on affected resources, built environments, and aquacultural and agricultural practices. Steps should be taken to avoid or minimize adverse impacts.

Workshops should be conducted in communities where *Spartina* infestations occur to educate the public about *Spartina* identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

Before hand removal of *Spartina*, unless there is no possibility of harming non-target plants, a search of the Washington Natural Heritage Information System, which is a database of known localities of TES species, should be conducted for the vicinity of the treatment site. Sites near known TES species populations or ones in which large areas may be impacted should be examined for TES species. Measures should be taken to avoid or minimize impacts to TES species. Habitats should be enhanced for TES species, when these occur in the vicinity.

Sites should also be surveyed for cultural resources prior to the initiation of any activities that might damage the resources. The State Office of Historic Preservation and appropriate Native American tribes should be consulted for records of known cultural sites. Identified sites should then be managed to protect significant scientific and interpretive values.

It may be impractical for individual landowners to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to act as a repository of information on TES species and cultural resources for a geographic region (*e.g.*, Willapa Bay). This agency could then identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Hand removal treatments should be timed to avoid disruption of fish spawning in eelgrass beds and salmon migration through estuaries, and to minimize noise disturbance to wildlife, tourists, and recreationists. Precautions should be taken to prevent oil and fuel from motorized equipment from entering waterbodies. Workers should wear mudluks when walking on soft sediments to minimize soil disturbance.

Containment booms can be placed to intercept floating propagules where large stands of *Spartina* are pulled or dug. The vicinity of the treatment site should be inspected for propagules at different times of the tide cycle. Vehicles and footwear should be cleaned before leaving the site to avoid dispersal of seeds or vegetative propagules to new sites. To minimize seed dispersal, hand pulling should be done before seed set. To avoid replanting rhizome or root fragments, mud removed during digging should be transported away from tidal areas. Bare areas left in vegetated salt marshes should be planted with native vegetation after complete eradication of *Spartina*. Soil removed while digging could be used to refill pits in salt marshes or tidal flats after all propagules have perished, although this may not be desirable in some areas where sediment accretion has had adverse impacts.

Hand removal techniques are labor-intensive. However, labor required for *Spartina* control could create jobs. Personnel involved in implementing control methods should receive appropriate safety training.

2.1.2 Covering

Spartina species grow in open sun and cannot tolerate moderate to dense shade. Covering methods use black geotextile fabric, black plastic, or heavy soil fill to block light and smother *Spartina* plants. Wracks of cut vegetation and vegetable fiber mats, which would eventually degrade, have also been proposed (Aberle 1990). Large black plastic sheets or geotextile fabric mats are easily made and are also used under highways, for lining landfills, and for landscaping projects (Aberle 1990). A typical geotextile fabric used for covering *Spartina* is Mirafi 700x, which is made of woven polypropylene and is sold in 3.7m by 91.4m (12ft by 300ft) rolls weighing 81kg (179lb).

2.1.2.1 Efficacy

Several attempts have been made to control *Spartina* using black plastic sheets or woven plastic fiber coverings, with varying success.

Geotextile fabric mats (700X Mirifi) were applied to 12 *Spartina* clones approximately 3 meters (10 ft) in diameter at the Willapa National Wildlife Refuge in 1989 (Hidy 1989). Each clone had been mowed the previous day and tides had removed cut grass stems from the sites. The mats were gas and water-permeable but did not allow light to penetrate . They were anchored over the clones by reinforcing hem lines around the edges of the mat with cord, and securing with cords tied between grommets in the fabric and 1.2-m (4 ft) wood lath stakes driven at least one meter (3.3 ft) into the mud. After three and a half months *S. alterniflora* plants had grown beyond the edges of the mats. This was attributed to incomplete covering of the clones at the outset of the experiment. Mats remained anchored and only two yellowed leaves remained among the dead or dormant stubble in the one plot for which final results were given. Rhizomes and roots were not killed. In other plots, after nearly one month of covering (beginning August 10), resprouted stems were horizontal and leaves were curled and faded. It was estimated that better results would be obtained if clones were covered earlier in the growing season. Fabrication of mats, mowing, and placement of mats for each patch took an average of 3.1 person hours, although it is not clear whether this included transportation to and from the site. Materials for a 3.7 by 3.7-m (12 by 12 ft) mat cost approximately $50. Hidy found no detectable deterioration of the mats after one season and estimated that the mats could be used at least three seasons .

A 450 m^2 (4800 m^2) patch of *S. alterniflora* in Humboldt Bay, California has been treated by diking off the patch, cutting the stems at the soil surface, and covering with black geotextile fabric (K. Kovacs, pers. comm. 1993; see also Eicher and Sawyer 1989). The fabric was measured out and cut before being hauled out to the site, was attached to gabions (wire cages filled with rock) used for dike construction, and weighted down with sand bags. The *Spartina* patch was killed after about 2 years, probably due to the covering treatment (K. Kovacs, pers. comm. 1993). At this time, the geotextile fabric covers have been in place for 3.5 years and show little sign of degradation.

In Willapa Bay, a double-layer cover was applied to 120 circular clones, 0.3-1 m (1-3 ft) in diameter (DNR 1992). Clumps of *Spartina* with secure covers were killed after one year . Covers installed in September didn't accumulate enough sediment to hold them in place and came undone during winter storms. Covers were difficult to remove at the end of the treatment due to accumulated sediments. It was suggested that the treatment would not be practical on a large scale, although size limits for treatment areas were not discussed.

Frequent causes of failure of covering attempts include inadequate anchoring, which often results in dislodging of all or a portion of the plastic (Frenkel 1990). Torn plastic or improperly sealed seams between plastic sheets may allow plants to grow through the plastic (L. Kunze, pers. comm. 1992). In Dosewallips estuary, a Department of Natural Resources crew found that black plastic sheets shattered and added to marine plastic debris when used for *S. patens* control (J. Civille, pers. comm. 1992). They subsequently applied geotextile fabric, which they found to be difficult to handle when wet. They filled sandbags to anchor the corners, and stretched ropes between stacks of sandbags to keep the fabric in place.

Studies conducted by the University of Georgia showed that *S. alterniflora* can be smothered with 15.2 or more centimeters (6 or more inches) of silt or clay (Landin 1990). Inadequate depths of fill may improve the habitat for continued *S. alterniflora* growth, however, and filling must be carefully controlled and monitored (Landin 1990). Federal and/or state regulations may prohibit application of fill materials in salt marshes as a method for *Spartina* control.

To restore a site to pre-invasion conditions, accreted sediments would have to be removed (either by digging or through erosion) to restore former elevations. In areas vegetated prior to invasion, plantings (eelgrass, salt marsh plants) may also be required to ensure rapid regrowth.

Seasonal and Access Constraints

Covering *Spartina* may be hampered by high tides and stormy weather. Covers should be installed early in the growing season to curtail replenishment of food reserves and to minimize mowing pretreatments.

2.1.2.2 Environmental Impacts

Natural Environment

Sediments/Soils

Spartina plants killed by covering have intact (though dead) root and rhizome systems that decompose slowly. The decomposing roots and rhizomes continue to anchor sediments, especially in areas with weak or moderate tidal flows. Following eradication, however, there would be short-term increases in surface erosion, especially along stream banks and tidal channels. Sediment dynamics could be altered, with either beneficial or harmful effects. The weight of humans would result in temporary compaction of soils. During installation of covering materials, trampling and soil compaction would likely occur and pits may be produced. Fill placed in salt marshes may move to non-target areas due to daily tidal fluctuations.

Water Quality and Movement

Short-term increases in water turbidity may occur from activities associated with installation and monitoring treatment sites.

Mortality of Non-Target Biota

Areas in which *Spartina* stands have been killed by covering tend to have soils that are more anaerobic relative to soils in living stands (Hemminga *et al.* 1988). Hartman (cited in Aberle 1990) noted that covering with wracks of dead vegetation led to the buildup of sulfides in the soil and resulted in conditions toxic to many organisms. Hackney (1987 cited in Hemminga *et al.* 1988) found no significant effects of reduced soils on below-ground decomposition rates.

Infauna susceptible to elevated sulfide concentrations may die if covered with black plastic. Soil compaction and trampling associated with activities required for covering with plastic or soil may lead to death of infauna. Infauna and epifauna populations would be temporarily affected by changes in sedimentation and erosion, both within the area treated and in adjacent areas.

Improperly installed covers could trap epifauna and fish, although no animals were found trapped under fabric mats placed over *Spartina* clones in Willapa Bay (Hidy 1989) or Humboldt Bay (K. Kovacs, pers. comm. 1993). Unattached plastic or cord could entangle or smother marine mammals, fish, and seabirds.

Filling marshes with soil may destroy animals and plants utilizing them. Undetected populations of TES plants and/or animals could be harmed by covering with plastic or soil.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Competition between *Spartina* and more desirable wetland plant species would be reduced. Animal and plant populations such as infauna, eelgrass, and others, would be eliminated under coverings during control treatments. These may reoccupy the habitat once the disturbance ceases and native vegetation or mudflats are re-established. However, effects of alteration of sediment chemistry during control treatments on the reestablishment of native habitats are not known. Wading birds may be affected by loss of *Spartina* marshes. Herons and bitterns have been observed hunting in *S. alterniflora* stands in Willapa Bay (K. Sayce, pers. comm. 1992). Loss of these stands may adversely impact populations of these species.

In Humboldt Bay, California, large concentrations of rock crabs are utilizing the space under a black geotextile fabric cover that was put in place 3.5 years ago (K. Kovacs, pers. comm. 1993). They burrow into the mud, eat detritus from rotting vegetation, and take shelter under the cover from predators. When the cover was first put down, few crabs were seen, but utilization has since increased. The cover also provides roosting sites for shorebirds. Available roosting sites are limited in the area.

Trophic Interactions

Temporary increases in *Spartina* detritus would result in an increase in detritivore processing. Following this, decomposer population levels would be expected to decrease in salt marshes until revegetation is complete. In mud flats, decomposer population levels may quickly return to pre-infestation levels.

Eradication by covering would initially leave dead root and rhizome systems intact. In general, salt marsh species annually produce roots and rhizomes that equal or exceed above-ground production (Hemminga *et al.* 1988). Decay of dead *S. anglica* rhizomes and roots took 2.0-3.9 years when they were buried in soil at the sites from which they were taken. Decay took place in three phases: rapid biomass loss of the litter, active microbial decomposition, and slow decay of microbe-resistant materials. This study used experimental plots placed in living stands of *Spartina*. Thus, decay rates may vary for stands killed by covering.

Potential for Spread of Noxious Species to Unaffected Areas

Potential for spread is minimal, although workers walking through *Spartina* colonies may dislodge propagules, which could be dispersed to other sites.

Air Quality

Rotting *Spartina* may emit odors, but covering treatments are not likely to significantly impact air quality.

Aesthetic, Recreational, and Cultural Resources

Black plastic or other coverings, especially in natural settings, would be unattractive to most viewers. Unattached covering materials could litter beaches. Remains of dead plants after treatment may be unattractive. Recreational use of *Spartina* marshes, such as bird watching or hunting, would be eliminated. Control measures could potentially disturb or destroy cultural resources by direct impact or by changing erosion patterns.

Human Health

Worker risk would be greatest during site preparation (cutting/mowing/burning) prior to installation. Bending, lifting, or traversing uneven and slippery terrain could result in injury.

Agricultural/Aquacultural Environment

Effects of covering *Spartina* on sediments/soils, water quality and movement, and agricultural/aquacultural practices would be similar to those associated with the natural environment. Shellfish cultivation would be improved by the eradication of *Spartina*. Plant fragments may be washed out to open water and foul fishing nets. *Spartina* colonies used for grazing, as sources of paper fiber, or other agricultural purposes, would be harmed by control measures.

Built Environment

Effects on sediments/soils, water quality and movement, and cultural and aesthetic resources would be similar to those occurring in the natural environment.

Recreation

Covering treatments should not adversely impact recreation sites. Access to beaches and mudflats may be temporarily restricted. Eradication of *Spartina* could improve boating and other water-related sports.

Maintenance Practices

Covering treatments should not adversely impact maintenance practices in built environments. If *Spartina* is used for beach stabilization, alternative shoreline stabilization practices would be needed. *Spartina* removal methods could be incorporated into existing maintenance and beautification programs to keep sites free of *Spartina* and prevent its continued spread.

