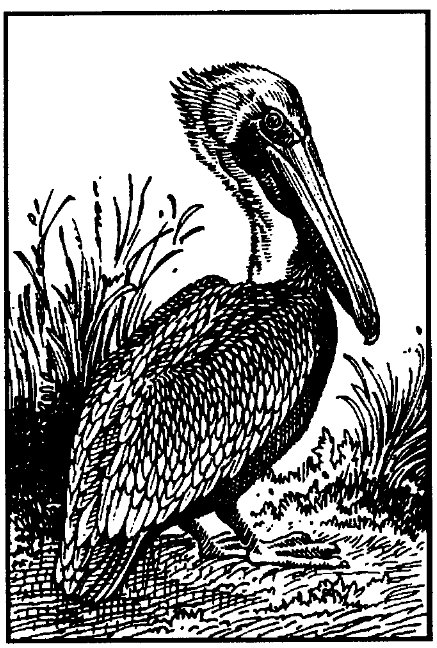
US Army Corps of Engineers
Waterways Experiment Station

Wetlands Research Program Technical Report WRP-RE-13

Studies of Plant Establishment Limitations in Wetlands of the Willamette Valley, Oregon

by U.S. Army Engineer Waterways Experiment Station



December 1995 – Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

Technical Report WRP-RE-13
December 1995

Studies of Plant Establishment Limitations in Wetlands of the Willamette Valley, Oregon

by U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

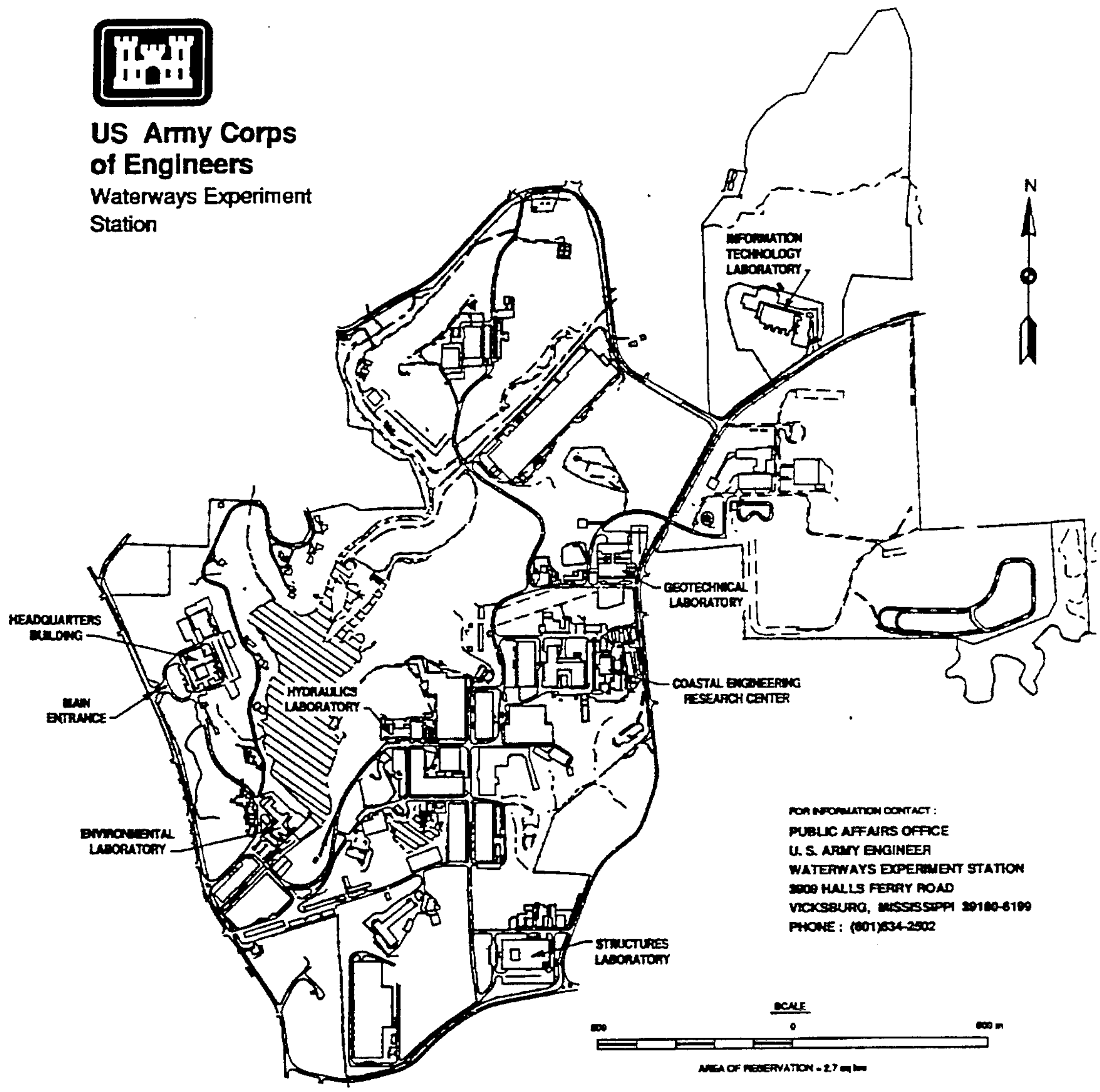
Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

US Army Corps of Engineers

Waterways Experiment Station



Waterways Experiment Station Cataloging-in-Publication Data

Studies of plant establishment limitations in wetlands of the Willamette Valley, Oregon / by U.S. Army Corps of Engineers, Waterways Experiment Station ; prepared for U.S. Army Corps of Engineers.

75 p. : ill. ; 28 cm. -- (Technical report ; WRP-RE-13) (Wetlands Research Program technical report ; WRP-RE-13)

Includes bibliographic references.

1. Wetlands -- Oregon. 2. Wetland plants. 3. Wetland conservation. I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Wetlands Research Program (U.S.) IV. Series: Wetlands Research Program technical report ; WRP-RE-13. V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; WRP-RE-13.

TA7 W34 no.WRP-RE-13

Corps of Engineers Research Report Summary, December 1995

Wetland Restoration

Studies of Plant Establishment Limitations in Wetlands of the Willamette Valley, Oregon (TR WRP-RE-13)

ISSUE:

Successful establishment of vegetation in wetland restoration sites is often limited by incomplete knowledge of the plant species' requirements for survival and growth. Recent interest in restoring the diverse vegetation of native wetlands in the Willamette Valley, Oregon, has increased the need to identify establishment requirements of these species.

RESEARCH:

Information to describe the natural wetlands of the Willamette Valley was collected, and four investigations into the limitation of establishing native wetland vegetation in this area were launched. These studies included: effects of burning, fallowing, and solarization on controlling exotic plant species; limitations of seed dormancy, germination, and establishment of native species; mycorrhizal colonization of selected species in several sites that differed in degree of disturbance; and performances of nursery stock and stem cuttings of selected woody native species.

SUMMARY:

Most limitations of wetland plant establishment can be overcome through proper site preparation and plant propagule selection and treatment. Control of pest plant species requires multiple year treatments to allow growth of native species that will eventually outcompete recovering pest species. Establishment of plants from native collected seeds can be enhanced with alternating temperature stratification and high seeding rates. Fungal spore density in agricultural sites may limit colonization of plants in wetlands. Nursery stock generally is more reliable than stem cuttings for establishing most species.

AVAILABILITY OF REPORT:

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About the Authors:

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Wetlands Restoration, Protection, and Establishment Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32761, "Wetlands Field Demonstration and Research," for which Dr. Mary C. Landin, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was Technical Manager. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for this work.

Mr. Dave Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, WES, was the Wetlands Program Manager. Dr. Landin was the Task Area Manager.

The work was performed by Fishman Environmental Services, Portland, OR. This report was prepared by Drs. Mark V. Wilson, Elaine R. Ingham, and Cheryl A. Ingersoll and Ms. Deborah L. Clark, Oregon State University, and Mr. Mark G. Wilson, Consultant, under contract No. DACW39-92-C-0065 under the general supervision of Dr. Landin, Research Wildlife Biologist, WES, and the direct supervision of Dr. Mary M. Davis, Wetland Ecologist, WES. Chapter 1 was prepared by Dr. Davis; Chapter 2, by Dr. Wilson, Ms. Ingersoll, and Mr. Wilson; Chapter 3, by Dr. Wilson, Ms. Ingersoll, and Ms. Clark; Chapter 4, by Ms. Ingham and Dr. Wilson; and Chapter 5, by Mr. Wilson and Dr. Wilson.

At the time of publication of this report, EL supervisory and management personnel were Mr. Ellis J. Clairain, Acting Chief, Wetlands Branch; Dr. Conrad Kirby, Chief, Ecological Research Division; and Dr. John W. Keeley, Director.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

U.S. Army Engineer Waterways Experiment Station and Oregon State University. (1995). "Studies of plant establishment limitations in wetlands of the Willamette Valley, Oregon," Technical Report WRP-RE-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
Fahrenheit degrees	5/9	Celsius degrees or kelvins[1]
feet	0.3048	meters
gallons (U.S. liquid)	3.785412	liters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
ounces (mass)	28.34952	grams
pounds (mass)	0.4535924	kilograms

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain kelvin (K) readings, use the following formula: K = (5/9) (F - 32) + 273.15.

Summary

The Willamette Valley was historically dominated by three types of wetlands: wet prairies, shrub/scrub, and forested. As a consequence of drainage for agriculture and urban development, most of these diverse wetlands have been lost. Restoration of native wetlands is limited by a lack of knowledge about native plant species' growth and establishment requirements. This report presents results from four investigations of establishing wetland vegetation native to the Willamette Valley.

In the first study, Pest Plant and Seed Bank Reduction (Chapter 2), three site preparation techniques were applied to a disturbed wet prairie that contained exotic species. The objectives of the study were to determine (a) whether the treatments reduced pest plant abundances for more than 1 year, (b) if treatments also reduced native plant species, and (c) whether treatment effects were consistent among years. Tilling with fallowing and solarization (heating under plastic) were generally found to be more effective than burning at reducing existing plants. Native plants were affected by all treatments. Although each treatment was effective at reducing at least one exotic plant species, none of the treatments were generally effective at controlling pest plants. This may have been due to cool, dry weather conditions during the treatments that were not conducive to seed germination. The authors conclude that site treatments should be applied for more than 1 year, and native plant materials should be planted as soon as possible to outcompete the recovering exotic species.

The second study, Seed Dormancy, Germination, and Establishment (Chapter 3), investigated native collected seed germination requirements, seed propagation under field conditions, and the performance of seeds in mixtures. Seed viabilities were found to vary greatly for the native species that were tested. This was due in part to a single collection date for each species that could not coincide with simultaneous ripening of all the seeds. Stratification with alternating temperatures sufficiently improved germination rates of the dormant species so that no further treatments were necessary. Poor seed germination rates in the field led the authors to recommend high seeding rates when native collected seeds are used. This helps offset the low germination rates of many species, but also increases the relative abundance of sown seeds to the seed bank. Differences in germination rates and times of different species in seed mixtures can be utilized in designing seed mixtures. The

authors recommend a strategy to first establish rapidly germinating, short-lived species to compete with exotics, followed by more slowly germinating perennial species that will permanently occupy the site.

Characterization of Mycorrhizae (Chapter 4) is an investigation of the potential for mycorrhizae to limit plant growth in restored wet prairies. The objectives of the study were to determine (a) the mycorrhizal requirements of selected herbaceous species, (b) if adequate mycorrhizal fungi were available for plant colonization at sites differing in levels of disturbance, and (c) if there is a correlation between spore density in the soil and actual colonization of the plants. Mycorrhizae colonized surviving plants at all sites. Lack of germination or survival of some plants at some sites suggested a lack of required fungal species. A positive correlation between spore density and colonization further suggests that limited mycorrhizae may affect plant growth in wetland restoration areas with low fungal spore densities.

Field Performance of Planted Nursery Stock and Stem Cuttings of Selected Woody Species (Chapter 5) further investigates the use of native plant materials for wetland restoration in the Willamette Valley. The objectives of this study were to (a) compare survival and growth of stem cuttings and nursery stock of four selected woody species, (b) determine growth of irrigated stem cuttings, and (c) determine effects of fertilization on native plant nursery stock and stem cuttings. Results of the study were very species specific. Only stem cuttings from willow and poplar survived; *Crataegus* and *Rosa* cuttings died. Nursery stock had best survival rates for all species; however, height growth of stem cuttings was best. Fertilization had no significant effect on survival or growth of nursery stock or stem cuttings. Fertilization, however, stimulated growth of competing herbaceous species and may have been detrimental to growth of target species.

1 Endemic Wetlands of the Willamette Valley, Oregon[1]

The Willamette Valley in northwestern Oregon was once the site of extensive wetlands that have largely been drained since the late 1800s. It is representative of many areas of the country that have lost wetlands, because the value of the wetlands is being recognized for flood attenuation, water quality improvement, wildlife habitat, and aesthetics. In addition, costs associated with protecting flood-prone areas of development that were once wetlands are becoming prohibitively high. Efforts are now being made to integrate wetlands of the Willamette Valley back into land management plans (U.S. Army Engineer District, Portland 1993).

Wetland restoration is a principal tool in the reestablishment of wetlands in the Willamette Valley. Natural wetland hydrology, soils, and vegetation is the target for many of the restoration efforts. This can be difficult to attain in the present day landscape. Conflicting demands for water can affect the volume and seasonality of water delivered to the wetlands. Soils in many wetlands have been plowed and fertilized, possibly changing fundamental properties of the soil that affect wetland processes. Natural vegetation has been largely removed and replaced with aggressive, less desirable species. The challenges for wetland restoration in areas such as the Willamette Valley are great.

Meeting the challenges for wetland restoration starts with an understanding of the natural wetland systems that are the target for restoration. This includes descriptions of the various types of wetlands, the natural processes that led to the development of the wetlands, and ecological limitations to restoring the wetlands in a disturbed landscape. This report provides a description of the natural wetlands of the Willamette Valley and results of four investigations into the limitations of establishing native wetland vegetation.

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1 Written by Dr. Mary M. Davis, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wetlands of the Willamette Valley

This chapter, taken from the U.S. Army Engineer District, Portland (1993), report provides an overview of the Willamette Valley and summarizes its change from a natural system to one modified for agriculture, flood damage reduction, and urban development. It covers a time frame prior to settlement in the early 1850s to completion of the flood protection projects by the Corps of Engineers in the late 1950s.

Natural environment

Before settlement in the early 1850s, the Willamette Valley contained broad expanses of prairie-savannah bordered by heavily wooded hills. The rivers lacked heavy runs of salmon which were abundant in other regions of the Pacific Northwest. The aboriginal inhabitants, therefore, did not depend primarily on fishing, but relied on hunting and gathering for subsistence. This fact made them unique among the other inhabitants of tributaries to the Columbia River.

The area was used by native Kalapuya Indians for hunting and collecting plants for food and medicinal purposes. The Kalapuya routinely burned the vegetation to maintain prairie conditions and to make hunting, traveling, and food gathering much easier. At that time, the valley resembled a Midwest prairie, cleared of most woody vegetation and dominated by *Deschampsia cespitosa* (tufted hairgrass) communities.

This region was characterized by a mosaic of various wetland types dominated by wet prairie. Wetter places contained marshes and wet forests which were too damp to burn. Wetland prairies were intermingled with upland prairies, wetland shrub/scrub, wetland marshes, and forested streams and swales.

Geomorphology and soils are important in explaining the distribution of wetlands in the Willamette Valley. During glacial times, huge volumes of water backed up onto the Willamette Valley, forming a large lake. Fine sediments (clays and silts) settled out of the lake and formed what is called the Calapooyia surface. Over thousands of years, the recurring floods resulted in multiple layers of sediment deposits. The topography of the Calapooyia surface has little relief causing a poorly defined swale pattern and slow drainage of surface water. The Calapooyia also has higher circular or oval mounded areas interspersed with lower, poorly drained braided areas. The Calapooyia soils are silty, clay loams (Holcomb, Dayton, Awbrig, and Natroy) with subsoil horizons formed from heavy clay (Malpass clay). The slowly permeable clay horizon in the soils, nearly level topography, and poorly defined drainage of the Calapooyia surface, along with rainfall in the area produce the perched water table needed to support wetland habitats.

Wetland types

Presettlement wetland types in the study area can be classified into three categories: seasonal wet prairie, shrub/scrub, and forested wetlands.

Seasonal wet prairie. Seasonal wet prairies dominated 200,000 to 300,000 ha in the Willamette Valley prior to settlement. These wet prairies were characterized by saturated soils and a system of braided stream channels which carried flows intermittently during high frequency flood events. Only about 1 percent of this rare Oregon plant community remains today.

Wet prairies had the highest plant diversity of any wetland type present in the area. As many as 100 native plant species have been identified in wet prairies in West Eugene. Wet prairies were dominated by grasses such as *Deschampsia cespitosa*, sedges, and forbs, and were typically flooded during high winter flows. *Lomatium bradshawii*, now a Federally listed endangered plant species, was found in higher wet prairie areas. Other species currently of state or local concern such as *Aster curtis, Erigeron decumbens,* and *Horkelia congesta* were also found in this wetland type.

Another feature of wet prairies is their unique mounded and swale topography known as the Calapooyia microtopography. This mounding helped establish "microhabitats" which created refuges from inundation and, consequently, the high plant diversity of wet prairies. The mounded topography was flattened through intensive agricultural activities.

Shrub/scrub wetlands. This wetland habitat type was historically found in small amounts throughout the area. It consisted of shrubby vegetation about 1 to 5 m in height with an understory of grasses, sedges, and small forbs. Vegetation in these wetlands was composed of Douglas spirea (*Spirea douglasii*), wild roses (*Rosa* spp), willows (*Salix* spp), ash (*Fraxinus* spp), and other brushy plants and thickets. *Lomatium bradshawii* was found in the higher areas of this wetland habitat type.

Shrub/scrub wetlands in the Willamette Valley typically occurred in riparian zones, in areas transitioning between wet prairie and forested wetlands, and in areas not affected by periodic burning. Due to these factors, it was not dominant prior to settlement. After settlement, however, periodic burning ceased and succession occurred, allowing shrub/scrub wetlands to increase in the area. At the same time, increased grazing activity may have decreased the amount of these wetland types. In general, the total amount of shrub/scrub wetlands has remained stable, but the location and uses of these wetlands may have changed.

Forested wetlands. Forested wetlands historically were found in areas slightly higher in elevation and in areas not periodically burned. These wetlands encroached upon the wet prairie and shrub/scrub wetlands.

Forested wetlands in the Amazon Creek basin are adapted to similar soil and hydrologic conditions as wet prairie. Historically, vegetation was dominated by ash, which is tolerant of saturated soils. Understory vegetation was similar to that found in shrub/scrub wetlands. These wetlands were used for logging, agriculture, and grazing, but because of the intrusion of forested wetlands into wet prairies, there have not been substantial losses of forested wetlands.

Development and drainage alterations

Settlement of the area coincided with dramatic changes to the natural environment. The Donation Land Act of 1850 attracted settlers to the Willamette Valley from the central and eastern United States. Under the Act, the Federal government granted 320 acres[1] per person to anyone willing to live on the land and "prove" it. Several Donation Land Claims were established. These large tracts were homesteaded and agriculture began to increase. The area remained primarily agricultural into the first half of the Twentieth Century.

Unlike the period before European settlement where vegetation was the only factor manipulated by human practices, this period marked the beginning of hydrologic change as well. Initially, individual parcels were drained by local interests using a variety of methods, including dikes, berms, tile, ditches, and furrows. Although flooding was somewhat reduced, it was still frequent during storm events and high seasonal flows.

Agriculture in the area was apparently restricted in location and consisted mainly of grazing and hay production up to the 1930s due to poor drainage and slow runoff. Increased drainage with ditch construction encouraged development of wetlands for agricultural use. These agricultural wetland habitat types were mostly former wet prairie and shrub/scrub wetlands. Most agricultural wetlands still show the soil and hydrologic conditions present in historic wet prairie wetlands.

Logging also affected the wetland resources of the area. With cessation of burn practices, parts of the area reestablished with Douglas fir and other commercially valuable timber. These areas have since been logged. With the arrival of rail transportation in 1913, other logging-related activities were established in the area. Timber companies used the natural wet conditions to construct log ponds to store logs by excavating pits and creating perimeter levees. Although some of these log ponds are still used today, others have reestablished as functional wetlands.

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page xi.

Urbanization followed agriculture, grazing, and logging. Industrial uses were quick to follow railroad lines and the coast route. As urban areas grew, public facilities and industrial areas were extended.

Agriculture and urban development affected the water quality of the natural streams by contributing contaminants from farm and urban runoff and by draining wetlands. Nutrients, fertilizers, and pesticides entered the creeks from agricultural areas, and nutrients, heavy metals, and organic contaminants entered the creeks from urban areas. Runoff also increased sedimentation. Removal of streambank vegetation resulted in increased water temperatures and erosion.

Subsequently, public works flood and drainage control projects were built which effectively altered the subregional hydrologic patterns. When Congress passed the Flood Control Act of 1936, flood control became a primary focus for involvement by the Corps of Engineers. Authorization for the construction of dams in the Willamette River basin was included in the Flood Control Acts of 1938, 1950, and 1960. As a result of the 1938 Act, a plan was developed to construct seven major reservoir projects for storing runoff water to reduce flooding, one of which was Fern Ridge Lake, completed in 1941. In addition, a number of channel improvements influencing drainage and hydrology in the Amazon basin occurred from 1940 to 1951 before the Corps constructed the flood damage reduction projects.

Problems Establishing Native Wetland Vegetation

Once the target wetland conditions have been identified, wetland restorationists try to establish similar conditions on the restoration project site. The assumption is that if the major controlling conditions are in place, a wetland will develop that functions as the reference wetland functions, and restoration will be successful. Wetland plans usually focus on reestablishing the hydrology, soils, and vegetation.

Since most wetlands in the Willamette Valley are either adjacent to streams or rivers or are perched wetlands, the hydrology is relatively easy to restore. The hydrology of riparian wetlands can be restored by reconnecting the wetland site with the river flow. Where sufficient drainage area supplies an adequate water supply, drainage can be blocked to restore hydrology to perched wetlands. Properties of disturbed soils are apparently not limiting to wetland restoration. Of the three parameters, restoration of native wetland vegetation is the most limiting to successful wetland restoration in the Willamette Valley.

Many of the problems with establishment of native wetland vegetation in the Willamette Valley are common to other parts of the nation. For example, it is important to match plant species with site conditions for successful establishment and growth of the vegetation. The ecology of most plant species is not well known, and consequently, it is very difficult to establish more than a few species in wetland restoration projects. The rich species diversity in wet prairies of the Willamette Valley is very difficult to reestablish due in part to many unknown factors limiting growth of these species.

In restoration projects, competition from nuisance species is a primary limitation to the growth of many native wetland plant species. Competitive plant species often become nearly monocultures in areas that have been disturbed such as fallowed agricultural fields. The exposed soil is rapidly colonized by existing seeds that were brought to the soil surface and seeds that dispersed from other areas. Nuisance species such as *Phragmites*, cattail (*Typha* spp), and reed canarygrass (*Phalaris arundinacea*) are capable of rapid growth and quickly occupying most of an exposed area. Once established, the nuisance species are very effective at reducing establishment of less competitive species, which often are the more desirable native species. A major challenge in wetland restoration is the control of nuisance species until desirable plant species are established.

Sources of native plant materials are often problematic in wetland restoration. Of the myriad plant species found in wetlands, relatively few are commercially available for restoration. This is often due to the lack of information about how to handle and grow the less common or more difficult plant species. In addition, large numbers of plants may be required for extensive wetland restoration projects that cannot be supplied by local commercial sources. Collection of plant materials from natural areas can be an alternative to the limited commercially available stock. Problems remain with handling native plant materials, however, that often must be investigated on a species-by-species basis.

Wetlands are usually restored in disturbed areas that still exist as or once were wetlands. A largely unaddressed problem in wetland restoration is the effect disturbances have on the success of restored wetlands. A primary effect of disturbance to soils is the disruption of the microbial and fungal communities that are critical to normal wetland functions. Microbes are the agents of nutrient transformation in wetlands. Some fungi infect plant roots in an association that is beneficial to both fungi and roots called mycorrhizae. These fungi help the plants attain limited nutrients such as phosphorus from the soil. The plants benefit with improved growth, and the fungi are rewarded with sugars from the plant. If microbes and fungi are lost in disturbed soils, plant establishment and normal functions of the wetland could be limited.

Plant Establishment Studies

The following four chapters address the problems with native wetland plant establishment in the Willamette Valley that were introduced above. The studies were all performed in former or existing wet prairies of the Amazon Creek basin near Eugene, OR (Figure 1).

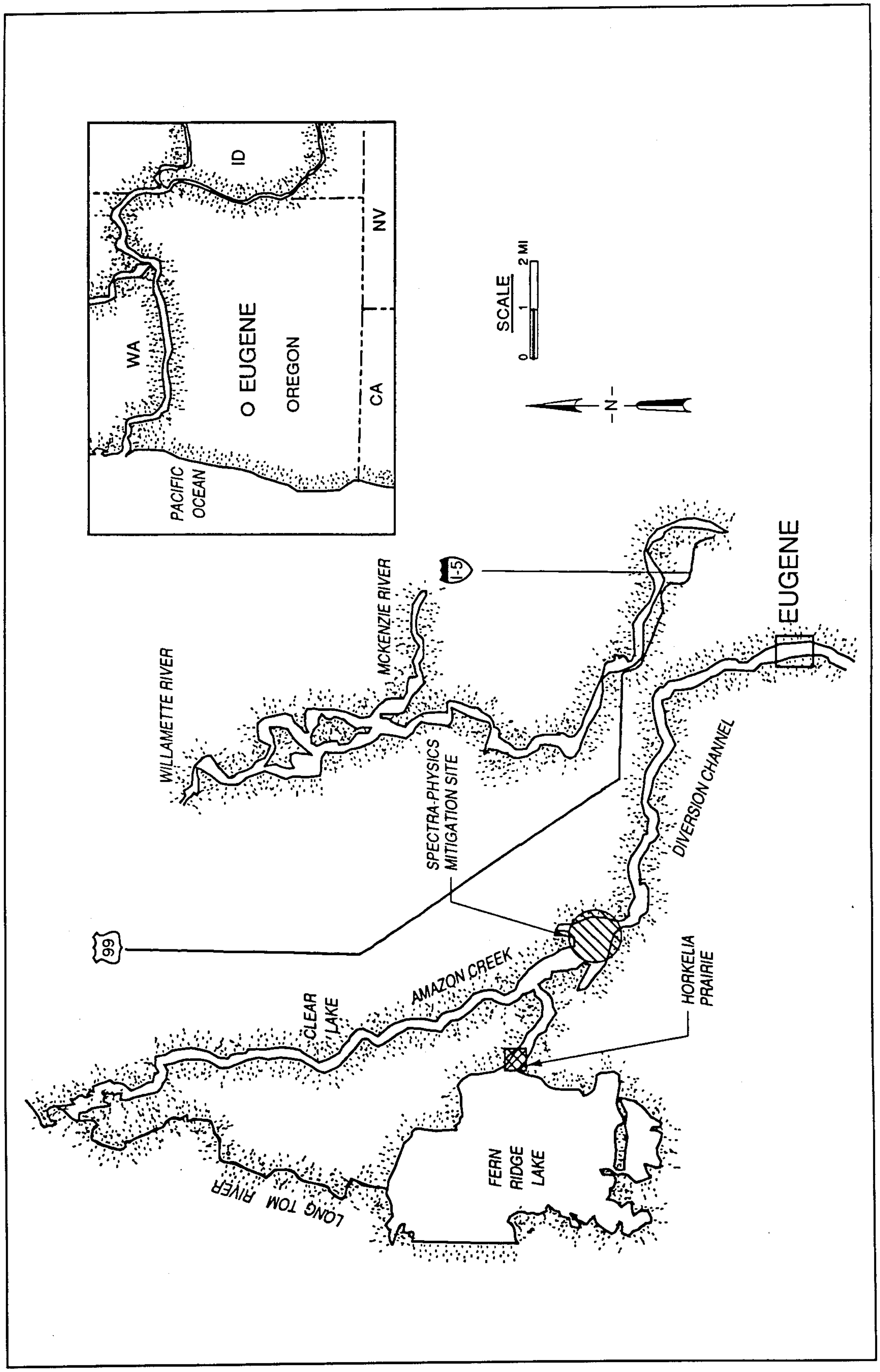

Figure 1. Location of study areas in Willamette Valley, Oregon

In the first study, Pest Plant Seed Bank Reduction (Chapter 2), three site preparation techniques were applied to a disturbed wet prairie that contained exotic species. The objectives of the study were to determine (a) whether the treatments reduced pest plant abundances for more than 1 year, (b) if treatments also reduced native plant species, and (c) whether treatment effects were consistent among years.

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2 Pest Plant and Seed Bank Reduction[1]

Introduction

Most vegetation restoration projects fail, often with weedy plant species rapidly becoming dominant (Kusler and Kentula 1990, Kentula et al. 1992). Therefore, weed control measures that are compatible with the establishment and increase of valued native species are crucial for future restoration efforts. This chapter describes results from preliminary tests of nonchemical weed control techniques.

Weed numbers can increase from the survival and reproduction of existing vegetative plants, germination from a soil seed bank (Roberts 1981, Leck et al. 1989), and by seed dispersal from offsite (Hume and Archibold 1986, Ghersa and Roush 1993). Three control techniques that aim to reduce the first two sources of pest plants were examined: fallowing (Mohler 1993), solarization (Bainbridge 1990), and burning (Howe 1994). The specific questions examined include the following:

- Do the test weed control techniques reduce pest plant abundance during the 2 years following treatment?
- Do the test weed control techniques also reduce the abundance of native plant species?
- Do patterns differ between the first and second year after treatment?