Cumulative Effects

Significant cumulative affects from covering *Spartina* colonies in bays or enclosed waterways could include negative impacts to non-target biota, including TES species, recreation and tourism, and accumulation of floating plastic litter. Following eradication, sediment dynamics could be altered. Trampling during repeated entry to install, monitor, and remove covers could produce substantial habitat disturbance from soil compaction and increases in water turbidity.

Site rehabilitation in former native salt marshes or mudflats would have significant positive effects, providing wildlife habitat, scenic vistas, and recreational opportunities.

2.1.2.3 Mitigation

Potential negative impacts caused by covering include adverse changes in sediment dynamics, death of non-target species including TES species, temporary degradation of water quality, temporary loss of habitat, adverse impacts to human health, and loss of cultural resources. Before initiating control measures, surveys should be done in the vicinity of the project area to determine potential impacts. Ways to avoid or minimize adverse impacts should be investigated.

Workshops should be conducted in communities where *Spartina* infestations occur to educate the public about *Spartina* identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Before application of fill, surveying should be done to map contours. After treatment, soil fill should be removed from the site and the original contours restored. Filled areas should be monitored to insure that fill is not shifted by tidal action.

In vegetated salt marsh areas, bare areas left after eradication of *Spartina* should be planted with native vegetation. Care should be taken to securely install covering materials.

Treatment sites should be monitored for fragmented or unattached covers, especially after storms. In areas with high bird or mammal use where these may be endangered by debris, covering may not be appropriate. Local residents should be informed of contacts for bird or mammal rescue. At the conclusion of treatments, covering materials, stakes, and anchoring cords should be removed from the site. Workers should wear mudluks when walking on soft sediments and use path systems to minimize soil compaction. Footwear should be cleaned before leaving the site to avoid dispersal of seeds or vegetative propagules to new sites. Personnel involved in field work should receive appropriate safety training.

2.1.3 Dewatering/Drainage

Dewatering/drainage control methods involve excavation of ditches or construction of dikes to exclude water from *Spartina* colonies. Construction is typically done with heavy equipment.

2.1.3.1 Efficacy

Draining wetlands may be effective in controlling *Spartina* infestations if the wetlands are adequately dewatered although, in many areas, habitat degradation of surrounding areas may outweigh benefits of *Spartina* eradication. Adequate drainage levels may need to be experimentally determined on a site-specific basis. Effectiveness of this control method for *Spartina* eradication is not known. Smith (1907 cited in Daiber 1974) suggested that ditching for mosquito control may actually enhance *S. patens* habitat by increasing water circulation and diminishing water logging. Moreover, the disturbance associated with ditch construction would increase chances for *Spartina* dispersal and spread.

Draining wetlands can have profound effects on species composition. Over a 10-year period following ditching, a pure stand of *S. alterniflora* covering a large area was mostly replaced by *Baccharis* (Bourn and Cottam 1950 cited in Daiber 1974). Habitat for tall forms of *S. alterniflora* was created adjacent to ditches provided water levels did not decline (Daiber 1974). Excavation of ditches by use of explosives to facilitate drainage has been suggested (Daiber 1974).

Dikes can be used to exclude water from an area. This technique may enhance upper marsh species and has been used to improve *S. patens* production and facilitate mechanical harvest (Daiber 1974).

To restore a site to pre-invasion conditions, accreted sediments would need to be removed to restore former elevations. In areas vegetated prior to invasion, plantings (eelgrass, salt marsh plants) may also be required to ensure rapid regrowth.

Seasonal and Access Constraints

Dewatering/draining should be done during the summer, when *Spartina* plants located higher in the marsh may be subjected to moisture stress. Moisture stress following treatment would be accentuated during the dry part of the year because of depressed water tables, increased insolation, increased temperatures, greater evapotranspiration rates, and less precipitation. Construction may be hampered by high tides and stormy weather.

2.1.3.2 Environmental Impacts

Natural Environment

Sediments/Soils

Following dewatering, surface erosion along stream banks and tidal channels may increase. Sediments could be redeposited outside the treatment area, if not contained. Soil chemistry would be altered by changes in hydrology, causing greater soil oxidation. Ditch or dike construction can cause soil compaction from foot traffic and vehicle tracks.

Water Quality and Movement

Construction of dikes or excavation of ditches would temporarily increase water turbidity. Decomposition of litter could cause increased nutrient and/or decreased dissolved oxygen levels. Improperly maintained machinery may release fuel or oil into the water. Biofiltration functioning of drained wetlands may be compromised. Water circulation patterns would be altered within the wetland and possibly in nearby deepwater habitats.

Mortality of Non-Target Biota

Draining *Spartina* colonies could change the hydrology of areas upslope of infestations targeted for treatment and may kill wetland plants and animals in these areas. Changes in wetland hydrology and soil oxidation levels in the treatment area would eliminate species intolerant to these changes that are unable to move to more favorable habitats. Dewatering would subject species to new competition from upland or upper marsh species. Ditch excavation, construction of dikes, soil compaction from heavy machinery, and trampling may lead to death of plants, infauna, and epifauna. Sediment transported away from the site could smother biota. Undetected populations of TES plants and/or animals (when present) could be harmed.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

If pretreatment hydrology can be restored after removal of dikes or filling of ditches, wildlife and plant habitat may return to preinvasion conditions. However, this process may take a considerable amount of time.

Ditching leads to marked declines in invertebrate fauna in tidal marshes. 43.5% of invertebrates, mostly mollusks and crustacea, were lost from a *S. alterniflora* association after ditching (Daiber 1974). In a *S. patens* association, 84.2% of the invertebrates were lost. These numbers reflected losses from both mortality and emigration.

Trophic Interactions

Detritus levels in *Spartina* marshes would temporarily increase from dewatering or draining, causing increases in detritivore populations. As vegetation changes to respond to new hydrological regimes, the amount of organic detritus may be reduced. This would limit detrital inputs to surrounding waters. At completion of the treatment, dikes would be removed, causing further loss of vegetation and increases in detritus. The process would be stabilized only after reestablishment of mudflats or native vegetation.

Potential for Spread of Noxious Species to Unaffected Areas

Heavy machinery used for ditch excavation or dike construction could dislodge rhizome fragments or entire plants. Propagules may be dispersed on vehicles or footgear or clothing worn by workers.

Air Quality

This control method is not likely to significantly impact air quality.

Aesthetics, Recreational, and Cultural Resources

Ditches or dikes and dead or dying patches of *Spartina* may be unattractive to viewers. Recreational use may be interrupted during construction for public safety. Boating may be adversely impacted by changes in water circulation and presence of dikes. Construction of dikes or ditches could disturb or destroy unidentified archaeological sites.

Human Health

Dewatering or drainage of *Spartina* wetlands should not affect human health. Workers would be exposed to hazards associated with the use of heavy equipment. They could be exposed to temperature extremes or stormy weather.

Agricultural/Aquacultural Environment

Dewatering *Spartina* marshes in agricultural/aquacultural environments would have similar impacts on sediments/soils and water quality and movement as in natural environments.

Agricultural/Aquacultural Practices

Available habitat for shellfish cultivation may be improved by eradication of *Spartina*. *Spartina* colonies used for grazing, as sources of paper fiber, or for other agricultural purposes would be harmed by control measures. Dewatering wetlands may change hydrology of cultivated fields nearby and affect irrigation practices.

Built Environment

Effects on sediments/soils, water quality and movement, aesthetics, cultural resources, and recreation would be similar to those occurring in the natural environment.

Recreation

Dewatering/draining treatments could impact recreation sites. Access to beaches and mudflats may be temporarily restricted. Eradication of *Spartina* could improve boating and other water-related sports. Noise from earth moving equipment could discourage recreational use and annoy local inhabitants. Ditches could be hazardous to swimmers or people walking in wetlands.

Maintenance Practices

Dewatering/draining treatments should not adversely impact maintenance practices in built environments. If *Spartina* is in use for beach stabilization, alternative stabilization practices would be needed.

Cumulative Effects

Dewatering/draining *Spartina* colonies in bays or enclosed waterways could have significant cumulative effects. Recreation and tourism may be impacted due to noise from motorized equipment, and exclusion from areas from which treatments are being performed. Sediment dynamics would be altered, and non-target biota may decline. Widespread dewatering of wetlands could lead to water contamination from agricultural runoff or other pollutants due to loss of biofiltration functions. Wildlife habitat would be altered while ditches or dikes were in place, possibly with long-term affects.

2.1.3.3 Mitigation

Potential negative impacts caused by dewatering/draining *Spartina* wetlands include adverse changes in sediment dynamics, death of non-target species including TES species, temporary degradation of water quality, temporary loss of habitat, adverse impacts to human health, loss of cultural resources, dispersal of propagules to new sites, and soil compaction. Surveys should be done in the treatment area before ground-disturbing activities occur to determine potential detrimental impacts. Steps should be taken to avoid or minimize adverse impacts.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Before construction of ditches or dikes, surveying should be done to map site topography. After treatment, ditches or dikes should be removed from the site and the original contours restored if appropriate. Bare areas left in salt marshes after eradication of *Spartina* should be planted with native vegetation. Navigational maps should be updated to reflect changes in bottom contours resulting from alterations in water circulation patterns. Personnel involved in implementing control methods should receive appropriate safety training.

2.1.4 Flooding/Inundation

Due to decreased oxygen availability to plant tissues, *Spartina* species cannot tolerate permanent inundation and must be exposed during part of the day (Aberle 1990). Flooding tolerance may be somewhat site-specific and eradication attempts employing flooding should take into consideration flooding tolerance of the population at the treatment site. In England, *S. anglica* plants tolerate immersion for up to 23 hours during neap tides (Hubbard 1969). The lower limit of *S. anglica* in England and New Zealand coincides with the level of low neap tide (Hubbard and Partridge 1981). *S. alterniflora* may survive to a depth of 0.24 m below mean low water in its native range (McKee and Patrick 1988). *S. patens* occurs in middle and upper reaches of salt marshes, possibly due to its decreased ability to supply oxygen to underground organs during flooding (Gleason and Zieman 1981). In areas where both species occur, flooding of low-level impoundments may lead to replacement of *S. patens* with *S. alterniflora* (Daiber 1974).

Dikes can be used to flood or inundate *Spartina* colonies. Dikes should be constructed to be impermeable to water, to withstand tidal fluctuations and storms, and to be readily removed once the treatment is completed. The most economically built dikes that satisfy these requirements are made primarily of boulders 0.9-1.2 m (3-4 ft), but not less than 30 cm (1 ft) in diameter (B. Prabhakar 1993). These should be mounded with a slope no greater than 1:1.5 (rise:run) to the height required to adequately flood the *Spartina* colony. Polyvinyl chloride (plastic) liner, which is also used to line artificial ponds and some waste disposal sites, would be stretched along the slope of the dike facing the impoundment to make the dike impermeable to water. The plastic would need to form a water-tight seal at the base of the dike and this could be done by burying its lower edge in the mud or sand. Rock for dike construction can be brought in by three methods: 1) by land across the salt marsh at low tide, using backhoes or other heavy equipment; 2) by sea at high tide, using barges and cranes; or 3) along the top of the dike, using trucks and other heavy equipment. If rock is brought in along the top of the dike, the dike would need to be at least 2.4-3.0 m (8-10 ft) wide to accommodate vehicular traffic. A water control structure, such as a stoplog weir, could be used to regulate flows of water exiting the impoundment.

To restore a site to pre-invasion conditions, sediments accreted by *Spartina* would need to be removed and former elevations restored. In areas vegetated prior to invasion, plantings (eelgrass, salt marsh plants) may also be required to ensure rapid regrowth.

2.1.4.1 Efficacy

Flooding as a method of eradicating *Spartina* may be practical in some areas, such as small lagoons or embayments where dikes would not be subjected to high wave energy, and where hydrology is adequate to maintain deep pools. It would probably not be feasible or economical to control larger expanses of the grass (Aberle 1990). Additionally, the disturbance associated with dike construction may increase the chance for *Spartina* dispersal and spread.

Spartina may persist at higher elevations around the boundaries of impounded lagoons and care must be taken to ensure that an entire colony is adequately flooded. This technique would not work for populations reproducing by seed. Seeds may germinate and re-establish colonies in the shallow waters of a lagoon.