1 Written by Drs. Mark V. Wilson and Cheryl A. Ingersoll, Oregon State University, and Mr. Mark G. Wilson, a consultant in environmental horticulture.

Methods

Study site

This research was conducted in Horkelia Prairie, a wetland prairie at Fern Ridge in western Oregon's Willamette Valley. Before Euro-American settlement in the early 1800s, wetland prairies occurred on poorly drained low-lying areas, often near river courses. Frequent burning by the native people of the Valley maintained these seasonally wet prairies by killing the invasive but more fire-susceptible woody plants (Boyd 1986). Most (>99 percent) of the native wetland prairies of the Valley have now been lost to agriculture, urbanization, or natural succession to shrub/scrub or forest.

Some of the best wetland prairie remnants in the Willamette Valley occur at Fern Ridge (Wilson, Connelly, and Lantz 1993), a reservoir project managed by the Army Corps of Engineers. These prairie remnants at Fern Ridge are often surrounded by biologically depauperate ecosystems dominated by exotic species. The restoration of adjacent degraded ecosystems would enhance and protect the remnant wetland prairies.

Horkelia Prairie was particularly well suited for studies of wetland prairie restoration. Horkelia Prairie contained a mixture of native and exotic species typical of other wetland prairies in the Willamette Valley. These dominant plant species included the natives *Deschampsia cespitosa*, *Panicum capillare*, *Danthonia californica*, and *Grindelia integrifolia* and the exotics *Agrostis tenuis*, *Anthoxanthum odoratum*, and *Hypochaeris radicata*. The soils and hydrologic regime of Horkelia Prairie were also typical of wetland prairies in the Valley (Patching 1987). Onsite soil inspection (Scoles Associates 1994) confirmed the poorly drained nature of the soil, with a thick clay pan close to the surface that causes seasonal perching of the water table. As a result, soils at Horkelia Prairie were saturated at least 2 months during the growing season, with a surface-driven water regime (Scoles Associates 1994). On the other hand, soils at Horkelia Prairie have low water-holding capacity and become droughty during summer.

Horkelia Prairie was also adjacent to high-quality native wetland prairie (Rose Prairie), facilitating comparisons and increasing the value of restoration at the site. The study site was also suitable because of its protection as part of the Fern Ridge Corps of Engineers project.

Study species

Plant species encountered during this study were assigned to categories of native species, exotic species, and pest species. Native and exotic species were identified in Hitchcock and Cronquist (1973). Pest plant species were defined as woody plants or exotic herbaceous plants with the potential to invade or become dominant in wetland prairies.

Treatments

Three nonchemical weed control techniques commonly used in restoration projects were examined. In the fallow treatment, 5-m by 5-m plots were tilled on 12 May 1992 and 3 June 1992 by rototilling with a three-point 48-in. Howard HA Rotovator. Thereafter, the plots were unmanipulated. This treatment was designed to kill some vegetative plants and stimulate the germination of seeds stored in the soil, which would be killed by the second tillage.

In the solarization treatment, plots were tilled as described above and then covered with a 6-m by 6-m sheet of 6-mil polyethylene treated with UV inhibitors. Backfilling into 30-cm-wide by 12-cm-deep trenches anchored the edges of the sheets, thereby reducing loss of heated air and soil moisture. Small, soil-filled plastic bags were used to weight the remainder of the sheet and ensure tight coverage of the plot. The final solarized unit was 4.3 m by 4.3 m. This treatment was designed to kill some vegetative plants with the tillage and to reduce vegetative plants and seeds stored in the soil with the hot and moist conditions under the polyethylene.

In the burn treatment, 5-m by 5-m plots were ignited with drip-torches, first on the downwind margin of each plot, then on the upwind margin and continuing on all sides. The herbaceous plants and their litter provided a continuity of 1-hr fuels through each plot. This procedure produced a rapid convection burn, lasting between 0.9 and 2.0 min with approximate flame lengths between 1.2 m and 2.7 m. Smoldering sections along the perimeter of the plots were doused with water, but no water was applied to plot interiors. This treatment was designed to kill directly vegetative plants and seeds on the soil surface.

No-manipulation plots served as controls for the weed-control treatments.

Treatments were applied in a randomized complete block design. Five 30-m by 5-m blocks were established by first partitioning the study area into topographic sections to ensure interspersion throughout the study site. Block locations were then set randomly within each section. Treatments were assigned randomly to 5-m by 5-m portions of each block, except that the untilled burn and no-manipulation plots were at either end of blocks.

Sampling

Pest plants. Abundance as vegetative cover was recorded for all species with nine 0.25-m^2 quadrats per treatment plot. Quadrats were located randomly and permanently marked within 4-m by 4-m units centered within each plot, to allow for a 0.5-m buffer to reduce edge effects. Cover was estimated visually, using calibrated templates and the same observers to maintain consistency. Cover measurements were taken between 7 and 16 June in 1993 and 28 May and 11 June in 1994.

Soil seed bank. Both the short-term (transient) and long-term (persistent) potential of the soil seed bank to contribute new seedlings were examined. To measure the short-term contribution, the density of seedlings emerging in the field during the autumn, winter, and spring rainy seasons was recorded. Emergence was recorded within five 15-cm by 15-cm quadrats per treatment area on 12 October 1992, and 13 January, 22 January, 2 February, and 20 April 1993. At each date, individuals were mapped to account for mortality and new emergence. Seedlings and vegetative sprouts were differentiated by noting the presence or absence of coleoptiles or cotyledons, and by noting more vigorous growth of vegetative sprouts. Rapid mortality among emergents prevented identifying them to species. Field emergence was recorded separately in the fallow treatment, solarization treatment, and no-manipulation control plots.

Viable seeds remaining in the soil after autumn, winter, and spring periods of emergence constitute the persistent seed bank. The density and composition of the persistent seed bank was measured by growing seedlings from soil removed from plots after spring emergence. Twelve 24.6-cm^2 by 5-cm soil samples were removed from each treatment plot (for a total of 296 cm^2 removed per treatment per block). Soil was stratified under cold (about 5 °C), moist conditions for 2.5 months. Soil was then spread in thin layers on growing flats in an Oregon State University greenhouse to allow seeds to germinate. Emergence by species was monitored once per week, identifying seedlings to species. Species identification was aided by simultaneously growing seedlings from seed collected from plants of known taxonomic identity. Seedlings and vegetative sprouts were differentiated by noting the presence or absence of coleoptiles or cotyledons, by noting more vigorous growth of vegetative sprouts, and by digging around root systems. Greenhouse emergence was recorded separately for the fallow treatment, solarization treatment, and no-manipulation control plots.

Analysis

Species composition (vegetative plants and seeds within the soil seed bank) was summarized for each treatment. Treatment effects were tested statistically using the Friedman nonparametric analysis of variance for randomized complete block experimental designs.

Results

Vegetative plants

Unmanipulated vegetation of Horkelia Prairie. Horkelia Prairie was dominated by a mix of native and exotic species in 1993 (control plots, Table 1) and in 1994 (control plots, Table 2). Exotic species contributed slightly more cover than did native species in both years (control plots,

Table 1
Cover (percent) of 10 Most Abundant Species in Each Treatment in 1993

Name	Native?	Cover, percent
Control Plots		
Agrostis tenuis	E	12.0
Anthoxanthum odoratum	E	9.1
Deschampsia cespitosa	N	9.1
Panicum capillare	N	5.5
Hypochaeris radicata	E	5.2
Rosa nutkana (?)	N	3.6
Danthonia californica	N	2.3
Grindelia integrifolia	N	1.7
Plantago lanceolata	E	1.6
Prunella vulgaris	N	1.2
Burn Plots		
Agrostis tenuis	E	26.8
Anthoxanthum odoratum	E	6.3
Deschampsia cespitosa	N	5.3
Briza minor	E	4.3
Panicum capillare	N	3.6
Danthonia californica	N	2.2
Plantago lanceolata	E	2.1
Aira caryophyllea	E	1.4
Hypochaeris radicata	E	1.3
Festuca arundinacea	E	0.9
Fallow Plots		
Juncus bufonius	N	56.9
Anthoxanthum odoratum	E	3.2
Agrostis tenuis	E	2.9
Juncus marginatus	E	2.2
Briza minor	E	1.0
Lotus purshiana	N	0.3

(Continued)

Note: E = Exotic; N = Native.

Table 1 (Concluded)

Name	Native?	Cover, percent
Fallow Plots (Continued)		
Hypochaeris radicata	E	0.3
Panicum capillare	N	0.3
Aira caryophyllea	E	0.2
Plagiobothrys figuratus	N	0.1
Solarized Plots		
Juncus bufonius	N	11.8
Anthoxanthum odoratum	E	10.8
Agrostis tenuis	E	3.1
Rumex acetosella	E	2.6
Panicum capillare	N	1.7
Lotus purshiana	N	1.4
Briza minor	E	0.7
Juncus marginatus	E	0.6
Deschampsia cespitosa	N	0.4
Hypericum perforatum	E	0.1
Average		
Juncus bufonius	N	17.3
Agrostis tenuis	E	11.2
Anthoxanthum odoratum	E	7.3
Deschampsia cespitosa	N	3.7
Panicum capillare	N	2.8
Hypochaeris radicata	E	1.7
Briza minor	E	1.6
Danthonia californica	N	1.1
Rosa nutkana (?)	N	0.9
Plantago lanceolata	E	0.9

Tables 3 and 4). Pest plants, both native and exotic species considered management problems (Table 5), were abundant in both years (control plots, Tables 3 and 4).

Table 2
Cover (percent) of 10 Most Abundant Species in Each Treatment in 1994

Name	Native?	Cover, percent
Control Plots		
Anthoxanthum odoratum	E	28.2
Deschampsia cespitosa	N	13.6
Agrostis tenuis	E	6.7
Panicum capillare	N	6.4
Grindelia integrifolia	N	4.5
Hypochaeris radicata	E	3.7
Rosa sp.	N	3.6
Leontodon nudicaulis	E	1.9
Danthonia californica	N	1.8
Plantago lanceolata	E	1.6
Burn Plots		
Anthoxanthum odoratum	E	22.7
Deschampsia cespitosa	N	20.7
Agrostis tenuis	E	11.6
Plantago lanceolata	E	4.6
Panicum capillare	N	3.4
Danthonia californica	N	2.6
Hypochaeris radicata	E	2.2
Festuca arundinacea	E	2.1
Lotus purshiana	N	1.0
Lotus formosissimus	N	0.9
Fallow Plots		
Agrostis tenuis	E	17.2
Anthoxanthum odoratum	E	14.5
Panicum capillare	N	8.0
Juncus marginatus	E	5.9
Deschampsia cespitosa	N	4.3
Hypochaeris radicata	E	2.9

(Continued)

Note: E = Exotic; N = Native.

Table 2 (Concluded)		
Name	Native?	Cover, percent
Fallow Plots (Continued)		
Juncus bufonius	N	2.0
Lotus purshiana	N	1.0
Prunella vulgaris	N	0.8
Eriophyllum lanatum	N	0.8
Solarized Plots		
Anthoxanthum odoratum	E	20.6
Agrostis tenuis	E	14.5
Panicum capillare	N	8.6
Deschampsia cespitosa	N	6.3
Lotus purshiana	N	5.8
Juncus bufonius	N	2.1
Juncus tenuis	N	1.9
Juncus marginatus	E	1.2
Myosotis discolor	N	1.1
Rubus discolor	E	0.9
Average		
Anthoxanthum odoratum	E	21.5
Agrostis tenuis	E	12.5
Deschampsia cespitosa	N	11.2
Panicum capillare	N	6.6
Hypochaeris radicata	E	2.3
Lotus purshiana	N	2.2
Juncus marginatus	E	1.7
Plantago lanceolata	E	1.7
Grindelia integrifolia	N	1.4
Danthonia californica	N	1.2

Effects of treatments on pest plant abundance. The fallow and solarization treatments significantly reduced exotic and pest plant species cover in 1993 (Table 3). By 1994, however, cover of exotic species and pest plants did not differ significantly among treatments (Table 4).

Table 3
Overall Cover (percent) and Cover (percent) of Species Groups by Treatments in 1993

	Control	Burn	Fallow	Solarized
Overall cover	59.5 a	62.1 a	68.2 a	34.0 b
Natives	27.8 b	16.2 a	58.2 c	15.7 a
Exotics	31.8 b	45.9 b	10.0 a	18.3 a
Pests	33.2 b	40.1 b	8.8 a	17.4 a
Native/Exotic	0.9 b	0.4 a	9.9 c	1.2 b
Nat-Jubu	27.7 d	15.7 c	1.3 a	3.9 b
(Nat-Jubu)/Exo	0.9 a	0.4 a	0.0 a	0.2 a

Note: Native/Exotic: Ratio of cover of native species to cover of exotic species. Nat-Jubu: Cover of native species, excluding *Juncus bufonius*. (Nat-Jubu)/Exo: Ratio of cover of native species, excluding *Juncus bufonius*, to cover of exotic species. All values are arithmetic means, except for Native/Exotic and (Nat-Jubu)/Exo, which are geometric means. Treatments had statistically significant effects on all groups, except on (Nat-Jubu)/Exo. Values within rows with the same letter do not significantly differ (5 percent level).

Table 4
Overall Cover (percent) and Cover (percent) of Species Groups by Treatments in 1994

	Control	Burn	Fallow	Solarized
Overall cover	79.8 c	76.9 bc	60.5 a	68.0 ab
Natives	35.6	32.2	18.4	27.5
Exotics	44.2	44.7	42.1	40.2
Pests	47.6	44.9	42.1	40.0
Nat/Exo	0.8	0.7	0.4	0.7

Note: Nat/Exo: Ratio of cover of native species to cover of exotic species. All values are arithmetic means, except for Native/Exotic, which are geometric means. Total cover was the only category significantly affected by treatments (5 percent level). Treatments had statistically significant effects only on overall cover. Values within rows with the same letter do not significantly differ (5 percent level).

Only three of the pest or exotic species were significantly affected by the treatments in 1993: *Hypochaeris radicata*, *Agrostis tenuis*, and *Leontodon nudicaulis* were significantly reduced in both the fallow and solarized treatments (Table 6). Results were different in 1994. Although *Hypochaeris radicata* and *Agrostis tenuis* continued to be abundant and *Leontodon nudicaulis* increased in abundance, their cover no longer differed significantly among treatments. *Anthoxanthum odoratum*, a common exotic grass, had significantly less cover in burn treatments compared with controls, and still less in fallow and solarized plots (Table 7), although its 1994 abundance was higher than its 1993 abundance in all treatments (Tables 5 and 6). The exotic

Table 5
Species Designated as Pest Plants

Agrostis tenuis
Anthoxanthum odoratum
Chrysanthemum leucanthemum
Cynosurus echinatus
Festuca arundinacea
Hypericum perforatum
Hypochaeris radicata
Juncus marginatus
Leontodon nudicaulis
Parentucellia viscosa
Plantago lanceolata
Rosa sp.
Rubus discolor
Rumex acetosella
Senecio jacobaea
Spiraea douglasii
Trifolium dubium

species *Juncus marginatus* was present only in the fallow and solarized plots.