In Humboldt Bay, California, a 450 m^2 (4800 m^2) patch of *S. alterniflora* has been treated by diking an area surrounding the patch, cutting the stems at the soil surface, and covering with black geotextile fabric (K. Kovacs, pers. comm. 1993; see also Eicher and Sawyer 1989). This dike was primarily intended to prevent *Spartina* spread and to inhibit oxygen and nutrient exchange by obstructing tidal action, and not to permanently flood the patch. The dike was constructed of rock-filled gabion baskets with dimensions of 0.9 by 0.9 by 1.5 m (3 by 3 by 5 ft), which were stacked in 3 layers. A vertical layer of visqueen plastic was incorporated in the gabions to limit water movement through the dike. The total cost of construction of the dike and placement of covers was approximately $55,000. The largest component of this cost was for placement of the gabions using a crane. The dike will eventually be removed, as required by provisions of all permits for its construction, and removal is expected to cost approximately $40,000. After two years, the *Spartina* patch was killed, probably due to the covering treatment. The primary beneficial affect of the dike may have been to limit the spread of rhizomes beyond the dike. Tidal action was not impeded because tears in the visqueen occurred during installation of the gabion baskets. The shear weight of the gabions (approximately 2.7 metric tons [3 tons] each) may have sufficiently compacted the mud substrate to prevent rhizome growth beyond the dikes (K. Kovacs, pers. comm. 1993). K. Kovacs (pers. comm. 1993) indicated that important factors in use of dikes for control of *Spartina* include cost (diking is very expensive) and accessibility of the site. The patch treated in Humboldt Bay was readily accessible to machinery used in placing the gabions, but less accessible sites may further constrain practicality of this control method.

On a small scale, Garbisch (cited in Aberle 1990) proposed to place short cylinders around clumps of *Spartina*. These would fill with water during incoming tides and increase the length of time the clump was submerged. Similar proposals have suggested driving corrugated metal into mud surrounding infestations to retain water over patches of *S. patens* for greater periods of time. Water could be admitted using a tide gate or pump (Minter cited in Aberle 1990).

Seasonal and Access Constraints

Dike construction could be done during any season when high waves would not threaten the integrity of the dikes. However, it may be more effective when hydrology from tides is supplemented by high water tables and high levels of precipitation. Flooding would be accomplished more rapidly and possibly, to a greater depth under these conditions. In some areas, construction may need to be done during the dry season to allow access of heavy earthmoving equipment. Construction should be scheduled to avoid stormy weather. Barges used for delivering rock should be brought in at high tide.

2.1.4.2 Environmental Impacts

Natural Environment

Sediments/Soils

Changes in water circulation patterns inside and outside the treatment area may alter sediment dynamics, with various effects. Dike construction can cause soil compaction from foot traffic and vehicle tracks. Soils could become anaerobic.

Water Quality and Movement

Construction of dikes would temporarily increase water turbidity and possibly increase nutrient or decrease dissolved oxygen levels. Oil and fuel from machinery may enter waterbodies. Water circulation patterns would be changed by the presence of dikes. Due to creation of lagoons with increased water depths, the elevation of the water table may, in rare cases, be elevated adjacent to the lagoons, possibly causing infusion of saline water farther inland and contamination of freshwater ponds. Freshwater/saltwater mixing and salinity levels may be altered in the treatment area (Daiber 1974).

Mortality of Non-Target Biota

Many species of plants and animals subjected to flooding in the lagoon would not survive. Species outside the lagoon may be affected by altered water circulation patterns. Construction of dikes, soil compaction from heavy machinery, and trampling may kill plants, infauna, and epifauna. Biota would be temporarily affected by changes in erosion, sediment transport, and water circulation patterns, both within the area treated and elsewhere. TES plants and/or animals, if present, could be harmed by flooding or inundating the wetlands.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Diking would have a detrimental effect on fish habitat by limiting fish access to impounded areas. Fish migration may also be impacted (C. Samuelson, pers. comm. 1992). Dikes could impede seal or sea lion access to areas used for reproduction (seals) and foraging, and as haul-out or resting sites (P. Gearin, S. Osmek, pers. comm. 1993). Warning lights placed on dikes could potentially impact marine mammals (P. Gearin, S. Osmek, pers. comm. 1993). Man made structures such as dikes, breakwaters, and log booms have been used as haul-out sites by seals and sea lions in Washington (S. Osmek, pers. comm. 1993). Impoundments may increase habitat diversity by providing interspersed uplands and wetlands and increasing edges between uplands and emergent wetlands and between emergent wetlands and deepwater habitats. This may be beneficial to wildlife (Daiber 1974). Completion of flooding treatments would involve removal of dikes, and there may be insufficient time during the treatment for habitat diversity to fully develop or be beneficial.

Trophic Interactions

Initially, detritivore populations tolerant of flooded and perhaps anaerobic conditions would be enhanced. Detrital inputs to surrounding waters would be reduced due to decreased water exchange. Dikes would be removed at completion of the treatment and newly established vegetation would be lost, resulting in increases in decaying material.

Potential for Spread of Noxious Species to Unaffected Areas

Rhizomes may be dislodged and dispersed during construction of dikes if these are immediately adjacent to *Spartina* colonies. Seeds may be transported on tracks of heavy equipment or on footwear. Rhizomes probably would not grow through the dikes and vegetative spread should be contained (Aberle 1990).

Air Quality

Rotting vegetation and anaerobic soils could release foul odors.

Aesthetic, Recreational, and Cultural Resources

Dikes, cylinders, or metal containment structures would be unattractive while in place. These would be removed after the colony was eradicated. Dead or dying patches of *Spartina* may be unattractive to viewers. Construction may temporarily interrupt recreational use. Boating may be adversely impacted by changes in sediment deposition and water circulation. Cultural resources could be destroyed or damaged by changing erosion patterns or dike construction.

Human Health

Human health should not be adversely impacted by flooding treatments. Operation of heavy equipment during the construction of dikes could be hazardous. Flooding may create mosquito habitat (Daiber 1974), or areas unsafe for swimmers.

Agricultural/Aquacultural Environment

Effects of flooding *Spartina* on sediments/soil stability and water quality and movement would be similar to those associated with the natural environment.

Agricultural/Aquacultural Practices

Spartina colonies used for grazing, as sources of paper fiber, or for other agricultural purposes would be harmed by flooding. Flooding wetlands may change hydrology of nearby cultivated fields and affect crop health and vigor.

Built Environment

Effects on sediments/soils and cultural and aesthetic resources would be similar to those occurring in the natural environment.

Water Quality and Movement

In addition to impacts described for the natural environment, diking would change water circulation, leading to changes in erosion and sediment deposition that could alter navigable areas and cause hazards.

Recreation

Flooding treatments could have minor impacts on recreation sites. Access to beaches and mudflats may be temporarily restricted. Eradication of *Spartina* would improve , boating and other water-related sports. Noise from heavy machinery could discourage recreational use and annoy local inhabitants. Ponds and lagoons could be hazardous to swimmers and may emit foul odors.

Maintenance Practices

Flooding of *Spartina* colonies may impact beautification practices near parks and inhabited areas. Navigable waters could be impacted by changes in water circulation and sediment deposition.

Cumulative Effects

Cumulative effects of flooding bays or enclosed waterways include negative impacts to non-target biota, recreation and tourism, fish migration, and wildlife habitat. Changes in water circulation patterns and sediment dynamics could impact boating, aquaculture, and surrounding native habitats.

2.1.4.3 Mitigation

Potential negative impacts caused by flooding *Spartina* wetlands include adverse changes in sediment dynamics, death of non-target species including TES species, temporary loss of habitat, loss of cultural resources, and soil compaction. Before initiating control measures, surveys should be done in the project area to determine potential impacts on affected resources, built environments, and aquacultural and agricultural practices. Steps should be taken to avoid or minimize adverse impacts.

Dikes should be constructed of erosion-resistant material to withstand wave action. Topography of the affected area should be surveyed before construction of dikes. After treatment, dikes should be removed and the original contours restored, if appropriate. The size and pool elevation of the lagoon should be minimized, to avoid disrupting water flow patterns and habitats in other areas of the water body. Navigational maps should be updated to show dikes and to reflect changes in bottom contours resulting from alterations in water circulation patterns. Dikes may need to be lighted at night. Hydrologic studies should be conducted if freshwater wells are nearby to determine if impoundments could increase salinity in the wells. Personnel involved in implementing control methods should receive appropriate safety training. Bare areas left after eradication of *Spartina* should be managed to restore pre-infestation habitat either by leaving bare or by planting with native vegetation.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

2.1.5 Burning

Burning can be used as a method to curtail seed production or to reduce biomass and stress the plants. Prescribed burning in *Spartina* colonies is accomplished by igniting colonies or by flaming individual plants. The most appropriate type of fuel for use in salt marshes and other wetlands is propane (D. Dolstad, pers. comm. 1993). Other fuels, such as diesel, gasoline, or fuel oil may cause soil and water pollution if not burned completely. During colony ignition, workers walk along the edge of the stand with a propane flamer, creating a line of fire. If sufficiently dry, *Spartina* stems and leaves fuel the fire. In discontinuous patches, hay may be used to sustain burning between clumps. Alternatively, single plants or clumps can be flamed with a flame torch or other means to scorch plants without producing a self-sustaining fire. The heat destroys tissues by precipitating proteins and making them inactive (D. Dolstad, pers. comm. 1993).

2.1.5.1 Efficacy

Although not effective in eradicating infestations, burning can decrease the vigor of *Spartina* colonies and reduce chances of colony spread. In Georgia, Turner (1988) found that burning *S. alterniflora* reduced both peak biomass and net above-ground primary production by 35%. Following burning, *S. alterniflora* plants were smaller, but stem density was greater. Burning has been unsuccessfully tried to control *S. patens* in the Siuslaw Estuary, in Oregon (Frenkel 1990). Burning may be used to prevent seed production and to slow spread. Although no data are available, it is reasonable to assume that burning could be used to singe and reduce viability of seeds.

Spartina stands are often resistant to burning because of dried salt on above-ground parts and the daily wetting of vegetation. Dry litter is generally not present (Landin 1990). Thus, this control method may be feasible only at higher tidal elevations. Volatile fuel, such as diesel or gasoline has been used to ignite the plants and can be supplemented with dry hay to improve burning in areas where plants are spaced too widely to carry the fire (Turner 1988).

Seasonal and Access Constraints

Burning should be timed to allow for maximum drying of aerial portions of the plants. This occurs when tidal amplitude is low, midway between full moon and new moon (Turner 1988). Burning should be done before seed set if the objective is to control seed production and dispersal. Burning may be hampered by wet weather or high tides.

2.1.5.2 Environmental Impacts

Natural Environment

<u>Sediments/Soils</u>

Following burning, there may be short-term increases in surface erosion, changes in sediment dynamics, and temporary compaction of soils. Soil chemistry is affected by burning. Burning increases amounts of available nutrients, especially nitrogen, although total nutrients are diminished. In a study of burned *S. bakeri* marshes in Florida, Schmalzer and Hinkle (1992) found that changes in soil chemistry were most pronounced in the upper 5-cm (2 in) layer. Soil pH increased immediately post-burn but was restored to pre-burn levels in one month. Organic matter increased and remained elevated for at least nine months. Ca, Mg, K, PO_4-P, NH_4-N and NO_3-N levels increased and increases persisted for 6-12 months.

Water Quality and Movement

By-products from incomplete combustion of vegetation would enter waterways. Ash would temporarily increase nutrient levels. Short-term increases in water turbidity may occur from walking in the wetland.

Mortality of Non-Target Biota

Animals and aerial stems of plants living among *Spartina* colonies would be destroyed after a burn. Infauna and epifauna populations would be temporarily affected by changes in sedimentation and erosion if *Spartina* colonies are eliminated, both within the area treated and nearby. Burning may adversely impact populations of TES plants and/or animals. Fire-intolerant species may be eliminated if not reintroduced to the treatment area.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Fire-intolerant species would be eliminated, although some only temporarily. Temporary loss of wildlife habitat, until recolonization, would also occur. Fish populations may be affected by temporary loss of cover and pollution from ash.

Trophic Interactions

Most detritus would be removed by burning, although incomplete combustion would provide additional detritus from injured aerial stems and leaves. Decreased levels of decaying vegetation would locally reduce populations of detritivores and associated higher trophic organisms. *Spartina* would recover rapidly from this treatment because burning does not kill underground portions of plants. Single treatments would have minimal impacts to long-term trophic interactions.

Potential for Spread of Noxious Species to Unaffected Areas

There is little potential for spread of *Spartina* using this control method, although propagules may be dispersed on footgear or clothing worn by workers.

Air Quality

Air quality would be adversely impacted when burning stands of *Spartina*. Burning may be hampered by wet and salt-covered *Spartina* plants and combustion could produce harmful gases and suspended particulates. Burning cellulose in the presence of chloride (salt) may produce chlorinated dioxins and furans, which are highly toxic and carcinogenic compounds (A. Carpenter, pers. comm. 1992).

Aesthetics, Recreational, and Cultural Resources

Burned colonies, ash floating in nearby water bodies, and smoke could be unattractive to viewers. If smoke is toxic, recreationists would be excluded from the vicinity of treatment sites. Cultural resources could be burned or charred by heat from fires, crushed by foot traffic, or washed away by changes in erosion patterns.

Human Health

Human health may be endangered when fire is employed to manage noxious plant populations. Workers involved in conducting burns would be subjected to the greatest health risks. Contact with smoke could cause eye, throat, and lung irritation. Chronic exposure of workers to smoke, and possibly furans and chlorinated dioxins, may lead to long-term health effects such as emphysema or lung cancer. During combustion, herbicides from treated vegetation may be mobilized or produce breakdown products that would be injurious to workers. Individuals could also be injured by flame torches during ignition operations or by contact with burning vegetation.

Agricultural/Aquacultural Environment

Effects of burning on sediments/soils and water quality and movement in agricultural/aquacultural environments would be similar to those associated with the natural environment.

Agricultural/Aquacultural Practices

Shellfish cultivation may be improved by eradication of *Spartina*. *Spartina* colonies used for agricultural purposes could be harmed by control measures. Fires that get out of control could threaten fields and farm buildings. Water pollutants (dioxins, furans, may affect survival or edibility of shellfish.

Built Environment

Effects on sediments/soils, water quality and movement, and cultural and aesthetic resources would be similar to those occurring in the natural environment.

Maintenance Practices

Beautification practices in the vicinity of parks and towns could be adversely impacted.

Recreation

Recreation sites may be closed during burning treatments for public safety.

Cumulative Effects

Cumulative effects due to burning *Spartina* could be significant. Recreation and tourism would be impacted due to smoke, and exclusion from areas from which treatments are being performed. Air and water quality would be diminished. Non-target biota, especially TES species (if present), may suffer long term declines. Total eradication of *Spartina* would alter sediment dynamics.

2.1.5.3 Mitigation

Potential negative impacts from burning include adverse changes in sediment dynamics, death of non-target species, temporary degradation of air and water quality, temporary loss of habitat, adverse impacts to human health, and loss of cultural resources. Before initiating control measures, surveys should be done in the vicinity of the project area to determine potential impacts on affected resources, built environments, and aquacultural and agricultural practices. Steps should be taken to avoid or minimize adverse impacts.

Workshops should be conducted in communities where *Spartina* infestations occur to educate the public about *Spartina* identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Bare areas left in salt marshes after complete eradication of *Spartina* should be planted with native vegetation. Vehicles and footwear should be cleaned before leaving the site to avoid dispersal of seeds or vegetative propagules to new sites. Workers should wear mudluks when walking on soft sediments to minimize soil disturbance.

Acceptable safety standards for human exposure to smoke from burning *Spartina* should be established before initiating burning programs. Worker exposure to smoke should be minimized by use of masks and protective clothing. Adverse impacts to air quality could be mitigated by timing burns at low tides, when plants are more likely to be dry and combustion would yield less smoke. Burns should be done when winds would carry smoke away from inhabited areas. Local residents should be alerted to planned burning activities.

Herbicide-treated vegetation should not be immediately burned after spraying. This would minimize the risks of inhaling herbicide molecules upon combustion. Personnel involved in implementing control methods should receive appropriate safety training.

2.1.6 Explosives

Explosives have been suggested for use in draining wetlands (Daiber 1974). However, in a literature search, no reference to the use of explosives as a method for directly controlling *Spartina* infestations was found.

The most appropriate explosive for use in salt marshes is a high-explosive emulsion, due to its water resistance (B. Zylman, pers. comm. 1993). Other explosives are either more expensive (*e. g.*, plastic explosives), hazardous (*e. g.*, nitroglycerin), susceptible to moisture (*e. g.*, many types of dynamite), potential sources of water pollution (*e. g.*, ANFO, a mixture of ammonium nitrate and fuel oil), or ineffective. Typically, a charge would be placed in a hole drilled in the soil. In soft soils, holes can be drilled and expendable cardboard tubing slid down the outside of the augur bit (which is later removed) to prevent the borehole from collapsing while the charge is being placed (Morhard 1987). The high explosive emulsion is loaded into the borehole with a detonator (blasting cap) imbedded in a primer, and this is connected via a wire to a small hand-held electric generator. The hole is then filled with soil or rock to confine the energy released during the explosion.

2.1.6.1 Efficacy

Detonation of explosives in intertidal sediments results in the formation of craters. High pressure gases expand during the explosion and a spherical shock wave compresses and deforms the soil (Morhard 1987). Where shock pressures exceed the dynamic crushing strength of the soil, material is crushed, deformed, and heated. Soil and plant tissues are lofted into the air. No studies have been done on the effects of the explosions on *Spartina* plants, but it is reasonable to assume that plants within a certain distance of the center of the blast would be killed. Rhizome fragments may survive and be scattered around.

A single treatment may be sufficient for small patches of *Spartina*, although dispersal of propagules may have a net negative impact. Larger patches may require repeated treatments. Labor expenditures would be minimal and would involve placement and detonation of explosive charges. There are no seasonal or special access constraints.

2.1.6.2 Environmental Impacts

Natural Environment, Agricultural/Aquacultural Environment, and Built Environment

Environmental impacts would be similar for natural, agricultural, and built environments and are therefore discussed together.

<u>Sediments/Soils</u>

Explosives could have minimal or significant impacts on sediment dynamics, depending on how they are used. Isolated pools blasted in level colonies of *Spartina* would probably not result in much sediment movement, other than mud scattered during the explosion. The sediments lofted by the explosion might be trapped by surrounding *Spartina* vegetation. Channels created by explosives would transport sediments. Soil chemistry would be altered by changes in hydrology, resulting locally in greater soil oxidation or where ponds form, greater soil reduction.

Water Quality and Movement

Combustion products of explosives would probably be in low enough concentrations in the water to have negligible impacts. Water movement through *Spartina* colonies would be altered by channels or pools created by blasting.

Mortality of Non-Target Biota

Animals and plants in the blast area would perish or be injured. Changes in sediment dynamics could smother infauna, epifauna, and algae. Wetland hydrology and soil oxidation levels may change in excavated areas and could eliminate species intolerant to these changes that are unable to move to more favorable habitats. Undetected populations of TES plants and/or animals could be harmed.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Use of explosives to eradicate large patches of *Spartina* may lead to habitat degradation due to severe soil disturbance. Wildlife in the vicinity of the explosions would be startled or frightened. This may disrupt breeding activities. Soils would be severely disturbed and biota destroyed. Fish may be trapped at low tide in craters created by explosions.

Potential for Spread of Noxious Species to Unaffected Areas

Explosive charges detonated in *Spartina* colonies would scatter soil, rhizomes, whole plants, and seeds. Numerous propagules may survive. These could be washed out by tidal action and subsequently establish new colonies.

Air Quality

Detonations would probably not be frequent enough to significantly impact air quality.

Aesthetic, Recreation, and Cultural Resources

Heavily disturbed areas would be unattractive to viewers. Recreational use would be prohibited in the vicinity while explosives are being placed and detonated. Detonation of explosives could potentially disturb or destroy unidentified cultural resources. Adverse impacts could occur from foot traffic or changes in erosion patterns.

Human Health

Use of explosives could impact human health if charges are accidentally detonated or workers are struck by flying debris.

Cumulative Effects

Significant cumulative affects of exploding *Spartina* colonies include negative impacts on recreation and tourism, wildlife, water quality, and possibly sediment dynamics.

2.1.6.3 Mitigation

Potential negative impacts caused by explosives include changes in sediment dynamics, death of non-target species including TES species, temporary degradation of water quality, temporary loss of habitat, soil compaction, and loss of cultural resources. Surveys should be done of the project area before treatments to determine potential adverse impacts. Steps should be taken to avoid or minimize adverse impacts.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Appropriate safety training should be provided. Containment booms should be placed to intercept floating propagules and should remain in place through more than one tide cycle. Timing of treatments should be planned to minimize disturbance to recreationists and wildlife, especially during the breeding season for affected wildlife. Local residents should be alerted to planned activities.

2.2 PURPLE LOOSESTRIFE

Efficacies and impacts of the various physical methods for controlling purple loosestrife are summarized in Table 2.

2.2.1 Hand Removal

Equipment needed for hand removal of purple loosestrife is similar to that for *Spartina*.

2.2.1.1 Efficacy

Hand pulling can effectively eradicate an infestation of purple loosestrife, but it is extremely time consuming, laborious, and expensive. The labor force required to effect treatment of an infested site depends upon many variables, including stem density and topography.

Table 2. Efficacy and major environmental impacts associated with the various physical methods for controlling purple loosestrife. Mitigation opportunities for impacts are described in text.

Physical Control Method	Most Practical Applications	Use Constraints	Significant Environmental Impacts
Hand pulling or digging	Eradication of isolated plants or small, sparse infestations	Labor-intensive; multiple treatments may be required; plants must be readily accessible and old enough to be identified	Loss of substrate affixed to roots; increased potential for soil erosion; compaction of soils from foot traffic; regrowth from dislodged seeds could contribute to spread
Covering	Eradication of seedlings and reduction of older plant vigor in small, monospecific areas	Expensive and labor-intensive over a large area; treatment sites must be mowed or burned initially; wind or waves may dislodge covers	Desirable plants and infauna beneath covers would be impacted; compaction of soils from foot traffic; runoff from covers may cause downslope erosion
Dewatering/drainage	Eradication or reduction of young plants vigor in sparse infestations	Expensive; most effective during summer; not recommended for heavy infestations	Non-target plants and animals will be affected; disruption of aquatic food webs; drawdowns may enhance germination of seeds; disturbances associated with dike construction
Flooding/inundation	Eradication of young plants	Expensive; not feasible in croplands or pastures; spring flooding most effective; several years may be necessary to kill older plants	Non-target plants and animals will be affected; disturbances associated with dike construction

Table 2. Continued.

Physical Control Method	Most Practical Applications	Use Constraints	Significant Environmental Impacts
Burning	Controlled burning: large, continuous infestations; Flame torching: isolated plants, discontinuous patches; prevention or reduction of seed set; enhancement of plants susceptibility to other control methods	Spring burning most effective; effective only in drier sites	Non-target plants and animals may be impacted; air quality temporarily affected; increased potential for soil erosion; burning may enhance conditions for seed germination
Explosives	Removal of heavy infestations in waterways; creation of channels to flood infestations	Use may be prohibited in some areas	Non-target plants and animals, soil and water resources would be significantly impacted; new infestations could be established from regrowth of broken stems blasted out of control areas

Hand extraction of purple loosestrife in isolated, newly- or lightly-infested sites is feasible (Cutright 1978). Density at such sites should not exceed 200 plants/ha (80 plants/acre) (Rendall 1989). Manual removal is not cost effective in heavily infested sites. It is highly unlikely that a single pulling will effect complete removal of purple loosestrife from a site, particularly if the infestation is comprised of different aged plants. The entire rootstock must be pulled since regeneration from root fragments is possible. Stem fragments, if allowed to contact moist soil or water, may form adventitious roots and develop into additional plants to reinfest the treatment area (Thompson *et al.* 1987). In addition, plants older than one year are usually too firmly rooted and are thus unlikely to be hand pulled successfully.

Seasonal and Access Constraints

Hand pulling operations cannot usually begin until mid-July or early August when purple loosestrife plants are large enough to be readily identified. Earlier in the growing season, seedlings may be difficult to detect amongst other vegetation, and human-induced disturbance of soils during pulling operations may induce additional recruitment of purple loosestrife seedlings from the seed bank.

Manual removal of purple loosestrife is little affected by weather conditions. However, hand pulling is more readily facilitated from moist or wet soils.

Hand removal of *L. salicaria* is most effectively accomplished in sites easily reached by workers, vehicles, and boats. Plants growing along stream banks, shorelines, and in shallow water areas can readily be pulled. Plants occurring in more remote sites are difficult to access and thus are not amenable to hand pulling. The species composition and density of other vegetation at an infested site often influences its accessibility.

2.2.1.2 Environmental impacts

Natural Environment

<u>Sediments/Soils</u>

Hand extraction of purple loosestrife may remove small quantities of the substrate affixed to root masses. Removal of solid stands by hand methods may cause small, short-term increases in surface erosion, particularly along stream banks and shorelines, until vegetation reoccupies treatment sites. In flowing water habitats, plant removal may also decrease sedimentation rates. The weight of humans and machinery used in pulling and/or cutting operations will cause temporary compaction of wetland soils.