Effects of treatments on native species. Seven native species had significantly lower cover in 1993 in some treatment plots as compared with control plots (Table 6). The only native species with significantly higher cover in treatment plots was *Juncus bufonius*, which had very high cover in the fallow plots (Table 6). *Juncus bufonius*, although native to the area, is also a rather cosmopolitan and weedy species.

The average cover of native species within untreated control plots was 28 percent in 1993 (Table 3). The cover of native species was significantly higher (58 percent) in the fallow treatment (Table 3). This pattern was caused entirely, however, by the high abundance of *Juncus bufonius* in the fallow

Table 6
Cover (percent) of Species With Statistically Significant Responses to Treatments in 1993 Measurements

			Control	Burn	Fallow	Solarized
Agrostis tenuis	E	P	12.0 b	26.8 b	2.9 a	3.1 a
Aster hallii	N		0.5 b	0.2 b	0.0 a	0.0 a
Danthonia californica	N		2.3 b	2.2 b	0.0 a	0.0 a
Deschampsia cespitosa	N		9.1 b	5.3 a	0.0 a	0.4 a
Eriophyllum lanatum	N		0.7 b	0.6 b	0.0 a	0.0 a
Grindelia integrifolia	N		1.8 c	0.5 b	0.0 a	0.0 a
Hypochaeris radicata	E	P	5.3 b	1.4 b	0.3 a	0.0 a
Juncus bufonius	N		0.1 a	0.5 a	56.9 c	11.9 b
Leontodon nudicaulis	E	P	0.5 b	0.2 ab	0.0 a	0.0 a
Lotus formosissimus	N		0.6 c	0.8 bc	0.0 a	0.1 ab
Prunella vulgaris	N		1.2 c	0.6 b	0.1 a	0.0 a

Note: Within rows, values with the same letter do not significantly differ (5 percent level). E = Exotic; N = Native; P = Pest plant species.

Table 7
Cover (percent) of Species With Statistically Significant Responses to Treatments in 1994 Measurements

			Control	Burn	Fallow	Solarized
Anthoxanthum odoratum	E	P	28.2 c	22.8 b	14.6 a	20.7 a
Danthonia californica	N		1.8 b	2.7 b	0.3 a	0.2 a
Eriophyllum lanatum	N		0.2 ab	0.5 b	0.8 b	0.0 a
Grindelia integrifolia	N		4.6 c	0.8 b	0.2 a	0.2 a
Juncus bufonius	N		0.0 a	0.0 a	2.1 b	2.1 b
Juncus marginatus	E	P	0.0 a	0.0 a	5.9 c	1.3 b
Juncus tenis	N		0.1 a	0.3 a	0.1 a	2.0 b
Lotus formosissimus	N		1.3 c	1.0 bc	0.4 ab	0.2 a

Note: Within rows, values with the same letter do not significantly differ (5 percent level).
E = Exotic; N = Native; P = Pest plant species.

plots (Table 1). The cover of native species, excluding *Juncus bufonius*, was highest in the control plots, and significantly less in the burn, solarized, and fallow treatments, in that order (Table 3). That is, the weed control techniques also reduced the abundance of native species.

The relative effect of treatments on native species versus exotic species can be seen in the ratio of their cover values. The highest ratio of native species cover to exotic species cover in 1993 was in the fallow treatment plots (Table 3), again dictated by the high abundance of *Juncus bufonius* in fallow plots. The ratio of native to exotic cover, excluding *Juncus bufonius*, did not differ significantly among treatments (Table 3).

The species patterns were similar in 1994. Four native species had significantly lower cover in 1994 in some treatment plots as compared with control plots (Table 7). All four of these species had similar patterns in 1993. Two native species, *Juncus bufonius* and *Juncus tenuis*, had significantly higher cover with one or both of the tillage treatments.

The average cover of native species within untreated control plots was 36 percent in 1994 (Table 4). No treatment significantly increased or decreased the cover of native plants in 1994. The ratio of native species cover to exotic species cover in 1994 was highest in the burn treatment, but differences were not statistically significant (Table 4).

Soil seed bank

About 60 percent of the seedlings that emerged in the fall, winter, and spring within measurement plots at Horkelia Prairie were monocots (Table 8). Fallow plots had significantly more emerging monocot seedlings than did control or solarized plots. Solarized plots had significantly fewer emerging dicot seedlings than did control plots.

Table 8
Fall and Spring Seedling Emergence in Treatment Plots (Values are number of emergents per square meter)

	Control	Fallow	Solarized	Overall
Monocots	140 a	1,020 b	250 a	470
Dicots	680 b	220 ab	30 a	310
Total	820	1,240	280	780

Note: Treatments had statistically significant, although different, effects on monocot and dicot emergence. Within rows, values with the same letter do not significantly differ (5 percent level).

Forty-two species were recorded in the persistent seed bank. The most common species were *Juncus bufonius*, *Hypericum perforatum*, *Panicum capillare*, and *Agrostis tenuis* (Table 9).

The solarized treatment significantly decreased the density of monocot seeds persisting in the soil (Table 10). The large and nearly significant ($0.90 < P < 0.95$) increase in emergence of native species in the fallow plots compared with the solarized plots was entirely due to the large number of *Juncus bufonius* seeds in the soil (Table 9).

The seed bank densities of five species were significantly changed by the treatments (Table 9). The persistent seed bank of *Juncus bufonius* was significantly larger in fallow than in solarized plots. *Agrostis tenuis* seed bank density was higher in the control than in the fallow treatment, and higher in the fallow treatment than in the solarized treatment. Three grass species (*Deschampsia cespitosa*, unknown grass No. 1, and unknown grass No. 2) had higher seed bank densities in the control plots than in either treatment.

Discussion

This study addressed three questions: (a) Do the tested weed control techniques reduce pest plant abundance? (b) Do they also reduce the abundance of native plant species? and (c) Do patterns differ between the first and second

Table 9
Seed Densities of the 13 Most Abundant Species in the Soil Seed Bank Within Each Treatment

		Control	Fallow	Solarized	Overall
Juncus bufonius	N	5,240 ab	8,580 b	2,970 a	5,600
Hypericum perforatum	E	2,990	3,110	3,650	3,230
Panicum capillare	N	2,870	4,160	1,860	2,960
Agrostis tenuis	E	3,110 c	1,350 b	510 a	1,660
Rumex acetosella	E	70	100	2,330	830
Myosotis discolor	N	1,320	170	980	820
Triodanis perfoliata	N	980	610	810	800
Briza minor	E	540	610	200	450
Unknown grass No. 1		640 b	300 a	340 a	430
Deschampsia cespitosa	N	740 b	200 a	300 a	420
Juncus marginatus (?)	E	100	740	200	350
Hypochaeris radicata	E	740	70	70	290
Unknown grass No. 2		470 b	240 a	140 a	280

Note: Values are number of emergents per square meter, determined from samples of 296 cm^2 per treatment. Seed bank densities significantly varied among treatments for five species. Within rows, values with the same letter do not significantly differ (5 percent level).
N = Native; E = Exotic.

Table 10
Soil Seed Densities and Number of Species Within Different Categories of Species

	Seed Bank Density (per m^2)				Number of Species			
	Control	Fallow	Solarized	Overall	Control	Fallow	Solarized	Overall
All species	21,150	21,660	15,370	19,390	26	33	27	42
Native species	11,350	14,560	7,160	11,030	9	17	11	19
Exotic species	7,910	5,510	7,300	6,900	10	10	10	14
Unknowns	1,890	1,590	910	1,460	7	6	6	9
Monocots	14,430 b	16,860 b	7,060 a	12,780	14	15	12	16
Dicots	6,720	4,800	8,310	6,610	12	18	15	26

Note: Values are density per square meter, determined from samples of 296 cm^2 per treatment. Only monocot seed densities varied significantly among species. Within rows, values with the same letter do not significantly differ (5 percent level).

year? Questions (a) and (b) will be answered separately, considering year-to-year differences along the way.

Control of exotic and pest plant species

Plot tilling (as in the fallow and the solarized treatments) can be an effective method for reducing next year's cover of exotic species, including pest species. Most of this reduction in this study was probably from killing established plants, rather than seeds in the soil seed bank. The fallow treatment did not reduce the soil seed bank in this study, probably because the first tilling in 1992 was followed directly by unusually hot, dry weather (cf. Roberts and Potter 1980). A soil crust then formed quickly, decreasing germination: only about 4 percent of the soil seed bank (Table 10) was stimulated to germinate by the treatments (Table 8). As a result, few seedlings were present to be killed by the second tilling, and the soil seed bank remained large. Better results might well occur under more typical weather conditions.

No reduction in exotic and pest species was evident in the second year. Several factors could cause this loss of control. First, the undiminished soil seed bank probably served as a reservoir for new establishment, and these seedlings reached significant size by the second year. Second, some of the exotic plants seemed to be able to survive the fallow and solarization treatments. The reduced competition in the first year after treatment would allow these survivors to grow quickly, gaining dominance by the second year. Third, seed dispersal from offsite could have restocked the site.

The burn treatment was ineffective at reducing herbaceous pest plant abundance. In fact, the abundance of exotic species was higher in both the first and second years after burning. Only one pest species (*Anthoxanthum odoratum*) in one year (1994) was reduced by the burning treatment. This failure to control herbaceous pests does not, however, diminish the potential value of prescribed burning for controlling woody species, which are a major threat to wetland prairies.

Reduction of native species

The control techniques tested were as effective against native species as against exotic species. In fact, in 1993 the cover of native species (excluding *Juncus bufonius*) was lower in the burn, fallow, and solarized treatment plots. The ratio of native species cover (excluding *J. bufonius* in year 1) to exotic species cover did not significantly differ among treatments.

The effectiveness of the fallow and solarization treatments might be increasing over time. The ratio of native cover to exotic cover in 1994 for these treatments was greater in 1993 than in 1994 ($P > 0.95$, Mann-Whitney test). The ratio of native cover to exotic cover was still less in treatments than in control plots, however.

Evaluation, improvements, and recommendations

Each control technique was effective in reducing at least one pest species. For example, tillage diminished *Agrostis tenuis* and *Hypochaeris radicata*, and burning and tillage reduced *Anthoxanthum odoratum*. More widespread control might have occurred if weather conditions in 1992 had been more favorable.

One problem shown by these results is the loss of control by the second year. Some treatments reduced overall cover (solarization in 1993 and fallow and solarization in 1994). Surviving adults and seeds in these treatments then had diminished competition and could regain abundance. One solution to this problem is to continue control measures beyond a single year.

Weedy species often grow more quickly than do native species under conditions of low competition and high resources. Thus, any short-term advantage of reduced cover to native species can turn to favor the weeds. A solution to this problem is to boost the abundance of native species during the period in which exotic species (and native species) abundance is down. The early control of pest and exotic species might also be maintained in subsequent years by planting native species, which would boost their competitive suppression of undesired plants. As a result, adding seeds or transplants of native species can give natives a longer term advantage over exotic and pest species. Adding seeds or transplants of native species would probably not be useful without first reducing overall vegetative cover, because seedlings and young transplants would soon be crowded and eliminated.

These findings suggest a strategy for restoring sites with significant numbers of both exotic and native species. First, implement control measures to reduce overall cover. The fallow and solarization treatments were best in this study, although prescribed burning can be an effective control measure for woody plants. Control measures should continue until (a) vegetative cover is less than 50 percent (to provide ample open space) and (b) the soil seed bank of exotic species is down to a manageable level (perhaps $<1,000$ seeds per square meter). The number of years needed for control can be determined by monitoring plant cover and seed bank densities; at least 2 years will probably be required under most circumstances.

Second, once adequate control has been reached and before exotic species can rebound, promote native species by either sowing their seeds or setting out transplants. Sowing densities must be high enough to lead to significant numbers of surviving seedlings. Other studies at Horkelia Prairie (Chapter 3) suggest that sowing densities should be greater than 2,000 seeds per square meter (the equivalent of about 12 lb/acre of cleaned and filled *Deschampsia cespitosa* seed).

All conclusions are based on just 2 years of results. Studies by K. Connelly Pendergrass at Fern Ridge (Wilson, Connelly, and Lantz 1993) show that the effects of prescribed burning, for example, can shift significantly between years. Perhaps the burn treatments in this study might still be beneficial, but in future years. Since multiyear data are rare in Willamette Valley restoration experiments, continued monitoring of the plots at Horkelia Prairie would provide essential information for restoration management and science.

3 Seed Dormancy, Germination, and Establishment[1]

Introduction

Seed size, abundance, viability, dormancy, and germination requirements strongly influence plant establishment (Bostock 1978, Bewley and Black 1982, Fenner 1985, Baskin and Baskin 1988, Leck, Parker, and Simpson 1989) and therefore are important considerations in restoration of native vegetation. These characteristics provide criteria for selection of suitable species, development of collection and pretreatment methods, and determination of seeding densities. The first set of objectives of this study was to measure seed weights and test seed viability, dormancy status, and germination requirements for the species used in propagation by seed. The second set of objectives was to test seed propagation under field conditions and to compare the performances of different seed mixtures.

Methods

Study species

The species selected for direct propagation were *Deschampsia cespitosa*, *Wyethia angustifolia*, *Eriophyllum lanatum*, *Plagiobothrys figuratus*, *Microseris laciniata*, *Hordeum brachyantherum*, and *Danthonia californica*. Historically, *Deschampsia cespitosa* was the dominant species in Willamette Valley wet prairies; the other six species are locally abundant in the area. Species were hand collected from various sites in the west Eugene area. Collection dates were set to try to match periods of peak seed ripeness.

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1 Written by Drs. Mark V. Wilson and Cheryl A. Ingersoll and Ms. Deborah L. Clark, Oregon State University.

In addition, bulk seed mixtures were vacuum-collected from two sites in the west Eugene area ("West Coyote" and "SP"). The bulk mixtures were heavily dominated by one or more species of *Carex* (67 percent of the West Coyote mixture) and *Eleocharis* (99 percent of the SP mixture). *Eleocharis acicularis* (a perennial) and *E. ovata* (an annual) dominated the SP site, and presumably constituted most of the Eleocharis seeds in the collection.[1] Seeds were collected during the summer of 1992, cleaned, dried, and kept in cold storage until testing in the fall of 1992.

Study site

Field propagation was conducted at Horkelia Prairie, a portion of the Fern Ridge Project west of Eugene, managed by the Corps of Engineers. Horkelia Prairie is a degraded wetland prairie, grazed in the past, but with no evidence of tillage except for past trenching to reduce seasonal flooding. The vegetation of Horkelia Prairie was dominated by the exotic grasses *Agrostis tenuis* and *Anthoxanthum odoratum* and the native grass *Deschampsia cespitosa. Eriophyllum lanatum*, *Microseris laciniata*, and *Danthonia californica* were present at the site in low abundance. *Plagiobothrys figuratus* and *Eleocharis* spp. were found only in disturbed soil. *Wyethia angustifolia*, *Hordeum brachyantherum*, and *Carex* were not recorded on the site.

Seed weight

In order to determine seed weights, 5 to 19 replicates of 20 filled seeds per species were weighed. The number of replicates was set so that the coefficient of variation of estimated seed weight was < 16 percent.

Viability, dormancy, and germination

Three measures of seed vigor were used. Seed "fullness" was estimated visually. Seed viability was measured using the tetrazolium (TZ) test. Germination was recorded by holding untreated seeds at alternating temperature/light conditions of 4 °C/dark and 12 °C/light. For most species, separate lots of randomly selected (that is, unscreened for fullness) and filled seeds were tested. Only random seed lots of *Eleocharis* were tested because filled and unfilled seeds could not be distinguished. Seeds remaining ungerminated for more than 2 or 3 weeks were then tested for viability using the TZ test.

Dormancy rate was calculated as the difference between viability rate and germination rate. Stratification under cool and moist conditions was used to try to break dormancy for species with significant amounts of seed dormancy. Other dormancy-breaking methods were available for use, but stratification

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[1] Personal communication, M. G. Wilson.

proved sufficient for the species tested (*Carex*, *Hordeum brachyantherum*, and *Wyethia angustifolia*). Seeds were moistened and placed in sealed dishes at 3 °C for 3 months, then removed and placed at alternating 4 °C and 12 °C for germination. All treatments consisted of 10 replicates of 20 seeds each.

Seed mixtures and field sowing

Three seed mixtures were prepared for sowing at Horkelia Prairie (Table 11). Mixture 1 was a monoculture of *Deschampsia cespitosa*. One hundred filled seeds of *Deschampsia* were counted for sowing in each plot; this was the equivalent of about 77 viable seeds. Mixture 2 was a combination of seven native grasses and forbs (Table 11). *Deschampsia* was the most abundant species in Mixture 2 (30 filled seeds, 23 viable seeds).

Table 11
Sowing Densities in Seed Propagation Experiment

Species	Sowing Density (Seeds per 1,250-cm^2 Plot)	
	Filled	Viable
Mixture 1		
Deschampsia cespitosa	100	77.0
Mixture 2		
Danthonia californica	12	10.8
Deschampsia cespitosa	30	23.1
Eriophyllum lanatum	8.2	2.2
Hordeum brachyantherum	12	11.3
Plagiobothrys figuratus	12	10.9
Microseris laciniata	12	10.6
Wyethia angustifolia	3.2	2.7
Total	89.4	71.6
Mixture 3		
Carex sp.	212.6	29.8
Eleocharis sp.	92.3	0.9
Galium sp.	3.0	NT
Unknown grass	29.0	NT
Unknown dictos (5 spp.)	4.0	NT

Note: NT = Viability not tested.

Mixture 3 was created by combining 0.02 g of the bulk-collection from the SP site and 0.32 g of the bulk-collection from the West Coyote site. (Most of the weight of the West Coyote collection was in litter and other nonseed material.) The resulting 0.34-g mixture had about 340 seeds, dominated by *Carex* spp. and *Eleocharis* spp. (Table 11).

Seed beds were prepared at Horkelia Prairie on 12 May 1992 and 3 June 1992 by rototilling five randomly located 5-m by 5-m blocks. On 21 October 1992, six 1,250-cm^2 sowing plots were located at random within each of the tilled blocks, raked lightly, and sown with one of the three seed mixtures, two sowing plots for each mixture. A 1,250-cm^2 buffer area around each sowing plot was also sown with the same seed mixture. After sowing, seeds were gently raked into the soil.

Emergence from the sown plots was recorded by species on 9 and 16 June 1993 and 6 and 10 June 1994. Performance of each species in the treatment plots was analyzed after subtracting any emergence of that species in unmanipulated control plots.

The randomly located blocks spanned a flooding and soil wetness gradient within the wetland prairie study site. The effect of this gradient on establishment rates was tested with correlation analysis.

Results

Seed weight

Seed weights varied greatly among the species tested (Table 12). *Wyethia angustifolia* had the largest seeds, at 0.27 g per 20 seeds. *Plagiobothrys figuratus*, *Deschampsia cespitosa*, and *Eriophyllum lanatum* all had very small seeds (0.01 g per 20 seeds).

Table 12
Seed Weights of Study Species

Species	Weight of 20 Seeds, g	
	Mean	SE
Danthonia californica	0.084	0.003
Deschampsia cespitosa	0.013	0.001
Eriophyllum lanatum	0.012	0.000
Hordeum brachyantherum	0.082	0.002
Microseris laciniata	0.037	0.001
Plagiobothrys figuratus	0.014	0.001
Wyethia angustifolia	0.273	0.006

Note: SE = Standard error.

Viability

Seed viability of random lots among the nine species ranged between 1 and 87 percent (Table 13, column 2). Overall viabilities of *Eleocharis*, *Eriophyllum lanatum*, and *Carex* were quite low, while those of *Plagiobothrys figuratus* and *Hordeum brachyantherum* were very high. *Deschampsia cespitosa*, *Danthonia californica*, *Microseris laciniata*, and *Wyethia angustifolia* had intermediate viability rates.

Viability of filled seeds ranged between 1 and 96 percent (Table 13, columns 5 and 7). Viability of filled *Carex*, *Eleocharis*, and *Eriophyllum lanatum* seeds was very low, while that of *Danthonia californica*, *Hordeum brachyantherum*, *Microseris laciniata*, *Plagiobothrys figuratus*, and *Wyethia angustifolia* was high. (Visual estimation of seed fullness in *Carex* is particularly difficult because of the hard perigynium surrounding the seed.)

Laboratory germination

Untreated seeds of all but three species germinated at 4 °C/12 °C at rates that were se to their viability levels (Table 13). For example, 67 percent of collected seeds of *Microseris laciniata* were viable and 67 percent of the seeds germinated (for a success rate of 100 percent). Seeds of *Danthonia californica*, *Deschampsia cespitosa*, *Eriophyllum lanatum*, *Microseris laciniata*, and *Plagiobothrys figuratus* also germinated at rates comparable with their viability. In contrast, *Carex*, *Hordeum*, and *Wyethia* germinated at significantly lower rates than indicated by viability. Germination of *Wyethia angustifolia* was increased by stratification from 0 to 87 percent, *Carex* from 0 to 60 percent, and *Hordeum brachyantherum* from 26 to 83 percent (Table 13).

Patterns of emergence

Pure Deschampsia cespitosa sowings (mixture 1). In 1993, only an average of about 0.01 seedlings emerged per viable seed sown in the pure *Deschampsia cespitosa* mixture (Table 14). The average cover of seedlings was very low, about 1.3 cm^2 per plot and 1.6 cm^2 per emergent. Emergence from the 1992 sowing was higher in 1994, with an average of about 0.03 seedlings per viable seed sown (Table 15). This increase is probably because some small *Deschampsia* seedlings were recorded in 1993 as *Juncus bufonius* seedlings, which are equally small and similar in appearance, but were much more abundant. The 1994 seedlings produced considerably more cover than in 1993, 95.0 cm^2 per plot and 51.7 cm^2 per emergent.

Table 13
Dormancy and Germination Conditions of Collected Seeds

Species	From Random Seed Lots, Unstratified						From Filled Seed Lots			
							Unstratified			Stratified
	Filled	Viable	SE	Germinated	Via/Fill	Germ/Fill	Viable	SE	Germinated	Germinated
Carex	0.99	0.15	0.01	0.03	0.15	0.00	0.14	0.03	0.00	0.60
Danthonia	0.69c	0.62c	0.01	0.57			0.90	0.02	0.83	
Deschampsia	0.37	0.30	0.04	0.27	0.82	0.74	0.72c	0.09	0.59	
Eleocharis		0.01	0.01	0.00			0.01	0.01		
Eriophyllum	0.29	0.08	0.02	0.03	0.26	0.10	0.28c	0.05	0.18	
Hordeum	0.89	0.84	0.02	0.26	0.94	0.29	0.95c	0.02	0.31	0.83
Microseris	0.75	0.68	0.01	0.67	0.90	0.89	0.86c	0.02	0.85	
Plagiobothrys	1.00	0.87	0.01	0.87	0.87	0.87	0.96c	0.01	0.96	
Wyethia	0.67	0.56c	0.02	0.00		0.00	0.83	0.03	0.00	0.87

Note: Values are proportions. Via/Fill = Proportion of filled seeds in random seed lots that were viable; Germ/Fill = Proportion of filled seeds in random seed lots that germinated. SE = Standard error. Values followed by "c" were calculated from the other, directly measured seed characteristics for that species.

Table 14
Emergence Results in 1993

Species	Emergents (per Plot)	Emergents/Filled Seed	SE	Emergents/ Viable Seed	Cover (cm^2/Plot)	Cover/Filled Seed (cm^2/Seed)	Cover/Viable Seed (cm^2/Seed)	Cover/Emergent (cm^2/#)	SE
Mixture 1									
Deschampsia	0.8	0.01	0.00	0.01	1.3	0.0	0.0	1.6	1.4
Mixture 2									
Deschampsia	0.0	0.00	0.00	0.00	0.0	0.0	0.0	n.d	
Wyethia	3.4	1.06	0.26	1.28	10.0	3.1	3.8	2.9	
Eriophyllum	0.8	0.10	0.04	0.36	2.5	0.3	1.1	2.8	
Plagiobothrys	1.9	0.16	0.08	0.17	21.3	1.8	1.9	11.9	
Microseris	0.2	0.02	0.01	0.02	1.3	0.1	0.1	6.3	
Hordeum	0.0	0.00	0.00	0.00	0.0	0.0	0.0	n.d	
Danthonia	0.2	0.02	0.02	0.02	0.0	0.0	0.0	0.0	
Entire mixture	6.5	0.07	0.02	0.09	35.0	0.4	0.5	5.6	3.2
Mixture 3									
Eleocharis	2.5	0.03	0.01	2.71	33.8	0.4	36.6	13.5	4.1
Carex	0.0	0.00	0.00	0.00	0.0	0.0	0.0	n.d	

Note: Mixture 3 includes other species whose emergence was not monitored. Values have been adjusted for emergence of target species in unsown control plots. Plot sizes were 1,250 cm^2. SE = Standard error for the results in the previous column. n.d. = Not defined.

Table 15
Emergence Results in 1994

Species	Emergents (per Plot)	Emergents/Filled Seed	SE	Emergents/ Viable Seed	Cover (cm^2/Plot)	Cover/Filled Seed (cm^2/Seed)	Cover/Viable Seed (cm^2/Seed)	Cover/Emergent (cm^2/#)	SE
Mixture 1									
Deschampsia	2.1	0.02	0.01	0.03	95.0	1.0	1.2	51.7	11.7
Mixture 2									
Deschampsia	0.8	0.03	0.01	0.04	16.3	0.5	0.7	38.9	
Wyethia	2.7	0.84	0.27	1.02	20.0	6.3	7.5	7.4	
Eriophyllum	0.3	0.04	0.04	0.14	5.0	0.6	2.3	11.1	
Plagiobothrys	0.1	0.01	0.01	0.01	0.0	0.0	0.0	0.0	
Microseris	0.4	0.03	0.02	0.04	3.8	0.3	0.4	9.4	
Hordeum	0.0	0.00	0.00	0.00	0.0	0.0	0.0	n.d	
Danthonia	0.0	0.00	0.02	0.00	1.3	0.1	0.1	6.3	
Entire mixture	4.3	0.05	0.01	0.06	46.3	0.5	0.6	13.5	6.7
Mixture 3									
Eleocharis	0.0	0.00	0.00	0.00	0.0	0.0	0.0	n.d.	
Carex	0.0	0.00	0.00	0.00	0.0	0.0	0.0	n.d	

Note: Mixture 3 includes other species whose emergence was not monitored. Values have been adjusted for emergence of target species in unsown control plots. Plot sizes were 1,250 cm^2. SE = Standard error for the results in the previous column. n.d. = Not defined.

Multispecies sowings (mixture 2). In 1993, an average of about 0.09 seedlings emerged per viable seed sown in the multispecies mixture (Table 14). The average cover in 1993 was much higher than in mixture 1, with 35.0 cm^2 per plot and 5.6 cm^2 per emergent. Results in 1994 were about the same, with 0.06 emergents per viable seed sown and 13.5 cm^2 cover per emergent (Table 15). The best performing species in 1993 were *Wyethia angustifolia* (highest emergence) and *Plagiobothrys figuratus* (highest cover). No *Deschampsia cespitosa* were recorded from the mixed-seed sowings. By 1994, however, *Deschampsia*'s late emergence and rapid growth made it the top performer in cover per emergent. *Wyethia* continued in 1994 to have the highest emergence per viable seed sown in 1992. In contrast, *Plagiobothrys* dropped precipitously from dominance in 1993 to a single seedling in 1994.

Four species sown into treatment plots also emerged in unmanipulated control plots. *Eriophyllum lanatum*, in particular, established naturally at rates almost as high as in sown plots (0.6 emergents per control plot versus 0.9 emergents per sown plot in 1994). Emergence rates of other species in control plots were all very low.

Bulk collection (mixture 3). Of the two genera monitored from the bulk collection (representing 90 percent of the seeds sown), the only emergence was by *Eleocharis* in 1993, with high emergence rates and cover per emergent (Table 14). No *Eleocharis* were recorded in 1994.

Comparisons with control plots. In all mixtures, the monitored species contributed relatively little to the overall cover within plots (Table 16). The cover of unmonitored species did not differ significantly among the three mixtures and the controls (Student's t-test, $\alpha = 0.05$).

Table 16
Vegetative Cover of Sown Species, Other Species, and Total for Plots Receiving the Three Sowing Mixtures and the Controls

Mixture	Cover, percent		
	Sown Species	Other Species	Total
1993			
1	0	60	60
2	3	55	58
3	3	45	48
Control	0	59	59
1994			
1	7	55	62
2	3	58	61
3	0	55	55
Control	0	70	70

Emergence versus hydrology. Scoles Associates (1994) measured average water table depth adjacent to each of the five treatment blocks for field sowing. No significant correlations (Kendall's test, $\alpha = 0.05$) were observed between total emergence per block and several measures of soil wetness, for any mixture in either year.

Discussion

Suitability of species

Several of the tested species show promise for use in future restoration efforts. *Plagiobothrys figuratus* seeds were highly viable, emerged at a fairly high rate, and rapidly produced high cover. By the second year, however, its cover was low. These characteristics suggest the use of *Plagiobothrys* as an early site-occupying species. (Alternatively, *Plagiobothrys* could have been favored by the wet winter and spring of 1993 but not favored by the more normal weather in 1994.) The species of *Eleocharis* tested showed similar patterns, except that its seed viability appeared to be very low. Its use in restoration projects would require very high sowing rates. *Deschampsia cespitosa* seeds were moderately viable, but significant vegetative growth did not occur until the second year, at which time it had the highest cover of all sown species. *Wyethia angustifolia* also performed well, with moderately high seed viability, the highest field emergence rate, and adequate cover per emergent.

The relatively high cover produced per emergent of *Eriophyllum lanatum*, *Microseris laciniata*, and *Danthonia californica* was countered by their low seed viabilities. The use of these species in restoration projects would require sowings at higher-than-average densities. *Hordeum brachyantherum*, although it had the highest rate of seed viability, emerged at the lowest rate in the field trials. *Wyethia*'s success is somewhat surprising because it is otherwise absent from the study site.