<u>Water Quality and Movement</u>

Hand pulling has a low potential for adverse impacts on water resources. In some habitats, a localized, short-term increase of surface water turbidity may occur upon uprooting the plants. Increased nutrient and/or decreased dissolved oxygen levels will not develop if the excised plant biomass is removed from the treatment area. Plant removal will also increase surface water volume since evapotranspiration rates will be reduced. Oil and fuel from motorized equipment used in removing pulled plants from the treatment site could enter waterbodies. However, manual removal techniques are not expected to negatively affect groundwater quality or public water supplies.

Flow rates in streams, rivers, and irrigation waterways and current patterns in ponds and lakes will be increased by the physical removal of purple loosestrife.

Mortality of Non-Target Biota

Hand pulling is a selective form of control and typically causes minimal disruption to indigenous and introduced species of flora and fauna. Some non-target plants may be injured by human foot traffic during hand extraction operations. The presence of humans engaged in pulling activities may cause some animals to temporarily leave the control site.

In some sites where roots and stems occur in standing water, hand extraction of plants may cause a short-term disturbance of the associated benthic epifauna and infauna. Some smaller animals that may be unable to evade workers or equipment used to remove pulled plants may be injured or killed. Populations of insects that pollinate *L. salicaria* and exotic insects introduced for the biological control of purple loosestrife may be reduced at the site.

Undetected populations of sensitive, threatened, and endangered plants and/or animals could be inadvertently harmed by manual removal methods. However, manual removal methods can be species specific and are generally utilized for small areas, so measures can be taken to protect at-risk species.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Pulling and cutting operations directed against purple loosestrife should not cause a substantial loss of habitat utilized by native or exotic wildlife. Removal of purple loosestrife and subsequent regrowth of other wetland plants will probably improve habitat quality for fish and wildlife.

Some animals may be temporarily displaced during the on-site implementation of manual control methods but will likely reoccupy the habitat once disturbance ceases. However, abundances of some insect pollinators and introduced bioagent species may be permanently reduced in an area once purple loosestrife is removed (G. Piper, pers. comm. 1992).

Trophic Interactions

Manually-induced reductions in *L. salicaria* aerial and subterranean biomass and its exportation from the treatment site may reduce the amount of organic matter available for detritivore processing. However, increases may actually occur in nutrient regeneration rates once purple loosestrife is replaced by other plants. The woody stems of *L. salicaria* are not quickly decomposed upon senescence and nutrients within the tissues cannot enter the nutrient pool.

Potential for Spread of Noxious Species to Unaffected Areas

Hand removal methods have the potential to contribute to purple loosestrife spread. Disturbance of wetland soils by humans or machinery may provide sites favorable for seed germination and seedling growth (Thompson *et al.* 1987). Seeds may also be inadvertently transported to new sites within or away from the treatment site in mud attached to the footwear of control personnel, cutting equipment, or to vehicles and boats entering the operations area. If hand pulling is delayed until the bloom period, some seeds may be dislodged from early-ripened capsules and fall to the soil surface, thus enhancing the extant seed bank. Some seed may be transported on the clothing of workers.

Air Quality

Air quality will not be affected by hand pulling purple loosestrife. Emissions will be produced by the combustion of gasoline and diesel oil used to power transport equipment, i.e., vehicles, and outboard motors. The small amounts produced, however, are not likely to significantly impact air quality.

Aesthetic, Recreation, and Cultural Resources

The manual removal of *L. salicaria* especially during the flowering period, may have either a positive or negative impact on aesthetics, depending upon the attitude of the observer. For example, weed control and wildlife personnel may consider the absence of the plant to be highly desirable, whereas an apiarist may view its occurrence as a welcome addition to the landscape. Others may find its blooms aesthetically appealing and object to its removal.

Manually removing purple loosestrife is not expected to negatively impact the quality or quantity of recreational opportunities. Removal should enhance fishing, hunting, boating, swimming, wildlife watching, and other recreational activities. Manual control measures could potentially disturb or destroy unidentified cultural resources on or near the soil surface.

Human Health

Ungloved hands may become irritated or blistered from sustained periods of uprooting plants. Chronic back problems, arthritis, or other such ailments may be exacerbated in some workers engaged in pulling operations. Falls may occur when traversing uneven terrain or upon contact with slippery soils. When temperatures and humidities are high, workers may experience increased fatigue, heat exhaustion or stroke, and heart or respiratory problems. Certain individuals may experience allergic reactions upon contact with pollens produced by

L. salicaria or other plants. Persons may also be exposed to stinging and biting arthropods or venomous reptiles during work activities.

Agricultural Environment

Sediments/Soils

The removal of purple loosestrife from cultivated crop sites and riparian hay meadows by pulling would have negligible impacts on soil stability and chemistry. Uprooting *L. salicaria* growing along or in irrigation canals and ditches could result in increased soil erosion.

Water Quality and Movement

An ephemeral increase in water turbidity could occur from sediment influxes associated with removal of purple loosestrife growing along or in irrigation canals and ditches. Large quantities of cut stems falling into the water may affect flow within supply ditches or impede water entry into field irrigation furrows. However, removal of purple loosestrife will greatly improve water movement in canals and ditches and reduce water losses attributable to evapotranspiration.

Agricultural Practices

Removal of *L. salicaria* from pastures and hay meadows will increase the quantity and quality of desirable forage plants available for livestock consumption. However, pulling operations will lessen visitation opportunities by honey bees and other pollinators of the plant. Thus, managed or feral honey bee colony size might be reduced and honey production in managed hives could be impacted.

Built Environment

The impacts of hand pulling purple loosestrife on sedimentation rates, soil stability, soil chemistry, and water quality and movement in built environments would be similar to those occurring in natural environments.

Aesthetic, Recreation, and Cultural Resources

Hand extraction of purple loosestrife from lands and waters utilized for recreation will not impact access to, use of, or the quality and quantity of sites. However, access to *L. salicaria*-infested watercourses and impoundments may be temporarily restricted when pulling operations are undertaken in order to ensure public safety. Manual removal of plants on beaches and around watercraft launching facilities will improve swimming, boating, and other water-related sporting activities. Unidentified cultural resources on or near the soil surface could be inadvertently destroyed from trampling or removal of soil associated with control activities.

Maintenance Practices

Hand pulling of purple loosestrife should not adversely impact maintenance practices in built environments. These removal methods could be incorporated into existing maintenance and beautification programs to keep sites free of the plant or to prevent its continued spread within a site.

Cumulative Effects

Adverse cumulative effects are dependent upon purple loosestrife infestation severity. Where hand pulling is used to eliminate incipient infestations, the affected site may only need to be entered on one or two occasions to effect control, and the amount of disturbance inflicted upon the habitat would be minimal. In situations where hand pulling is used against extensive infestations, repeated entry into sites could produce substantial habitat disturbance.

Positive cumulative effects of controlling infestations by hand pulling will occur from the on-site reestablishment of desirable vegetation. Wildlife habitat, wetland storage and irrigation ditch flow capacities, scenic vistas, and recreational opportunities would be benefitted by site rehabilitation.

2.2.1.3 Mitigation

Before hand removal methods are used, treatment sites should be examined for the presence of federally- or state-listed or candidate sensitive, threatened, or endangered animal or plant species. In addition, cultural resource surveys should be conducted at proposed treatment sites prior to the utilization of control methods. Identified cultural resources or species of concern should be protected through the application of appropriate measures.

Workshops should be conducted in communities where purple loosestrife infestations occur to educate the public about its identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to act as a repository of information on TES species and cultural resources for a geographic region. This agency could then identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Early season extraction of seedlings is not recommended. However, it is preferable to remove plants prior to flower and seed formation. If pulling is not possible until flowering has begun, flower spikes should first be clipped and bagged before attempting to uproot plants. This will minimize seed dislodgement from any capsules that have ripened.

Pulled plants should be bagged, removed from the site, and properly disposed through burning or landfill burial (Klaus *et al.* 1991). Plant parts should be buried to a depth of at least 1 m (3.2 ft) in a landfill. Incineration of limited amounts of plant residue at any one time and/or burning in approved incinerators designed to reduce particulate emissions should be used to prevent impacts to air quality.

Sites should only be subjected to hand pulling treatments one or two times annually to minimize impacts to non-target plants, animals, and soil and water resources. To minimize adverse impacts on the waterbody being treated, proper precautions should be taken to prevent oil and fuel from transport equipment from entering the water.

Pulling operations should be conducted on days when temperature and humidity are reduced in order to maximize worker comfort. Worker footwear and clothing should be washed or inspected for seeds and all vehicles, etc. used on-site should be cleaned before removal from the area to further minimize propagule spread.

2.2.2 Covering

Equipment and procedures for covering purple loosestrife are similar to those described for covering *Spartina*.

2.2.2.1 Efficacy

Covering or mulching stops weed growth by restricting sunlight penetration to the soil surface and limiting or preventing plant photosynthesis. In addition, certain mulches may unfavorably alter the immediate microclimate. Mulches can either be nonliving or living materials of enough density to exclude light penetration (Olkowski *et al.* 1991). In aquatic situations, a useful smothering material is black polyethylene plastic sheeting (Mayhew and Runkel 1962). The plastic should be of the highest durability to minimize deterioration from prolonged exposure to intense sunlight and wind.

The utility of this technique for managing purple loosestrife has not been fully ascertained. Limited experiments were conducted by the Washington Department of Wildlife in 1990 and 1991. Department personnel tested the effects of both black and clear plastic on seedling and adult plant survivability. In plots blanketed for five months by both types of plastic, seedling mortality was substantial and regrowth from established rootstocks was diminished but most plants were not killed. Ample carbohydrate reserves in older *L. salicaria* roots facilitated plant survival during the treatment period. Viability of seeds resident in soils of the denuded areas probably will not be adversely affected by covering. Once exposed to light and moisture, germination will occur, and in the absence of competition from other vegetation, dense stands of purple loosestrife seedlings may develop at these sites.

Covering would be expensive because of labor and material costs if applied over an extensive area. Sites to be covered would initially have to be readied (mowed or burned to remove old plant growth) before plastic could be positioned over the soil and secured in place. At the conclusion of the treatment period, the sheeting would have to be removed from all sites and disposed. Regular surveillance of covered sites would be required to detect and repair any tears in the plastic resulting from adverse weather conditions or vandalism. The amount of time a site has to remain covered to effect containment or eradication still must be determined through further experiments.

Seasonal and Access Constraints

To preclude purple loosestrife seedling development, sites should be targeted for plastic mulch treatments during early spring (April to May). It also may be possible to achieve some control of seedling and established plants by covering during July and August. At this time of year it would be necessary to cut the on-site plants to remove existing vegetative growth prior to covering with mulch.

Plastic mulch placed at sites exposed to strong winds may not be practical. Winds will eventually destroy the covering. Failure to expeditiously repair or replace the damaged sections will prevent attainment of the desired control effect.

Monospecific stands of purple loosestrife seedlings are probably most amenable to control by this method. Topographic irregularities may prevent the effective installation of a plastic mulch at some sites. Furthermore, the dimensions of the particular plastic sheeting utilized may dictate the size of individual treatment plots. Mayhew and Runkel (1962) indicated that a barrier larger than 278 m^2 (330 yd^2) may be too difficult to properly position and maintain.

2.2.2.2 Environmental Impacts

Natural Environment

<u>Sediments/Soils</u>

During the time a treatment site remains covered, soil stability should not be adversely impacted. Removal of covers will expose a soil surface devoid or nearly devoid of living vegetation. Precipitation runoff from the affected soils may transport quantities of dead or decomposed vegetation into adjacent waterbodies. In addition, soil may be compacted if water loss occurs in the uppermost soil profile during covering.

Gas exchange in covered soils will be greatly reduced. Anaerobic decomposer activity may cause the production of nitrates, sulfates, and phosphates that could eventually enter surface waters.

Water Quality and Movement

Soil covered by plastic sheeting will not be infiltrated by precipitation. During periods of heavy rainfall, some runoff from the covering may occur, especially if the covering is positioned on a slope. Fast-moving runoff water from the covered area could possibly erode contiguous downgrade soils and carry sediments into nearby surface water. Increased water turbidity would result.

Mortality of Non-Target Biota

Covering is a non-selective form of control since most, if not all, non-target biota beneath the covering are negatively impacted. However, plastic covering materials can be selectively used (spot treatments) within purple loosestrife-infested areas.