Three species (*Carex*, *Hordeum brachyantherum*, and *Wyethia angustifolia*) had high seed dormancy rates and benefitted from cool-moist stratification. Therefore, spring sowing with these seeds would require a stratification pretreatment. The high rate of field emergence by *Wyethia* shows that fall and winter conditions are suitable for breaking seed dormancy. Failure to break dormancy under field conditions might explain the low field emergence rates of *Carex* and *Hordeum*. *Danthonia californica*, *Deschampsia cespitosa*, *Eriophyllum lanatum*, *Microseris laciniata*, and *Plagiobothrys figuratus* had no apparent innate dormancy. Thus, these species would not require special pretreatments before their use in restoration efforts. Viability was so low in *Eleocharis* that dormancy could not be evaluated.

Suitability of mixtures

Emergence was low for all mixtures in the 2 years of measurements (generally 0 to 9 percent emergence per viable seed sown). By 1994, the pure *Deschampsia cespitosa* sowing (mixture 1) performed the best among the mixtures, with vegetative cover increasing from negligible to double that of mixture 2. The multispecies sowing (mixture 2) had the best balance of success over the 2 years of monitoring. This mixture had a moderate overall emergence rate in both years. The rapid growth of *Plagiobothrys figuratus* and *Microseris laciniata* contributed to the high cover of mixture 2 in 1993. The growth of some species in 1994 was balanced, however, by the rapid decline of *Plagiobothrys figuratus*. The bulk-collected sowing (mixture 3) did very well in 1993, because of the high emergence and rapid growth of *Eleocharis*. The complete decline of *Eleocharis* in 1994 made this mixture unsuccessful under these site and weather conditions.

Thus, the three mixtures of species showed separate values for field propagation in wetland restoration. Mixture 3 did best in first year establishment, mixture 1 did best in the second year, and mixture 2 was the only mixture to perform adequately both years. These differences in performances among mixtures and species suggest that careful combinations of species can be constructed to optimize establishment success in wetland restoration projects.

The high cover of other species (Table 16) shows that soil seed bank densities, seed dispersal rates, or plant survival of seed-bed preparation were high. Other studies at Horkelia Prairie (Chapter 2) recorded soil seed bank densities of at least 175 seeds/plot for similarly treated areas within the same experimental blocks. Thus, naturally occurring seeds (about one-third of which were non-native species) were more abundant than the sown seeds. Success in seed propagation for restoration would require either reducing the abundance of weed seeds in the soil seed bank or greatly increasing sowing densities.

Limitations

The results from this study must be evaluated in the face of possible limitations. Although these limitations do not invalidate the conclusions, they underscore the need for further, intensive study.

- Seeds were collected, by necessity, under conditions balancing seed ripeness and ease of collection. Species like *Eriophyllum lanatum* ripen over a wide period of time, so many seeds were probably immature when collected. In addition, *Eriophyllum* was collected at suboptimal times, so its poor performance in this study might not be representative of the species.

- The tetrazolium test is generally considered a definitive test for seed viability. However, the aberrant results for *Carex* and *Eleocharis* question its standard application to all species. For example, after stratification, 60 percent of filled *Carex* seeds germinated, yet the tetrazolium test showed only 14 percent viability.

- Anecdotal evidence points to a small (< 10 percent) drift of sown seeds outside on the treatment plots; therefore, emergence rates might be slightly higher than recorded.

- Field schedules dictated that emergence was recorded on just a few dates. *Plagiobothrys* emergence was probably underestimated, because some of its seedlings, which emerge very early, might have died before the field censuses. *Hordeum* and *Danthonia* were slow to germinate in the laboratory germination trials; emergence for these species was probably underestimated, because some might have emerged after the field censuses.

- Site hydroperiod might not have matched the requirements of the sown species.

- Small-scale (5 cm to 25 cm wide) mounds are characteristic of Willamette Valley wetland prairies. These mounds dry rapidly in late spring compared with level ground.[1] *Deschampsia cespitosa* typically grows on the top of these mounds and might be more tolerant than other species of the cycle of wet and dry soils. Tillage to prepare the sowing plots destroyed these mounds, reducing the possible advantage of *Deschampsia* over competing species.

- Assessing long-term contributions to revegetation would require recording survival and cover for several years.

Recommendations

Results suggest several guidelines for increasing the chance of successful establishment of native plant species by seed. These recommendations must be provisional, however, considering the limitations of this initial study.

- Sowing densities must take into consideration seed viability, with higher densities needed for species with lower viability. Viability among just the nine species investigated in this study ranged from < 10 percent to > 80 percent.

- Seeds should be sown in the fall, so any seed dormancy can be broken by winter stratification. Three of the nine species in this study had significant seed dormancy, which in each case was broken by stratification.

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[1] Personal communication, Phil Scoles.

- Weed seeds in the soil seed bank are a major impediment to restoration using seed propagation. Effective seed bank reduction measures should be instituted before field sowing. In addition, sowing densities should be much higher than the 100 to 300 seeds per 1,250-cm^2 rates used in this study.

- Seed mixtures with several species should have greater success than monocultures. First, a mixture that produces a succession of plants should be more effective in capturing the site against weed species. Mixtures that combine species (like the annual *Plagiobothrys figuratus*) that have rapid initial growth with species (like *Deschampsia cespitosa*) that become dominant after the first year are recommended. Second, year-to-year variability in weather makes it difficult to match species with their proper site conditions. Sowing mixtures that include species suitable for the range of soil and hydrological conditions in wetland prairies are recommended.

4 Characterization of Mycorrhizae[1]

Introduction

Mycorrhizal fungi can be extremely important in the establishment and survival of plants (Molina, Massicotte, and Trappe 1992). Mycorrhizae can serve a number of important functions in improving plant nutrition, such as increasing phosphorus, nitrogen, and micronutrient concentrations in whole plant or in specific tissues (Fitter 1990). Mycorrhizal fungi can protect the plant's roots against soil pathogens and increase the plant's resistance to aboveground herbivory by insects (reviewed in Ingham and Molina 1991).

Mycorrhizal fungi play an important role in the restoration of degraded habitats (Miller and Jastrow 1992). Some plant species are obligately mycorrhizal, meaning that they cannot survive without mycorrhizal colonization of their root systems (Molina, Massicotte, and Trappe 1992). Most trees and perennial grasses are examples of obligately mycorrhizal plants. However, some species of plants may be mycorrhizal only when the plant is stressed, for example, by competition with other plants for nutrients, by drought, or by nutrient limitation in the soil. Mycorrhizal colonization is "allowed" by the plant, apparently, only when the relationship gives the plant an advantage. Until stress occurs, these "facultatively mycorrhizal" plants may not be colonized at all, or may be colonized to a limited extent. Most herbs, annual grasses, and ephemeral understory species show this type of response to mycorrhizal fungi. However, there are plant species that are never mycorrhizal under any circumstance. These plants tend to be in the mustard family.

Clearly, obligately mycorrhizal plants require the presence of their mycorrhizal symbiont in order to survive and reproduce. Lack of the appropriate inoculum results in exclusion of that plant species from the community. In general, obligately mycorrhizal plant species have a wide range of fungi that can serve this role. Facultatively mycorrhizal species, in general, have a

[1] Written by Drs. Elaine R. Ingham and Mark V. Wilson, Oregon State University.

less wide host range. But in many areas, disturbance has destroyed the mycorrhizal inoculum in the soil, and several researchers have shown that the lack of the appropriate mycorrhizal fungi prevented establishment and survival of both annual and perennial grasses, of shrubs and trees, and of early colonizing species of plants (Miller and Jastrow 1992).

Loss of mycorrhizal inoculum results in sites unsuitable for restoration of important native species and may dictate the addition of mycorrhizal inoculum before restoration is possible (Miller and Jastrow 1992). If the number of mycorrhizal spores is reduced but all species survive, then colonization of plant roots may be limited, limiting the number of individuals of a plant species requiring that limited inoculum. If entire species of mycorrhizal fungi are eliminated, then one or more plant species may be lost from a plant community, resulting in an altered plant species composition. Colonization of other plant species may not be limited in any way, however, if only one or two disturbance-intolerant mycorrhizal species have been deleted from the fungal community.

Several of the sites used in the West Eugene Wetland Restoration Research Project have experienced different types and intensities of past land use. Thus, mycorrhizal inoculum might be reduced in numbers of spores or certain sensitive species might be lost. Lack of this inoculum might limit plant reestablishment.

Past vegetation influences the type of mycorrhizal inoculum present (Allen et al. 1992). For example, a site previously dominated by native grasses would likely have the fungal inoculum to support native grass species sown into the site, but would probably not have the inoculum to support nongrass species. However, if a native grass had been lacking from a site for some time, and if that native grass has a narrow range of mycorrhizal fungi with which it may associate, the specific mycorrhizal fungi would likely be missing from the soil.

Therefore, sites in which non-native species dominate would be less likely to have the mycorrhizal species needed by native plant species, even if the native species could germinate and begin to grow. Disturbances, such as plowing or herbicide application, reduce both numbers of vesicular-arbuscular mycorrhizae (VAM) spores and the diversity of VAM fungal species present. Reductions depend on other factors as well, such as soil type, abiotic factors, disturbance intensity, and the number of times a disturbance has occurred.

For example, one area at the spectra-physics (SP) restoration location (Figure 1) had become nearly a monoculture of reed canarygrass (*Phalaris arundiaçea*) before restoration efforts started in 1990. While this grass is mycorrhizal, the diversity of mycorrhizal inoculum required by other grasses or herbs would not be expected to be maintained by this monoculture.

The former ryegrass field at the SP restoration location was tilled and herbicided for several years before restoration efforts started in 1990. Both tilling and herbicide applications are detrimental to mycorrhizal fungi, but restoration has been occurring there for several years. Some VAM fungal inoculum could have spread from less disturbed sites nearby, if bird or small mammal populations were active.

Solarization kills mycorrhizal spores and plant root colonization potential (Allen et al. 1992). However, the intensity of a solarization event is extremely important. If temperatures are wet and cool during the solarization period, the degree of warming would be much less than when temperatures are higher. The solarized plot at Horkelia Prairie was tilled in May 1992 and covered with clear plastic over the summer. Even though the summer of 1992 was relatively hot and dry, the cooler temperatures of the Pacific Northwest mean that the impact of solarization on VAM spores, or any other organism group, was likely much less than might occur in warmer, drier climates.

Sod mats were transferred from a high-quality wetland to the SP restoration location. While the transfer of the plant community was successful, mechanical alterations might have disturbed the soil communities significantly.

In four of five sites, vegetation was removed and remained cleared for all intents and purposes throughout the entire summer. In the "HP control" site, however, removal of the site vegetation was not possible without severe disturbance of the site. Therefore, competition from other plants was strong during early seedling stages.

This study is part of a broader project on the effectiveness of wetlands restoration techniques, the West Eugene Native Wetland Restoration Research Project. The goal of this study was to determine the mycorrhizal colonization of six different plant species important in wetland restoration and the mycorrhizal inoculum potential of five different sites. The study was designed to gather preliminary information that would indicate whether further study was warranted. Three specific questions were asked:

a. Are the plant species in question mycorrhizal? Since plants were removed from all the mycorrhizal plots in order to plant seeds and allow them a chance to germinate and grow, plant-plant competition was reduced. Thus, facultatively mycorrhizal plants requiring plant competition for nutrients or space would be expected to remain nonmycorrhizal.

b. Is there any indication that one or more of the sites lack appropriate mycorrhizal species for the survival of any of the six representative plant species? Lower mycorrhizal colonization in one or all plant species in one particular plot, as compared with others, would indicate a reduction in overall inoculum level. However, reduction in colonization in just one plant species would indicate a specific mycorrhizal species was reduced or lost from the community. If a species does not appear in one plot, or germinates but then disappears from that one plot during the summer, a lack of appropriate mycorrhizal inoculum is implicated.

c. Is there a correlation between spore number (potential colonization) and actual colonization?

Methods

Study sites

Five sites in the west Eugene area were selected for study, three at the SP restoration location and two at Horkelia Prairie at Fern Ridge (Figure 1). The SP restoration location contains areas with a diversity of past land uses. Horkelia Prairie was probably grazed heavily in the past. Soil tillage was probably limited to trenching to lower water levels.

The study sites, ranked (most ⇒ least) by probable disturbance to mycorrhizae, included the following:

a. An area at the SP restoration location that had become nearly a monoculture of reed canarygrass (*Phalaris arundiacea*) before restoration efforts started in 1990 ("SP reed canarygrass").

b. A former ryegrass field at the SP restoration location ("SP ryegrass"), which had been tilled and herbicided for several years before restoration efforts started in 1990.

c. A solarized plot at Horkelia Prairie ("HP solarized") tilled in May 1992 and covered with clear plastic over the summer.

d. Sod mats transferred from a high-quality wetland to the SP restoration location ("SP sod mat"). These areas flood each spring.

e. An unmanipulated site at Horkelia Prairie ("HP control").

Study species

Six herbaceous species were selected to represent types of plants and types of mycorrhizal requirements. *Deschampsia cespitosa* and *Hordeum brachyantherum* are perennial grasses widespread in wetland prairies. Both are expected to require mycorrhizal association, and tentatively classified as obligately mycorrhizal plants. However, no information on the mycorrhizal associations of these plants in the Pacific Northwest was available, although related European species are known to be mycorrhizal.

Plagiobothrys figuratus and *Downingia elegans* are annual forbs and are expected to be facultatively mycorrhizal. *Microseris laciniata* is a perennial, rosette forb not reported in any other mycorrhizal literature. Based on the fact it is perennial, this plant is probably obligately mycorrhizal. *Eriophyllum lanatum* is a subshrub, whose closest relative reported in European literature is not mycorrhizal. Other related species have been reported to have mycorrhizal symbionts, although percentages of colonization were not great, suggesting a possible facultative host, depending strongly on the nutritional status of the plant.

Plant establishment

In October 1992, 60 seeds per species were sown into ⅛-m^2 areas cleared of existing vegetation at each study site and covered with plot soil. Only *Plagiobothrys figuratus* and *Downingia elegans* germinated from seed in the plots, suggesting possible mycorrhizal germination limitations for the other species. Since so few seeds actually germinated in the field, seeds for all species were germinated on sterile agar in the laboratory and transplanted into the site in May 1993, when the seedlings were 1 in. in height.

Mycorrhizal colonization of roots

Roots were obtained from field-grown plants in early August 1993. The August sampling was of all surviving plants, whether from field-sown seeds or from transplants. The soil was carefully loosened around the plants and the plants were lifted gently from the soil. The soil was gently removed from around roots and roots were placed in plastic baggies. The baggies were labeled according to plant species, field location, and site. Soil from areas disturbed by plant removal was placed in another plastic bag. Roots were clipped from the shoot material, and the entire root system was cut into approximately 1-cm lengths.

Roots were placed in 10 percent KOH for several hours and checked for extent of clearing of brown, senescent material. Since these were young plants, roots were not highly suberized, and the time to clear color from the roots was no more than several days for any plant.

Roots were removed from the KOH and placed in trypan blue-lactic acid stain for ½ to 2 hr to allow vesicular-arbuscular mycorrhizal (VAM) structures to stain clearly in the roots. Roots were rinsed in distilled water and stored in lactic acid until observed.

Cleared and stained roots were placed in a counting dish with a small amount of water. Total root length was estimated by counting the number of 2-cm root pieces, and the length of root occupied by VAM structures was measured using a dissecting microscope. The length of root colonized by arbuscles and vesicles was divided by total root length and multiplied by 100 to obtain percentage of colonization.

Spore density

The number of VAM spores per gram of soil was determined by mixing 5 g of soil with water in a centrifuge tube to a final volume of 12 ml, letting the soil hydrate for 15 min, centrifuging at 2,000 rpm for 10 min, resuspending the pellet containing the VAM spores in 2M sucrose-2 percent Calgon solution, centrifuging again for 10 min at 2,000 rpm, decanting the liquid into a 125-ml separatory funnel, and slowly letting the liquid drain from the separatory funnel (1 drop each 5 sec). The VAM spores adhere to the sides of the glass funnel and thus were obtained by rinsing the sides of the funnel with water into a beaker. The suspension was placed into a counting dish under a dissecting microscope; all the VAM spores in the dish were counted. The number of spores per gram was calculated by dividing the number counted by the amount of soil used.

Results and Discussion

Mycorrhizal status of species

All species that survived were mycorrhizal by the August sampling (Table 17). Surviving *Deschampsia cespitosa* and *Hordeum brachyantherum* were always mycorrhizal, even though clearing of vegetation reduced competitive stress. Therefore, it appears that these two species may be obligately rather than facultatively mycorrhizal. However, *Deschampsia cespitosa* had much lower colonization percentages compared with other plants in the same site in those sites where it survived. Either this plant species normally accepts less colonization, or inoculum levels were limited in all sites.

Plagiobothrys figuratus and *Downingia elegans* were expected to be facultatively mycorrhizal. Even though these species were planted in areas with little competition from other plants, colonization percentages were high (Table 17). This suggests either that the species is facultatively mycorrhizal and other stress conditions were present that resulted in a need for the mycorrhizal association to occur or these species are obligately mycorrhizal. One exception was in the HP control where *Downingia elegans* had low colonization rates. Lack of mycorrhizal inoculum could be invoked, but other explanations are possible as well, such as competition from other plants for sunlight.

Microseris laciniata was highly mycorrhizal, regardless of disturbance history. Whether it is facultative or obligately mycorrhizal remains to be determined. *Eriophyllum lanatum* was shown to be capable of being mycorrhizal, and in some instances, strongly mycorrhizal. On the other hand, *Eriophyllum lanatum* has an extremely low seed viability and germination rate (Wilson, Connelly, and Lantz 1993), which could explain its failure at two sites.

Table 17
Vesicular-Arbuscular Mycorrhizal (VAM) Colonization (Percentage of Root Lengths with Arbuscles or Vesicles) and Concentration of Spores in Soil

	SP Reed Canarygrass, %	SP Ryegrass, %	HP Solarized, %	SP Sod Mat, %	HP Control, %	Average of Sites, %
Hordeum brachyantherum	71.1	95.5	72.9	93.1	86.4	83.8
Deschampsia cespitosa	NP	60.9	46.7	NP	54.6	54.1
Downingia elegans	100.0	99.3	98.9	85.9	54.9	87.8
Plagiobothrys figuratus	97.1	100.0	99.7	88.9	85.8	94.3
Microseris lacinata	100.0	96.4	100.0	100.0	85.0	96.3
Eriophyllum lanatum	76.2	NP	96.4	NP	NP	86.3
Weighted average	82.9	85.3	88.5	90.9	68.9	83.3
Spores (number/g dry soil)	0.4	1.5	3.0	8.2	0.8	2.8

Note: Sites are listed in order of land-use intensity, from most disturbed (1) to least (5). The weighted average colonization figures account for differences in number of plants per species surviving at each site. Site averages include only those sites in which a species survived. NP = No plants survived for sampling.

Site differences

Eriophyllum lanatum did not survive in the HP control or the SP sod mat, suggesting a possible lack of inoculum in these sites. Interestingly, *Eriophyllum lanatum* survived in the solarized plot, and was strongly mycorrhizal, while it did not survive in the HP control at all. Competition from other plants may have been too great in the HP control during the period before that plant became mycorrhizal.

Deschampsia cespitosa did not survive in the SP sod mat, perhaps because the mycorrhizal fungi needed by this plant species was destroyed by the long flooding during this spring period.

All sites supported average mycorrhizal colonization rates greater than 80 percent, except "HP control" (Table 17). The competition of the young seedlings with the well-established, older roots of the site vegetation probably explains this lower colonization level, or the lack of spore inoculum (0.8 spores/g dry soil, Table 17).

All of these sites appear to have adequate mycorrhizal inoculum to support establishment of the majority of plants. The only sites in which lack of mycorrhizal colonizations might explain the results are the HP control, where competition by older plants may stress plants to the point that mycorrhizal relationships are needed. Few VAM spores were available at this site (see below). Flooding in the sod-mat sites seemed detrimental to *Deschampsia cespitosa* and *Eriophyllum lanatum* survival.

Individuals of all plant species survived at the "HP solarized" site, and root colonization was high. This suggests that the solarization treatment did not harm the mycorrhizal potential of the soil. An alternative explanation is that the small size of the solarized plots allowed recolonization of mycorrhizal inoculum from adjacent, undisturbed soil via small mammal movement.

Spores

VAM spores were recovered from each site (Table 17), showing that each site had the potential for mycorrhizal colonization. As stated above, this potential was borne out by the high root colonization rates. "SP sod mat" contained the largest concentration of spores, suggesting that the failure of *Deschampsia cespitosa* and *Eriophyllum lanatum* was not due to lack of mycorrhizal inoculum.

Elevated temperatures under solarized treatments in agricultural fields are thought to kill fungal spores associated with plant diseases. Yet spore concentration was 3½ times higher in the "HP solarized" site than in the adjacent "HP control" site. Thus, solarization conditions were probably not extreme enough, even under the relatively hot and dry weather that year, to reduce spore densities.

Average colonization rates were higher at sites with greater VAM spore concentrations (Kendall's $\tau = 0.8$, $P = 0.05$). This implies that spore availability might be limiting to mycorrhizal colonization.

Although VAM spore concentration differed twentyfold among sites, spore concentration was not related to intensity of past land use (Kendall's $\tau = 0.2$, $P = 0.62$).

Conclusions

Restoration efforts of specific species might fail as the result of flooding or competition from established plants in particular sites. While lower root colonization levels may occur in the reed canarygrass as the result of plant competition, the mycorrhizal species required by these representative test plants is present in the site. Solarization resulted in no significant loss of spores in the soil, nor in reduced colonization of the roots.

Differences among sites and among species, however, show that uniform restoration results should not be expected. In particular, higher concentrations of VAM spores are positively related to root colonization rates, which could lead to greater plant success in restoration. The different land-use histories of these sites were apparently unrelated to their potential for supporting mycorrhizal colonization.

5 Field Performance of Planted Nursery Stock and Stem Cuttings of Selected Woody Species[1]

Introduction

The acquisition and planting of woody native plant materials is a very costly and time-consuming component of wetland mitigation and restoration projects. Additionally, the availability of commercial Pacific Northwest native species is often nonexistent, in short supply, or of differing genotypes than the local population. Therefore, the consideration of alternatives to the standard practice of purchasing nursery-grown materials may be an important means of increasing the diversity and quantity of appropriate plant materials available for revegetation and lowering project costs.

This chapter analyzes the field performance of nursery container stock and locally collected dormant stem cuttings of the following wetland species: *Crataegus douglasii*, black hawthorn, *Populus balsamifera v. trichocarpa*, black cottonwood, *Rosa nutkana*, Nootka rose, and *Salix sitchensis* Sitka willow, during a 15-month period. All four of these species are common wetland edge species within the West Eugene wetlands study area. Preliminary review of plant propagation literature and interviews with local nursery experts suggest that all four genera have been successfully propagated from dormant propagules. The local *Salix* and *Populus* species are known to root easily from sections of dormant hardwood stem cuttings. Hardwood stem cuttings of ornamental *Rosa* species are widely used commercially in the propagation of rose rootstocks (Hartmann, Kester, and Davies 1990), and the propagation of the *Crataegus*, commonly commercially propagated by seed,

[1] Written by Mr. Mark G. Wilson, a consultant in environmental horticulture, and Dr. Mark V. Wilson, Oregon State University.

was attempted from dormant stem cuttings on the basis of limited success by several local nurseries with the Pacific Northwest (PNW) species *C. douglasii*.

In summary, several questions guided the design of this study:

a. During the first year following planting, is the percent survival of locally collected propagules of *Crataegus douglasii*, *Populus balsamifera v. trichocarpa*, Rosa nutkana, and *Salix sitchensis* comparable with the survival of purchased nursery stock?

b. How much growth can be expected from irrigated propagules of *Crataegus douglasii*, *Populus balsamifera v. trichocarpa*, *Rosa nutkana*, and *Salix sitchensis* during the first year after planting?

c. Does the fertilization of native plant nursery stock or stem cuttings during the first year following planting influence percent survival or growth?

Study Site Location and Existing Conditions

The experimental study plots were sited on a 0.5-acre old field in rural Junction City, OR, just north of the Army Corps of Engineers (ACOE) Fern Ridge Reservoir and just south of Clear Lake Road and the ACOE-Fern Ridge Dam Unit Office. The site's soils are composed of clay loams (*Willakenzie* soil series) on a 2 to 12 percent slope with a due south aspect. Prior to site preparation, existing vegetation was dominated by the nonindigenous grasses *Festuca arundinacea*, tall fescue, and *Anthoxanthum odoratum*, sweet vernal grass. The site was chosen because it typified the vegetative cover and level of disturbance commonly found on uplands adjacent to wetlands in the West Eugene area.

Plant Propagule Acquisition

In January 1993, 96 Oregon nursery-contract-grown plant materials were delivered to the site. Of this total, 24 of each of the following species were supplied: *Crataegus douglasii*, *Populus balsamifera v. trichocarpa*, *Rosa nutkana*, and *Salix sitchensis*. During the last week of January 1993, 200 stem cuttings, 50 each of the same species as the purchased nursery-grown materials, were collected in the West Eugene area. The purchased 1-gal container nursery stock was propagated from unknown genotypes; the stem cuttings were collected from local genotypes within a 10-mile radius of the Fern Ridge study site.

The purchased nursery stock and collected plant materials were acquired according to the following specifications:

- **Nursery-grown plant materials**: One- to two-year-old bare root seedlings of willow (*Salix sitchensis*) and 1-gal container plants of the other three species. All plant materials were healthy, disease-free stock propagated from seed or cutting at the nursery (no wild collected stock). Trunks had no severe bends or girdling injuries, and all stems/branches exhibited a measurable amount of growth during the previous year. Roots were well spaced around the trunk; and plants were not rootbound in the container.

- **Locally acquired stem cuttings**: Propagation stem cuttings selected from healthy, moderately vigorous 1- to 3-year-old wood on plants growing in full sunlight. Tip portion (1 to 4 in.) of shoots discarded and stems cut into 18- to 24-in. lengths making the basal (bottom) cut straight and just below a dormant bud and the top cut on a slant 1/2 in. to 1 in. above a dormant bud. The diameter of pieces reserved for planting were not less than 1/4 in. and not greater than 3/4 in. in diameter, and each piece contained a minimum of two dormant buds for each foot of length. Cuttings were not gathered if temperatures were below 32 °F. After collection cuttings were stored in a refrigerator at 35 to 40 °F until planting.

Plot Design and Planting

During the first week of April 1993 the entire 14-m by 14-m Fern Ridge study plot was cultivated with a tractor-drawn disc. The entire plot was disced and then cross-disced to incorporate the existing vegetation of nonindigenous grasses. On 16 April 1993, the plot was divided into 48 3-m^2 cells with permanent stakes and twine; each cell measured 1.5 m by 2 m. Half of the plots (24 cells) were designed to measure the effect of fertilization; these plots were located downgrade on an approximately 5 percent slope from the other half of the plot (24 cells) that would receive no fertilization. Each 3-m^2 cell was planted with a randomized selection of species, nursery-container stock, and cuttings using a predesigned random planting plan. The four native shrubs and trees to be tested as cuttings and containers were allocated to the plots randomly, taking care that treatments were interspersed over the experimental area. When cuttings were called for in the planting plan, two stem cuttings of the same species were placed at each specified location, as it was anticipated that the cuttings would have a greater mortality than the bare root and container stock.

The container plants (*Crataegus douglasii*, *Populus balsamifera v. trichocarpa*, and *Rosa nutkana*) were placed in planting pits in the ground at the same height as they had been growing in the containers; bare root plants (*Salix sitchensis* only) were placed in planting pits at the same height as they had been growing in the ground. A total of 96 containerized or bare root plants (24 of each of the four species) were planted.

Stem cuttings were prepared and planted according to the following specifications:

- **Preparation of stem cuttings**: 24 hours prior to planting, all the *Crataegus douglasii* and *Rosa nutkana* cuttings were removed from refrigeration and totally immersed in a 5-gal container containing a 0.02 percent solution of indolebutyric (I.B.A.) and naphthalacetic (N.A.A.) acids. The *Populus balsamifera v. trichocarpa* and *Salix sitchensis* were not treated with rooting hormone prior to planting.

- **Planting of stem cuttings**: Using a dibble of a diameter slightly smaller than the cutting, pilot holes were prepared in the bare soil. The 18- to 24-in. cuttings were inserted not more than 6 in. apart into the ground with the slant ends (top) up deeply enough so that just one dormant bud (or a pair of opposite buds) showed above the ground. Care was taken not to reverse the polarity of the cuttings. After placement, soil was firmed around the cuttings with fingers and heel of the foot. A total of 192 cuttings (48 of each of the four species) were placed in the study plot.

Plot Maintenance: 1993-1994

Plot irrigation

The growing season in western Oregon is generally typified by a dry season of little rainfall extending from June through September, and the irrigation of all crops except grains, grass seed, and hay is widely practiced. In the initial discussions of project design, it was determined, based on prior experiences, that the entire experimental plot should be irrigated during the first growing season with approximately 4 to 6 in. of water per month from May through mid-September. However, during the 1993 growing season, a very wet spring and early summer made irrigation of the entire plot unnecessary until 30 June 1993. Irrigation continued through 15 September 1993 and was carried out according to the following specification:

- **1993 irrigation procedure**: Using a gas-powered "trash" pump and 2-in. fire hose reduced to 5/8-in. garden hose irrigation water was withdrawn from Fern Ridge Lake and applied on the experimental site through a series of soaker hoses. Water was applied as needed; the goal being rain and/or irrigation of 4- to 6-in. per month. Small containers were spread throughout the site to serve as rain gauges; regular monitoring determined irrigation frequency.

No artificial irrigation was performed during the 1994 growing season.

Plot fertilization

Three applications of slow-release fertilizer were made to the fertilizer subplot between June 1993 and February 1994. The fertilizer chosen was Osmocote, a slow-release, sulphur-coated urea product in a 14-14-14 formulation of nitrogen, phosphorus, and potassium.