Desirable plants may be injured or killed by cutting or fire treatments applied to the sites preparatory to covering while others may be impacted by human activities associated with the installation of covers. Significant mortality of annual and biennial plants beneath the covering will occur; perennials will probably be affected to a lesser extent but some mortality is inevitable. Animal abundance and activity in treatment areas will be reduced during cutting and burning operations that precede cover installation. Wildlife will be denied access to covered vegetation. Covering portions of the habitat in April and May could adversely affect avian breeding behavior. Populations of surface dwelling and subterranean invertebrate decomposers and consumers will be diminished due to changes in the physical environment beneath the covering. The extent of animal disruption and mortality will vary according to the amount of habitat covered.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Portions of wetland habitats blanketed by plastic will be rendered unusable by amphibians, reptiles, birds, and mammals for variable periods of time. Species abundance and diversity reductions may occur if large areas are covered. The replacement of purple loosestrife by other wetland plants will probably benefit wildlife populations since the value of loosestrife to wildlife appears limited. Fish will not be affected by the terrestrial application of a plastic mulch. Vegetation removal would temporarily displace some insect populations, including those species released for the biocontrol of purple loosestrife.

Trophic Interactions

The activity of some detritivores may be hindered by soil covering. Reduced decomposition rates may cause organic matter accumulations beneath the coverings. Detritus-feeding organisms should rapidly repopulate treated soils upon removing covers. Anaerobic decomposer populations should not be deleteriously impacted during treatment periods.

Potential for Spread of Noxious Species to Unaffected Areas

Dissemination of *L. salicaria* seed could occur during site pre-treatment if mud-coated seeds become affixed to equipment or worker clothing.

Air Quality

The use of plastic sheeting to control purple loosestrife is not expected to affect air quality. However, air quality could be degraded by emissions from petroleum-powered cutting equipment and/or by smoke produced during burning operations conducted preparatory to covering. See Hand Removal and Burning sections for discussions of specific adverse effects on air quality assignable to these control methods.

Aesthetic, Recreation, and Cultural Resources

The aesthetic appeal of natural landscapes covered by plastic will be diminished. Animal and plant populations will be noticeably altered in the treatment sites. Dead patches of vegetation will be highly visible amongst surrounding untreated plants. This could be considered to be either a positive or negative impact on aesthetics depending on the observer and his or her attitude toward *L. salicaria*.

Recreational activities in areas covered by plastic will be significantly disrupted. Public access may be restricted by control authorities to prevent damage to treatment sites. Fishing, hunting, and wildflower or wildlife observation may be most impacted. Covering activities could potentially disturb or destroy unidentified cultural resources on or near the soil surface.

Human Health

Human health is not expected to be seriously jeopardized by covering. Worker risk would be greatest during site preparation (cutting/burning) (see the Hand Removal and Burning sections for discussions of specific adverse effects on human health) and installation/removal tasks. Bending and lifting activities associated with the latter tasks could aggravate chronic back problems. Persons could also be exposed to biting and stinging arthropods or poisonous snakes in the work sites.

Agricultural Environment

Sediments/Soils

Following the use of plastic coverings along the edges of infested irrigation canals, exposed soils may be more prone to erosion by water flowing in the ditches and/or by precipitation runoff. Soils in wetland pasture should be little affected. Changes in soil chemistry will probably occur beneath covered areas.

Water Quality and Movement

Elimination of purple loosestrife via covering will greatly enhance water flow in irrigation canals and ditches, and water supplies available to agricultural producers will be increased due to reductions in evapotranspiration. Some siltation and turbidity increases will most likely occur upon the exposure of previously covered ditchbank soils to wind and rain erosion. No significant impact on groundwater is expected.

Agricultural Practices

Removal of purple loosestrife from irrigation systems will improve flow rate and utilization efficiency. Use of the method in wetland pastures and wild hay meadows may initially decrease forage availability to livestock but once purple loosestrife has been removed, forage quality and yield should increase. Covering may decrease the amount of available honey bee pasturage. Managed or feral bee colony size could decline and bee pollination-dependent crops grown in the vicinity of treatment sites could possibly be impacted.

Built Environment

The impacts of covering on sedimentation rates, soil stability, soil chemistry, water quality and movement, and aesthetic, recreation, and cultural resources in built environments will be similar to those occurring in natural environments.

Maintenance Practices

Covering purple loosestrife should not impact routine maintenance operations conducted in built environments.

Cumulative Effects

No significant deleterious cumulative effects are expected from cutting or burning pre-treatments used to prepare sites for covering. Continuous, repetitive, long-term (12+ months) utilization of plastic coverings could adversely affect the soil and plant and animal communities at treatment sites. Positive cumulative effects of controlling purple loosestrife by plastic coverings will occur from the on-site re-establishment of desirable vegetation.

2.2.2.3 Mitigation

In situations where *L. salicaria* grows amongst desirable vegetation, a survey of each proposed treatment site should be performed to determine habitat value of impacted non-target plant species and the potential consequences of their removal. In addition, cultural resource and threatened/endangered species surveys should be undertaken in proposed treatment sites and appropriate mitigation measures should be implemented. Such measures might include changing the location and/or size of the area to be covered, altering proposed treatments to avoid debilitation of critical animal feeding, breeding, nesting, and sheltering habitat, and rehabilitating damaged sites with desirable vegetation.

Workshops should be conducted in communities where purple loosestrife infestations occur to educate the public about its identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Covering sloped sites should be minimized or avoided to protect soils from erosion and prevent increases in sedimentation/turbidity of nearby waters. Upon uncovering sites, dying, dead or decomposing vegetation should be gathered, transported from the site, and properly disposed of to prevent excessive nutrient accumulations from entering waterbodies in proximity to treatment areas.

Prior to exiting the work site, equipment, vehicles, and worker footwear should be cleaned to prevent human-assisted dissemination of seeds to other areas.

Mitigation measures described for cutting or burning operations would be applicable when these methods are used preparatory to covering.

2.2.3 Dewatering/Drainage

Dewatering/draining control methods involve excavation of ditches or construction of dikes to exclude water from purple loosestrife infestations. Construction is typically done with heavy equipment.

2.2.3.1 Efficacy

Drainage of wet sites sufficiently alters habitat to prevent continued growth and survival of many hydrophytes, particularly shallow-rooted species. Soil moisture content can be reduced by diverting water away from a site via drainage ditches or dikes. Labor requirements necessary to effect dewatering will vary with the size of the area to be drained and the specific approach selected. Information on the amount of time a site must remain drained and the frequency water levels must be manipulated is not readily available. Additionally, there are no documented instances of this method being utilized against purple loosestrife.

Drainage of wetland habitat creates an ecological disturbance. Populations of certain plant species are eliminated or greatly reduced in density. Bottom sediments laden with purple loosestrife seeds become exposed and germination and seedling development occur. In the absence of competition, this opportunistic plant soon dominates the degraded habitat. This monopolistic behavior of *L. salicaria* has been evidenced whenever natural water reductions or human-generated drawdowns of wetland sites occur (Thompson *et al.* 1987). Consequently, drainage should not be considered for use in sites already heavily infested by purple loosestrife. In addition, not all purple loosestrife plants may succumb to dewatering. Established plants may be able to survive periods of moisture deprivation.

Seasonal and Access Constraints

Drainage should be conducted at times when plants are most vulnerable to moisture stress and when rainfall is not expected to recharge the storage basin. Dewatering an area during summer when high temperatures and diminished rainfall prevail should produce the greatest plant mortality. In addition, dewatering during midsummer or the pre-bloom period may have adverse effects on the vigor and longevity of young *L. salicaria* plants. The thick, woody roots of established plants may be better adapted to survive periods of water deprivation than those of younger plants.

The topography of the site should have rapid drainage. Water can usually be more readily removed from shallowly flooded sites than from ones more deeply inundated. Spring-fed wetlands may not be able to be dewatered enough to curtail plant growth. Purple loosestrife infestations bordering streams and rivers are unlikely to be controlled with this technique.

2.2.3.2 Environmental Impacts

Natural Environment

<u>Sediments/Soils</u>

Bottom sediment loading will be increased by dewatering a purple loosestrife-infested area. Suspended sediments will be concentrated within the treatment site through water drainage or evaporation. Some sediments may leave the dewatering site in rapidly exiting drainage water and be subject to deposition in new areas distant from the treatment waterbody. The exposed, dried bottom soils of drained impoundments could be removed by wind and/or water erosion.

Organic matter (dead plants and animals) accumulation and decomposition activity will contribute to nutrient loading of bottom soils. This increase in available nutrients could benefit subsequent plant colonizers of drained or reflooded sites.

<u>Water Quality and Movement</u>

All surface water will be removed from a treatment site. The volume of water in adjacent waterbodies will be increased by water exiting the site. If the impounded water being drained is also used as a public water supply, consumer availability will be reduced.

Mortality of Non-Target Biota

Drainage of a waterbody is not a selective form of control and all resident biota will be adversely impacted. All free-floating, submersed, and most emergent hydrophytes, including weedy and non-weedy species, will be killed. Aquatic animal species abundance and diversity will markedly decline in the treatment site. Benthic faunas will be eliminated. Fish will be unable to survive site dewatering.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

Dewatering will eliminate habitat essential to the survival of many shore birds, some mammals, all fish, and benthic organisms. Re-establishment of fish and benthic infauna will occur after refilling, although not immediately, and most wildlife species will benefit from purple loosestrife removal in the affected habitat. However, the loss of the plant could significantly impact introduced insect natural enemy survivability.

Trophic Interactions

Aquatic food webs in the treatment area will be highly disrupted or totally destroyed by dewatering. Decomposer populations will benefit from the enormous influx of organic matter made available for decomposition.

Potential for Spread of Noxious Species to Unaffected Areas

Purple loosestrife seeds present in wet soil could be transported out of the treatment area on equipment brought in for drainage ditch or dike construction purposes. Seeds could also be exported in drainage water outflows from a site. As the water level drops, seed-laden bottom soil will be exposed. Mud-covered seeds could adhere to the feet or body surfaces of animals traversing such soils and be carried to other areas.

A drawdown exposes *L. salicaria* seeds in bottom sediments to optimum germination conditions. A post-drainage flush of seedling development would probably occur (Thompson *et al.* 1987). If the resultant infestation is not controlled, the dewatering effort may be negated.

Air Quality

Air quality may be affected by odors produced from the decomposition of plants and animals killed by the drainage operation.

Aesthetic, Recreation, and Cultural Resources

The elimination of purple loosestrife would be aesthetically pleasing to some, but not all people.

Boating, swimming, hunting, fishing and other water-dependent sporting activities would be impacted during the dewatered periods. Dewatering could potentially expose or destroy unidentified cultural resources.

Human Health

Dewatering a site should not appreciably affect human health. A noticeable increase in flies and other saprophagous insects will occur, the presence of which could affect the health and well-being of people living in the vicinity of the drained site. A reduction in the incidence of biting flies and mosquitoes would be an incidental benefit resulting from the drainage of standing water in purple loosestrife-infested areas.

Agricultural Environment

Sediments/Soils

The use of dewatering to eliminate purple loosestrife in irrigation water supply canals and drainage ditches could alter the stability of ditchbank soils. Fast-moving surface runoff water could erode and degrade bank slopes and increase sediment loading of ditch bottoms.

Water Quality and Movement

Controlling infestations of purple loosestrife in irrigation ditches will improve water flow velocity and diminish plant evapotranspiration losses. Sedimentation rate will also be slowed by plant removal. The transport of *Lythrum* seeds by irrigation water into cultivated crops will be minimized.

Agricultural Practices

Drainage of wetland pasture to control purple loosestrife would be detrimental to the interests of livestock producers as valued forage plants would also be eliminated. In irrigated crop production sites, plant growth would be benefitted by reducing *L. salicaria* occurrence in water delivery systems. Unfortunately, it may not be possible for a grower to keep irrigation canals drained for the amount of time necessary to control purple loosestrife infestations because of regional and seasonal water use demands.

Built Environment

The impacts to sediments/soils, water quality and movement, and aesthetic, recreation, and cultural resources in built environments resulting from dewatering or draining would be similar to those occurring in natural environments.

Maintenance Practices

In many built environments, water deprivation may not be an appropriate technique to control *L. salicaria* . Other management methods are far less environmentally disruptive. However, dewatering may be of some limited value in suppressing incipient infestations in parks.