On 30 June 1993, the experimental subplot was initially fertilized with Osmocote. Each propagule (nursery stock or cutting) within the fertilizer subplot received 2 oz of the fertilizer. On 16 October 1993, each propagule within the fertilizer subplot was again fertilized with 2 oz of Osmocote. A third application of fertilizer was made on 6 February 1994 with 2 oz of Osmocote.

Results

Percent survival of stem cutting propagules: 4/16/93-7/17/94

The performance of *Rosa* and *Crataegus* stem cuttings was very poor. While latent buds located in the stem nodes area broke dormancy and the cambium of these two species remained alive for some time during the first 6 months (measured 16 October 1993), none of the *Crataegus* cuttings and only 2 percent of the *Rosa* cuttings produced branches during the period extending from 16 April 1993 through 5 May 1994 (13 months after planting). By July 1994, all *Rosa* and *Crataegus* stem cuttings were adjudged to be dead.

The performance of the *Salix* and *Populus* cuttings was good; 98 percent of the *Populus* cuttings and 100 percent of the *Salix* cuttings broke dormancy, produced lateral branches, and exhibited measurable growth following planting (measured 16 October 1993). On 5 May 1994, approximately 1 year after planting, 75 percent of the *Salix* and 54 percent of the *Populus* cuttings survived. By 17 July 1994, the *Salix* had declined to a 71 percent survival, and the *Populus* declined to a 48 percent survival.

Percent survival of nursery stock propagules: 4/16/93-7/17/94

All container stock or bare root seedlings broke dormancy during the first growing season and were fully leafed. On 5 May 1994, approximately 1 year after planting, 58 percent of the *Salix* nursery stock, and 96 percent of the *Populus*, *Rosa*, and *Crataegus* nursery stock survived. By 17 July 1994, *Salix* survival increased to 63 percent due to root sprouting, and the *Populus*, *Rosa*, and *Crataegus* propagules remained at a 96 percent survival.

Table 18 summarizes propagule survival data.

Table 18
Survival of Woody Plant Material to the 16 October 1993, 7 January 1994, 5 May 1994, and 17 July 1994 Sampling Dates

Material	No. Planted	Percent Survival To			
		10/16/93	1/7/94	5/5/94	7/17/94
All plantings	286	98	57	51	50
Nursery stock	97	100	98	87	88
Cuttings	189	97	36	33	30
Salix	72	100	83	69	68
Populus	72	99	74	68	64
Rosa	72	96	33	32	31
Crataegus	70	97	37	36	36
Salix (n)	24	100	92	58	63
Salix (c)	48	100	79	75	71
Populus (n)	24	100	100	96	96
Populus (c)	48	98	60	54	48
Rosa (n)	23	100	100	96	96
Rosa (c)	49	94	2	2	0
Crataegus (n)	26	100	100	96	96
Crataegus (c)	44	95	0	0	0

Note: n = Nursery stock; c = Cuttings.

Propagule growth: April 1993 through July 1994

Project design called for determinations of propagule growth by: (a) measuring the height of the propagule and (b) counting the number of branches.

Growth as expressed by height of propagule

During the study, the height of each individual propagule was measured twice, and no significant height increase of the nursery stock was noted from the time of planting until the conclusion of the study.

At the time of planting, the average aboveground height of the nursery stock was approximately 2.5 to 3 ft higher than the height of the cuttings. At the conclusion of the first growing season (measured at the beginning of the second growing season 7 January 1994), the average height of surviving *Salix* and *Populus* nursery stock was only 1.5 ft higher than surviving *Salix* and *Populus* cuttings (Table 19). (Note: All *Crataegus* cuttings and 98 percent of the Rosa cuttings failed.)

Table 19
Average Heights of Propagules

Material	No. of Observations	Average Height, in.[1]
Nursery stock	96	38.1b
Cuttings	67	17.3a
Salix	60	28.5b
Populus	53	29.0b
Rosa	24	21.9a
Crataegus	26	40.2b

[1] Heights (in.) of planted material surviving to 7 January 1994. Average for material type and for species followed by different letters do not significantly differ (5 percent level).

Growth as expressed by number of branches on propagules

All primary shoots that arose directly from the main stem of either cuttings or nursery stock were counted as branches. On the nursery stock, secondary shoots that arose from the existing primary shoots were not counted as branches.

All propagules initiated new branches during the duration of the study, although the nursery stock did not form any new branches during the first growing season as measured on 16 October 1993. On average, *Salix* cuttings grew new branches steadily throughout the study; *Salix* nursery stock experienced dieback in the period from October 1993 through July 1994. Table 20 summarizes propagule branch production.

As noted above, the growth of propagule branches was offset by branch dieback on all surviving propagules. Surviving nursery stock was particularly prone to die back during the duration of the study. All species except the surviving *Crataegus* nursery stock experienced seasonal dieback. *Salix* nursery stock branch production and subsequent decline is noteworthy because the nursery stock plantings were 1-year-old bare root "whips" at the time of planting. Proportionally, the branches of surviving *Salix* nursery stock died back more during the winter of 1993 and spring of 1994 than they grew during the entire duration of the study. *Salix* cuttings grew steadily during the first growing season (1993) and died back slightly during the winter of 1993 and spring of 1994. Table 21 contrasts this propagule growth/dieback phenomena.

Table 20
Average Number of Branches of Surviving Woody Plant Material

Material	No. of Branches		
	At Planting	Survived to 10/16/93	Survived to 7/17/94
All plantings	1.9	2.6	4.9
Nursery stock	5.5	5.5	6.0
Cuttings	0.0	1.1	3.1
Salix	1.0	2.8	3.2
Populus	3.1	4.2	6.1
Rosa	1.4	1.6	5.2
Crataegus	1.9	2.0	5.4
Salix (n)	3.1	3.1	2.8
Salix (c)	0.0	2.6	3.4
Populus (n)	9.2	9.2	9.5
Populus (c)	0.0	1.6	2.7
Rosa (n)	4.4	4.4	5.2
Rosa (c)	0.0	0.1	ns
Crataegus (n)	5.2	5.2	5.4
Crataegus (c)	0.0	0.0	ns

Note: n = Nursery stock; c = Cuttings; ns = No survivors.

Fertilization effect on propagule survival

When the data for propagule survival were statistically analyzed, it was determined that there was no significant effect of fertilization on the survival of either cuttings or nursery stock.

Discussion

On the basis of field data analysis and observation the following conclusions can be drawn.

Table 21
Proportion of Surviving Woody Plant Material Increasing Number of Branches (Growing) or Decreasing Number of Branches (Dying Back)

Material	Growth		Dieback	
	Planting to 7/17/94	10/16/93 to 7/17/94	Planting to 7/17/94	10/16/93 to 7/17/94
All plantings	0.54	0.22	0.10	0.16
Nursery stock	0.25	0.25	0.16	0.16
Cuttings	0.98	0.18	0.00	0.16
Salix	0.71	0.12	0.08	0.16
Populus	0.63	0.30	0.13	0.24
Rosa	0.32	0.32	0.18	0.18
Crataegus	0.24	0.24	0.00	0.00
Salix (n)	0.07	0.07	0.27	0.27
Salix (c)	1.00	0.15	0.00	0.12
Populus (n)	0.30	0.30	0.26	0.26
Populus (c)	0.96	0.22	0.00	0.22
Rosa (n)	0.32	0.32	0.18	0.18
Rosa (c)	ns	ns	ns	ns
Crataegus (n)	0.24	0.24	0.00	0.00
Crataegus (c)	ns	ns	ns	ns

Note: n = Nursery stock; c = Cuttings; ns = No survivors.

Survival and growth of cuttings and nursery stock

Approximately 90 percent of all the nursery stock survived for 15 months after planting. The nursery stock grew very little during this time, however, and no growth (as evidenced by an increase in numbers of branches) could be measured after the first growing season (summer 1993). The phenomena of shoot growth followed by shoot dieback not withstanding, the aboveground portion of the *Salix* and *Populus* cuttings increased biomass proportionally quicker than the nursery stock of the same species. Due to the limits of the study, it cannot be determined if the cuttings of these species will eventually catch up to the nursery stock or whether they will in the long term outperform because they were selected from local genotypes.

Approximately two-thirds of all *Salix sitchensis* propagules survived for 15 months after planting. In this study, 48 stem cuttings of *S. sitchensis* had nearly the same percent survival 15 months after planting as 24 nursery grown plants of the same species over a 15-month period.

Recommendation: The placement of *Salix sitchensis* cuttings seems to be as successful as the planting of *S. sitchensis* nursery stock when irrigation is provided during the first growing season. When computing the number of *Salix sitchensis* stem cuttings to plant on a project, a 35 percent overage should be specified. Additional research regarding the asexual propagation of other Pacific Northwest native *Salix* species is recommended.

Approximately 50 percent of all *Populus trichocarpa* cuttings survived 15 months after planting versus a 95 percent survival of *Populus* nursery stock. However, of the total of 16 propagules observed to have been girdled by rodents, 10 were *Populus* cuttings.

Recommendation: When computing the number of *Populus trichocarpa* cuttings to plant on a project, a 50 percent overage should be specified.

Failure of *Rosa nutkana* and *Crataegus douglasii* cuttings

More research regarding the asexual propagation of both of these species is recommended.

Fertilization of woody nursery stock

As stated in the Results above, fertilization had no affect on propagule mortality, but fertilization of the propagules did affect the growth of ground-layer herbaceous plants, particularly the nonindigenous grasses *Festuca arundinacea* and *Anthoxanthum odoratum*. In the nonfertilized plot, *Festuca arundinacea* and *Anthoxanthum odoratum* regrowing from disced culms and the seed bank provided 25 percent cover at the end of the study; the balance of the cover was provided by native and non-native forbs. *Festuca arundinacea* had an average height of 0.25 m. In the fertilized plot, *Festuca arundinacea* and *Anthoxanthum odoratum* provided nearly 100 percent of the cover. *Festuca arundinacea* attained an average minimum height of 1 m, overtopping all propagules. The fertilized plot also contained great numbers of the pest plants *Cirsium arvense* and *Cirsium vulgares*.

Recommendation: The standard practice of fertilizing native woody plants placed on wetland restoration or mitigation projects may provide no clear benefit. Fertilization of native woody plants may decrease the supply of available water and nutrients and favor the establishment of aggressive non-native grasses.

Irrigation of propagules-1993

Irrigation of the entire plot improved survival of all propagules during the first growing season. It should be noted, however, that the summer of 1993 was the coolest and wettest on record in Western Oregon; in a growing season of average temperature and precipitation, propagule survival may be less than the project data state.

Recommendation: Woody PNW native species benefit from irrigation applied during the first growing season after planting.

Summary

On the basis of this study, a review of the questions posed at the beginning of this report is appropriate.

During the first year following planting, the growth and percent survival of locally collected propagules of *Crataegus douglasii*, *Populus balsamifera v. trichocarpa,* and *Rosa nutkana* were not comparable with the growth and survival of purchased nursery stock. The growth and survival of *Salix sitchensis* cuttings, however, was equal to the growth and survival of purchased *S. sitchensis* nursery stock.

The fertilization of all four species had no effect on propagule survival, but fertilization did affect the growth and species composition of surrounding herbaceous vegetation and may have limited propagule growth.

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1995

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Studies of Plant Establishment Limitations in Wetlands of the Willamette Valley, Oregon

5. FUNDING NUMBERS
Work Unit 32761

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199;
Fishman Environmental Services, Portland, OR

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report
WRP-RE-13

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Willamette Valley was historically dominated by three types of wetlands: wet prairies. shrub/scrub, and forested. As a consequence of drainage for agriculture and urban development, most of these diverse wetlands have been lost. Restoration of native wetlands is limited by a lack of knowledge about native plant species growth and establishment requirements. This report presents results from four investigations of establishing wetland vegetation native to the Willamette Valley.

In the first study, Pest Plant and Seed Bank Reduction (Chapter 2), three site preparation techniques were applied to a disturbed wet prairie that contained exotic species. The objectives of the study were to determine (a) whether the treatments reduced pest plant abundances for more than 1 year, (b) if treatments also reduced native plant species, and (c) whether treatment effects were consistent among years. Tilling with fallowing and solarization (heating under plastic) were generally found to be more effective than burning at reducing existing plants. Native plants were affected by all treatments. Although each treatment was effective at reducing at least one exotic plant species, none of the treatments were generally effective at controlling pest plants. This may have been due to cool, dry weather conditions during the treatments that were not conducive to seed germination. The

(Continued)

14. SUBJECT TERMS
See reverse.

15. NUMBER OF PAGES
75

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

authors conclude that site treatments should be applied for more than 1 year, and native plant materials should be planted as soon as possible to outcompete the recovering exotic species.

The second study, Seed Dormancy, Germination, and Establishment (Chapter 3), investigated native collected seed germination requirements, seed propagation under field conditions, and the performance of seeds in mixtures. Seed viabilities were found to vary greatly for the native species that were tested. This was due in part to a single collection date for each species that could not coincide with simultaneous ripening of all the seeds. Stratification with alternating temperatures sufficiently improved germination rates of the dormant species so that no further treatments were necessary. Poor seed germination rates in the field led the authors to recommend high seeding rates when native collected seeds are used. This helps offset the low germination rates of many species, but also increases the relative abundance of sown seeds to the seed bank. Differences in germination rates and times of different species in seed mixtures can be utilized in designing seed mixtures. The authors recommend a strategy to first establish rapidly germinating, short-lived species to compete with exotics, followed by more slowly germinating perennial species that will permanently occupy the site.

Characterization of Mycorrhizae (Chapter 4) is an investigation of the potential for mycorrhizae to limit plant growth in restored wet prairies. The objectives of the study were to determine (a) the mycorrhizal requirements of selected herbaceous species, (b) if adequate mycorrhizal fungi were available for plant colonization at sites differing in levels of disturbance, and (c) if there is a correlation between spore density in the soil and actual colonization of the plants. Mycorrhizae colonized surviving plants at all sites. Lack of germination or survival of some plants at some sites suggested a lack of required fungal species. A positive correlation between spore density and colonization further suggests that limited mycorrhizae may affect plant growth in wetland restoration areas with low fungal spore densities.

Field Performance of Planted Nursery Stock and Stem Cuttings of Selected Woody Species (Chapter 5) further investigates the use of native plant materials for wetland restoration in the Willamette Valley. The objectives of this study were to (a) compare survival and growth of stem cuttings and nursery stock of four selected woody species, (b) determine growth of irrigated stem cuttings, and (c) determine effects of fertilization on native plant nursery stock and stem cuttings. Results of the study were very species specific. Only stem cuttings from willow and poplar survived; *Crataegus* and *Rosa* cuttings died. Nursery stock had best survival rates for all species; however, height growth of stem cuttings was best. Fertilization had no significant effect on survival or growth of nursery stock or stem cuttings. Fertilization, however, stimulated growth of competing herbaceous species and may have been detrimental to growth of target species.

14. Subject Terms.

Exotic plant species
Mycorrizae
Native collected stock
Nursery stock
Seed dormancy
Site preparation
Wetland restoration
Willamette Valley, Oregon