Cumulative Effects

Positive cumulative effects of controlling purple loosestrife by dewatering will occur from the on-site re-establishment of desirable native or non-native vegetation. Wildlife habitat, water storage capacity, scenic vistas, and recreational opportunities would benefit from site rehabilitation.

2.2.3.3 Mitigation

To minimize impacts related to habitat loss from site drainage, a survey of each proposed treatment site should be conducted prior to treatment to determine the habitat value of resident plant species, and the presence of listed or candidate sensitive, threatened, or endangered species. Cultural resource surveys should also be undertaken prior to the initiation of any control activities and appropriate protective measures implemented.

Once a waterbody is drained, any fish or other animals killed by the procedure should be removed and disposed of to reduce odiferous emissions resulting from their decomposition, and to reduce breeding habitat for certain insects that could be negatively impact human health. Restocking a waterbody with fish, if present before draining, could be a mandatory mitigative measure.

Drainage ditch and dike construction equipment should be cleaned prior to exiting the work site to remove purple loosestrife seeds. Screens should be installed at all water outlets to intercept floating seeds and seedlings present in the drainage water.

2.2.4 Flooding/Inundation

Materials and procedures to construct dikes to flood purple loosestrife infestations would be similar to those described for *Spartina*.

2.2.4.1 Efficacy

Flooding plants kills them by denying the roots and leaves oxygen. The reduction in purple loosestrife density achieved at treatment sites will depend upon the amount of time a site is flooded and the age structure of the population. Prolonged submersion of first-year plants will cause substantial mortality (Thompson *et al.* 1987), but older plants may be able to survive flooded conditions for several years (Smith 1964). Thompson *et al.* (1987) found that prolonged flooding of an area with 70 cm (28 in) of standing water killed most *L. salicaria* seedlings. However, plants two or more years old can survive submersion to depths of 60 to 90 cm (24 to 35 in) for lengthy periods (Smith 1964). Older plants can develop aerenchyma in their stems and roots, a feature that enhances survival during unfavorable periods. Malecki and Rawinski (1985) demonstrated that this tissue was slower to form on deeply flooded plants. Purple loosestrife seeds are relatively unaffected by submersion and may even be dispersed to new sites by flood water (Thompson *et al.* 1987).

Flooding a large area may be an expensive and labor consumptive task if dikes have to be built to retain the water. It may be necessary to maintain an elevated water level at a site for two or more years before the loosestrife population is demonstrably affected (Malecki and Rawinski 1985).

In addition, flooding is not a technique feasible for use in cultivated crop and wetland hay meadow sites because prolonged flooding would prevent crop production or animal grazing. Other physical, chemical or biological control methods would be more appropriate in these agricultural environments.

Seasonal and Access Constraints

Spring flooding of a purple loosestrife-infested site is preferable since seed germination would be inhibited and shoot regrowth from established rootstocks would be diminished or prevented. An adequate water supply is required to maintain a flooded area at a depth damaging to the plant population. During drought years in some localities, it may not be possible to impound enough water to effect control. The water depth necessary to kill most established *L. salicaria* plants has yet to be determined.

2.2.4.2 Environmental Impacts

Natural Environment

<u>Sediments/Soils</u>

An elevation in water depth in a purple loosestrife-infested site may obscure and/or erode certain geologic resources in the target site. The forceful entry of additional water into a diked waterbody may contribute to erosion and could dislodge and re-suspend extant bottom sediments and/or introduce new uncontaminated or contaminated sediment loads. Re-suspended or imported sediments could contain high nutrient levels that fuel phytoplankton blooms.

<u>Water Quality and Movement</u>

Surface water may be adversely affected after flooding of heavily vegetated sites. A short-term increase in water turbidity due to sediment re-suspension could be experienced as the water level at the site is raised. Rapid decomposition of large quantities of plant biomass in bodies of non-flowing water could deplete dissolved oxygen and induce mortality in aquatic animals, especially fish. Additionally, quantities of phosphorous would be released into the water during the decomposition process. Uptake of this nutrient could trigger phytoplankton blooms of species capable of producing toxic compounds detrimental to surface water quality. If the impounded, contaminated water is also used for public consumption, human health could be jeopardized. However, no significant contamination of groundwater should result from a flooding operation.

Mortality of Non-Target Biota

Flooding is a non-selective form of vegetation control in that non-target plants within the treatment site would be negatively impacted. Most, if not all, emergent and some submersed plant species would be killed by flooding (Malecki and Rawinski 1985); free-floating species should not be adversely impacted. The incidence of mortality will vary with the length of time the target site vegetation remains submersed. A short-term negative impact on some animals may also result from increased water turbidity. Elevated water levels could preclude fish spawning in certain areas. Flooding purple loosestrife would negatively impact biocontrol insects by denying them access to their food plant.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

It may be necessary to keep an area flooded for two or more years to effectively control purple loosestrife populations (Malecki and Rawinski 1985). During this time, a noticeable alteration in utilizable wildlife habitat amount and quality would occur. Species abundance and diversity would probably decline when flooding is employed against *L. salicaria*. Elimination of emergent plants would affect wildlife feeding, sheltering, breeding, and nesting opportunities. Songbird, shorebird, and dabbling duck species habitat would be reduced by flooding; diving duck and other bird species habitat would be expanded. Aquatic arthropod population reductions linked to the disappearance of some plants could adversely impact the survival of some freshwater fish species. Benthic infauna in localized areas may be affected during the flooding process.

However, in the long-term, flooding to control purple loosestrife may benefit wildlife and fish through the removal of a monotypic species and its replacement with a diverse plant community.

Trophic Interactions

The change to a flooded habitat during the treatment period would alter the trophic dynamics of the treatment site.

Potential for Spread of Noxious Species to Unaffected Areas

Dike construction could disturb wetland soils and provide new sites for *L. salicaria* colonization within the target area (Thompson *et al.* 1987). Seeds could also be transported away from the treatment site on the footwear of workers and on construction equipment. *Lythrum* seeds produced by established, flood-tolerant plants would still be susceptible to water distribution within the inundated site. Propagules in bottom sediments probably would not be killed by prolonged flooding.

Air Quality

Flooding an area to manage purple loosestrife is not expected to affect air quality.

Aesthetic, Recreation, and Cultural Resources

Visible reductions in abundances of purple loosestrife and other emergent plant species would occur from flooding. This could have either a positive or an undesirable impact, depending on the attitude of the observer.

The quality of some recreational opportunities may be impaired by flooding. Hunting, fishing, and wildlife watching could be impacted because of reductions in or elimination of some plant and animal species populations. Certain water-oriented sporting activities such as swimming, boating, fishing, and hunting could also be enhanced through the removal of purple loosestrife from an area.

Flooding could potentially disturb or destroy unidentified cultural resources on or near the soil surface.

Human Health

Cyanobacteria blooms could contaminate the impounded water with toxic metabolites that, upon ingestion, may cause illness in people (Curtis 1983).

Agricultural Environment

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

Agricultural Practices

Prolonged flooding of sites would prevent crop production or animal grazing. It may also possibly result in the permanent saturation of certain irrigated agricultural lands, especially those in the Columbian Basin (C. Hovanic, pers. comm. 1992).

Built Environment

The impacts on soil integrity and chemistry, water quality and movement, and aesthetic, recreation, and cultural resources resulting from flooding purple loosestrife-infested areas in a built environment will be similar to those occurring in the natural environment.

<u>Maintenance Practices</u>

Flooding is a purple loosestrife control technique suited for use in only certain managed landscape situations. Its use would not be feasible around residences and along transportation rights-of-way where roadway integrity might be adversely impacted but could be valuable in parklands areas.

Cumulative Effects

Beneficial cumulative effects of controlling purple loosestrife by flooding will occur from the on-site restoration of a desirable plant community including increased wildlife habitat and improved recreational opportunities.

2.2.4.3 Mitigation

To avoid impacts related to the mortality of some submersed and emergent plant species, a survey of each proposed treatment area should be conducted to determine the habitat value of susceptible species, the occurrence of threatened or endangered plant or animals, and potential impacts resulting from their loss. Survey results would dictate appropriate mitigation measures. These might include partial flooding of the infested waterbody to avoid complete destruction of critical plant or animal species or mandated vegetative restoration of flooded sites. Cultural resources should also be inventoried within the treatment site and measures taken to avoid detrimental impacts.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Important shallow water fish spawning areas could be impacted by increased water depth. The treatment area should be evaluated to determine its importance to fisheries, and critical spawning areas should be preserved. To reduce the impact of dissolved oxygen depletion and nutrient increases on fish populations and phytoplankton, respectively, dying or dead plants should be removed from the flooded site and properly disposed.

Turbidity increases and sediment disturbance produced by incoming flood water could be mitigated by regulating its entry velocity and/or volume. Finally, seed transport to areas outside the flooded site may be minimized by ensuring that all dike construction equipment is cleaned prior to its removal from the work site.

2.2.5 Burning

2.2.5.1 Efficacy

Fire may be of some value in the management of *L. salicaria*. The plant typically grows in fire-resistant substrates, i.e., wet soils and water, and is relatively immune to fire damage during its vegetative and flowering phases. Its bud-laden roots occur several centimeters beneath the soil surface and are well-insulated from the heat generated by a surface fire (Thompson *et al.* 1987). Thus, fire would probably not eradicate an infestation. However, Louis-Marie (1944) evaluated the impact of flaming individual, actively growing plants and felt the control level achieved was comparable to that produced by mowing. Further assessment of the technique is required.

Fire can be used to remove the dried, woody stems that remain attached to the perennial root crown (McKeon 1959). The presence of these stems diminishes habitat utilization by other wetland plants and animals and impedes *L. salicaria* control activities. However, burning or flaming may stimulate shoot regrowth from root crowns of established plants. In addition, experimentation conducted by the Washington Department of Wildlife revealed that blackened soils in burned areas warmed earlier and experienced increases in surface illumination. These factors enhanced purple loosestrife seed germination at such sites and the resultant dense seedling mass could then be readily controlled with an herbicide.

Labor inputs to initiate and manage a controlled burn would be minimal since the fire itself is the physical agent of control. The amount of labor and fire control equipment required is dictated by the size of the area to be burned. A single seasonal burn should be sufficient to manage established stands of the weed. However, purple loosestrife may soon repopulate the burn site if other post-burn controls are not instituted to further diminish site favorability for the plant. Flaming individual plants would be a labor intensive undertaking.

Seasonal and Access Constraints

The phenology of *L. salicaria* is such that fire will only negatively impact the plant during the spring. The increased soil moisture levels at this time of year also reduce the speed of the burn and decrease the possibility of the fire spreading to non-target areas. Burns conducted during the summer and fall could jeopardize the survival of desirable vegetation or may not be permissible depending on local burning regulations. Burns should be carried out on precipitation-free, low to moderately windy days to achieve maximum destruction of the accumulated old growth. To prevent the formation of stagnant smoke columns, no burning should be undertaken when atmospheric inversion conditions exist.

Dense, continuous infestations of purple loosestrife on mudflats, in pastures, and along the edges of watercourses are good candidates for control by open fire whereas isolated plants, discontinuous patches, and plants infringing on open water areas are not. The latter plants may be better suited for control by flame torching or other methods.

2.2.5.2 Environmental Impacts

Natural Environment

Sediments/Soils

The removal of vegetative cover and litter by burning decreases the soil's ability to absorb and store moisture and renders it susceptible to wind and/or water erosion. However, because only small tracts of vegetation would be burned on any single occasion, increases in soil erosion would probably be small and of short-term duration. The loss of soil organic matter during the burn and from subsequent erosion would affect levels of nitrogen and sulphur, elements essential for plant nutrition.

Water Quality and Movement

Potential impacts on surface water quality resulting from burning operations include increases in sediment concentrations, nutrient influx from air and/or water transported ash, and surface runoff velocity following rainstorms. The magnitude of these impacts within the treatment area will depend upon the amount of vegetation burned, burn severity, soil surface exposure, and distance to the waterbody.

Mortality of Non-Target Biota

Flame torching individual plants is a highly selective form of control. Torching individual purple loosestrife plants would not adversely affect non-target plant species. A controlled burn would destroy or injure all existing vegetation. Fewer plant species would be affected by an early spring burn than by one conducted later in the season. Controlled burning would destroy those animals unable to flee treatment sites. A spring burn of target and non-target vegetation might destroy some bird nests containing eggs or young. Many beneficial, epigeal arthropods could also be lost during the burn. In addition, localized survival of introduced *L. salicaria*-feeding bioagents may be jeopardized by early spring burns.

Loss/Alteration of Wildlife, Fish, and Benthic Habitat

In the short-term, certain wildlife species that had used an area for food, cover, nesting, etc. prior to burning would be affected. However, in the long-term, higher quality habitat for birds, mammals, and other animals will result from limiting purple loosestrife occupation of the site (Thompson *et al.* 1987). No pronounced deterioration of fish habitat is expected to result from burning. Benthic habitat and associated organisms will not be directly impacted by burning.

Trophic Interactions

Burning of purple loosestrife and other vegetation results in the instantaneous elimination of a large quantity of potentially decomposable organic matter from the habitat. Many detritus-feeding arthropod and microorganism species will perish from the heat generated by the fire. Other species that do survive may not persist for long owing to the destruction of their food source. Nutrient capital held in vegetative growth, duff, and soil is volatilized during burning and may be lost from the site by wind and water erosion and leaching, and thus is not subject to utilization by plants and animals.

As few animals are dependent upon *Lythrum* as their primary food source, its removal from the habitat would not affect trophic level interactions. Those animals most impacted by the plant's demise would be the host-specific European insects released upon it.

Potential for Spread of Noxious Species to Unaffected Areas

The use of fire is not a control method that readily facilitates purple loosestrife propagule dissemination within or beyond treatment site boundaries. Some seed transport is possible in mud attached to footwear worn by workers and to vehicles driven into or near the burn site.

Air Quality

Air quality would be affected by burning but effects produced would be of a transitory nature. Visible smoke intrusions and slight increases in airborne particulates would result. Particulate levels from burning are not expected to exceed established federal and state air quality standards. Plant combustion would also yield small quantities of water vapor, carbon dioxide, carbon monoxide, sulfur oxides, nitrogen oxides, and various hydrocarbons into the air column. The quantity of smoke emissions would be influenced by the size of the burn area, quantity of burnable fuel, fuel moisture, and weather conditions.

Propane torches could be used to flame individual plants. Controlled burn ignition could be accomplished with hand-held drip torches that apply a burning mixture of diesel fuel and gasoline. Because only very small amounts of these fuels would be used, the resultant emissions produced by their combustion would not significantly impact air quality.

The general public is not expected to be exposed to injurious smoke levels or burning vegetation as most burns would be undertaken at sites distant from human occupation, and public access to burn sites would be prohibited during the course of the burn.

Aesthetic, Recreation, and Cultural Resources

Sites subjected to flaming and controlled burning would not be aesthetically pleasing to a viewer because of the distinctive color contrasts that would be created between burned (blackened) and unburned adjacent vegetation. Burning would expose bare or nearly bare soils to view as well. Smoke generated from a burn will temporarily impair visibility within the immediate vicinity.

Public access to and utilization of some recreation sites during burn periods may be restricted for health and safety reasons. Recreational activities would only be disrupted for brief periods. Burns would reduce purple loosestrife densities and lead to an improvement of the quantity and quality of available habitat and improve recreational opportunities for anglers, hunters, and other outdoor enthusiasts.

Human Health

Human health may be endangered in several ways when fire is employed to manage plant populations. Workers involved in conducting burns would be subjected to the greatest health risks. Contact with smoke could result in eye, throat, and lung irritation. Chronic exposure of workers to smoke may lead to long-term health effects such as emphysema or lung cancer. Burning of recently herbicide-treated vegetation would increase risk of inhaling herbicide molecules upon combustion. Individuals could also be injured by flame torch or drip torch fuels during ignition, burning operations, or by contact with burning vegetation. In the worst case scenario, worker fatalities could occur if a burn gets out of control.

Agricultural Environment

Sediments/Soils

Soil integrity and composition would be affected by burning just as is the case in natural environments. Burning irrigation ditchbank infestations would facilitate increased bank erosion by ditch flows or runoff from bank slopes.

Water Quality and Movement

Stream, river, pond and lake water quality could be impacted by sediments entering from the erosion of adjacent agricultural burn sites. Burning purple loosestrife infestations in irrigation ditches will increase both the water flow speed through the channels and the amount of water available to the agricultural producer for field utilization.

Agricultural Practices

Nonselective burning of infested wetland pasture and hay meadows might temporarily reduce the availability of preferred forage for livestock grazing. However, once purple loosestrife suppression is effected, the quantity and quality of edible forbs and grasses would be enhanced. Burning *L. salicaria* would also diminish its usefulness as a honey bee pasturage plant. Routine farming operations would probably not be significantly impacted by the application of this control method.

Built Environment

Impacts to soil stability and chemistry and water quality and movement in built environments resulting from the practice of burning would parallel those occurring in natural environments.

<u>Aesthetic, Recreation, and Cultural Resources</u>

The visual appeal of built environments could be diminished by burning. Burning could potentially destroy unidentified cultural resources on or near the soil surface. Purple loosestrife control by burning will both positively and negatively affect recreational opportunities undertaken in built environments. Increases in animal species abundance and diversity would likely occur and waterfowl and other gamebird hunting and wildlife watching opportunities would be enhanced. Control of *L. salicaria* in riparian areas would improve access to impounded or free-flowing waters by anglers. Swimmers, boaters, and other non-consumptive users of human-managed aquatic environments will also benefit from purple loosestrife control efforts.

Public access to parklands sites may be restricted during burning operations. Hunting and wildlife viewing activities would be reduced following burns until vegetation once again becomes established at the sites. In residential settings, the smoke from burning vegetation may impact the health and comfort of those living downwind from fire sites.

<u>Maintenance Practices</u>

In those situations where burning would be feasible and permissible, the tactic could be incorporated into existing noxious vegetation management programs.

Cumulative Effects

A positive cumulative effect resulting from the application of burning practices would be the diminishment of purple loosestrife density and the reattainment of desirable plant and animal communities at previously infested sites. Scenic vistas and recreational opportunities would also be enhanced.

2.2.5.3 Mitigation

In situations where purple loosestrife grows amongst desirable vegetation and where burning would be applied to effect control, a survey of each proposed treatment site should be completed to appraise habitat values of impacted plant and animal species and the consequences of their loss. Cultural resource surveys should also be conducted at proposed treatment sites prior to the utilization of burn methods. Survey results would dictate specific mitigation measures to be taken.

Workshops should be conducted in communities where purple loosestrife infestations occur to educate the public about its identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

It may be impractical to intensively survey each treatment site for TES species and cultural resources. However, it may be feasible for one agency, such as a county weed board, to identify potential impacts and appropriate mitigation opportunities for TES species and cultural resources while processing requests for permits to conduct treatments.

Burns should be carried out on precipitation-free, low to moderately windy days to achieve maximum destruction of the accumulated old growth. To prevent the formation of stagnant smoke columns, no burning should be undertaken when atmospheric inversion conditions exist. Smoke emission effects would be minimized by compliance with local burning ordinance requirements. Quick mop-up of controlled burn sites would also limit emissions since residual smoke has higher levels of contaminants than smoke generated during the flaming phase of a burn. To protect nearby population centers from excessive smoke emissions, only small areas should be burned at any one time. Residents should be provided with advance notification of burn times via appropriate mass media sources.

On-site smoke or burn hazards can be minimized by worker participation in training programs, adherence to proper controlled burn safety procedures, and use of personal protective equipment (Winterrowd and Clanton 1989). Public access to burn sites should be prohibited for health and safety reasons.

Herbicide-treated vegetation should not be burned for several months to a year after spraying to permit herbicide degradation and dispersal. This would minimize the risks of inhaling herbicide molecules upon combustion.

To minimize post-burn soil erosion, desirable, site-appropriate vegetation should be planted to stabilize soils and prohibit *L. salicaria* re-entry.

2.2.6 Explosives

2.2.6.1 Efficacy

Explosives such as dynamite might possibly be utilized to remove heavy infestations of purple loosestrife in waterways, create new irrigation channels, and to rapidly create a passageway through which water could enter to inundate an infested site. However, use of explosives in infested areas would probably result in transport and subsequent regrowth of plant parts off-site and the establishment of new infestations. There are no documented instances in the literature of this approach ever having been used for purple loosestrife control. In addition, the use of explosives is not discussed in any treatises on problematic vegetation management.

If this technique were to be used, labor expenditures would be minimal and involve only positioning and detonating the explosive charges. A single treatment should produce the desired results. Explosives could be deployed in natural and most agricultural environments; their use may be prohibited in certain managed landscape environments.

2.2.6.2 Environmental Impacts

Use of explosives in purple loosestrife dominated waterbodies would result in significant adverse impacts to most components of natural, agricultural, and built environments, including non-target biota, fish and wildlife habitat, and water and soil resources. Thus, its use as a management tool for controlling infestations of purple loosestrife appears limited.

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 a perennial herb with large tuberous roots, rapid growth, and abundant seed production.

2.3.1.1 Hand Removal

Hand removal methods of giant hogweed control include mowing, cutting, and digging. All are time-consuming, labor-intensive, and consequently, expensive.

Efficacy

Digging may destroy giant hogweed, but care must be taken to remove much of the rootstalk (Wright 1984; WSNWCB 1991). To kill the plant, it must be cut at 8-10 cm below ground level and removed (Wright 1984). Control by digging is most effective early in the spring, when plants are actively growing and are still small (Wright 1984).

A seed bank is formed in the soil, although seed survival in the field is not known (Roché undated). Following eradication of growing plants, seeds may germinate and reinfest the area.

Environmental Impacts

Environmental impacts to natural, agricultural, and built environments due to giant hogweed control measures would be negligible. Soils may be compacted due to increased foot traffic.

Debris may be toxic to some organisms. Water quality may be affected if plants are improperly disposed of and air quality may be locally affected due to odors from rotting vegetation. Aesthetics would be temporarily diminished from habitat disturbance.

Potential for Spread of Noxious Species to Unaffected Areas: Digging the plant after seeds have matured could result in seed dispersal (Hyypio and Cope 1982). Improper disposal of plants may spread infestations.

Human Health: Giant hogweed produces contact dermatitis in susceptible individuals (Camm *et al.* 1976, Reynolds *et al.* 1991), resulting in photodermatis, which sensitizes the skin to ultraviolet light (Wright 1984). Disposal of plants by burning may have detrimental health affects.

Mitigation

Seed dispersal should be minimized by digging plants before seeds have matured. Plants should be disposed of in a manner that would prevent plant dispersal and adverse impacts to air and water quality.

Workshops should be conducted in communities where giant hogweed infestations occur to educate the public about its identification, impacts of infestations, appropriate control methods, environmental concerns, and applicable regulations.

Workers should be properly clothed and should take measures to avoid contact dermatitis from exposure to giant hogweed. Sap should be washed off skin with soap and water as soon as possible.

2.3.2 Garden Loosestrife

Both species of garden loosestrife are deciduous perennials that spread aggressively by rhizomes. They inhabit moist habitats such as marshes, wet woods, and along lakeshores and river banks. No information is available on possible physical control methods, although it has been suggested that covering with black plastic may be effective in preventing seedling establishment in higher areas along the shores of Lake Sammamish (S. Taylor, pers. comm. 1993).

2.3.3 Indigobush

Indigobush occurs in a wide diversity of habitats, including river, creek, and lake shorelines, wet meadows, swamps, and floodplain depressions. It may form monospecific colonies that effectively displace native vegetation. It is a tall shrub that is multibranched at the base. No information is available on possible control methods.

3.0 RESEARCH AND INFORMATION NEEDS

Additional information on the utility of physical control methods for noxious emergent plants species is needed. Research could be undertaken to address the following questions:

For all species:

- How effective is hand pulling in containing or eradicating established populations?
- How long must seedling and established plants remain covered with black plastic or fabric for control to be effected?
- What is the largest site that can be effectively covered with plastic?
- Which growth stages are most susceptible to flooding?
- What critical water depth is required to kill established plants and how long must plants remain submersed?
- How efficacious is the practice of dewatering against seedlings and established plants?
- How long must a site remain devoid of water before control is effected?
- How effective are the practices of flame torching and controlled burning against variously aged plants?
- How cost-effective are all currently available physical control methods?
- How compatible are physical control methods with chemical and biological control methods?
- How are plant and animal occupants of wetland habitats impacted by the use of physical control methods?
- Are negative impacts to non-target species reversible?
- What are effective restoration measures following noxious species eradication?
- How frequently do burning treatments need to be done to be effective?
- How are sediment dynamics affected by removal of noxious emergent plants? Are pre-invasion regimes restored?

- How are biota within and below colony sites affected by changes in sediment dynamics following eradication?
- How can burning vegetation affect human health?
- Are there burning techniques that can reduce adverse affects?
- Would use of explosives disperse propagules?

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