AN ABSTRACT OF THE THESIS OF

Marilynn R. Bartels for the degree of Master of Science in Botany and Plant Pathology presented on March 13, 2000. Title: Conservation of *Sidalcea nelsoniana* Through Habitat Management: Effects of Burning, Mowing, and Altered Flooding Regime on a Rare Willamette Valley Perennial.

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Abstract approved: ______________________________
Mark V. Wilson

Active habitat management plays a key role in the preservation of native ecosystems and rare species, especially in the Willamette Valley of Oregon, where natural succession to woodlands threatens the few wetland prairies remaining after 150 years of agriculture and urbanization. *Sidalcea nelsoniana*, listed as threatened under the federal Endangered Species Act, is native to these wetland prairies. The studies described here provide basic information about the habitat requirements and tolerances of *S. nelsoniana* while testing for the first time the impact of specific management techniques on its growth and reproduction. The effects of prescribed burning and mowing on *S. nelsoniana* and its habitat were investigated in a field population at W.L. Finley National Wildlife Refuge near Corvallis, Oregon. Measurements of *S. nelsoniana* and aspects of the surrounding vegetation were recorded during the summer of 1998 within 112 permanent *S. nelsoniana*-centered quadrats. Burning and mowing treatments were applied in the fall of 1998 and the same measurements of *S.*

nelsoniana and the surrounding vegetation were recorded during the summer of 1999. Treatments had no direct effects on *S. nelsoniana* performance, but burning and mowing reduced canopy cover, a primary goal of prairie maintenance and restoration. Because perennials often respond slowly to changes in habitat, effects of these manipulations may be more evident in future years. Wetland species may also be sensitive to site hydrology, so maintaining the proper water regime is another important component of wetland prairie management and restoration. A second experimental study evaluated the flooding tolerance of *S. nelsoniana*. Rhizome fragments were transplanted into pots exposed to four flooding conditions: drained soil, saturated soil with no standing water, standing water from mid-November through mid-April and standing water from mid-November through mid-June. Plants with drained soil died as the spring rains declined, and plants flooded past April died by mid-June. Plants in saturated soils and those flooded until mid-April were most successful. These two treatments most closely match conditions found in Willamette Valley wetland prairies, including *S. nelsoniana* sites, and suggest that the current distribution of *S. nelsoniana* approximately matches its hydrologic requirements. Management plans to flood a *S. nelsoniana* site beyond mid-April might harm this protected species.

Conservation of *Sidalcea nelsoniana* Through Habitat Management: Effects of Burning, Mowing, and Altered Flooding Regime on a Rare Willamette Valley Perennial

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Marilynn R. Bartels

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Conservation of *Sidalcea nelsoniana* Through Habitat Management: Effects of Burning, Mowing, and Altered Flooding Regime on a Rare Willamette Valley Perennial

Chapter 1: Introduction

Sidalcea nelsoniana Piper (Malvaceae) (Nelson's checker-mallow) is a perennial plant native to the Willamette Valley, Oregon and some adjacent areas of the Oregon Coast Range and Cowlitz County, Washington (U.S. Fish and Wildlife Service 1993). *S. nelsoniana* is typically found in wetland prairies, ash swales, streamsides, and in roadside ditches. Associated vegetation includes graminoids such as *Festuca arundinacea*, *Phalaris arundinacea*, *Agrostis* spp., and *Carex* spp.; weedy forbs such as *Heracleum lanatum* and *Vicia* spp.; and woody species such as *Rosa* spp., *Rubus* spp., and *Fraxinus latifolia* (U.S. Fish and Wildlife Service 1993, personal observation, nomenclature follows Hitchcock and Cronquist 1973). The current distribution of *S. nelsoniana* is limited to just 64 sites (U.S. Fish and Wildlife Service 1998) and the species is listed as threatened with extinction under the federal Endangered Species Act (U.S. Fish and Wildlife Service 1993) as well as by the State of Oregon (State of Oregon 1995).

Although the historical distribution of *S. nelsoniana* is not known, land survey records from around the time of Euro-American settlement report that much of the mid-Willamette valley was grassland vegetation, including both wetland and upland prairie (Habeck 1961, Johannessen et al. 1971). It is believed that these open areas were maintained by periodic fires set by the Kalapuya Indians for thousands of years prior to settlement. As the area was settled, the regular fires ceased (Johannessen et al. 1971). Additionally, much of the land was plowed and drained for agriculture. These land use changes over the past 150 years have resulted in the loss or degradation of more than 99% of the original prairie habitat in the Willamette Valley. Therefore, it is likely that the current distribution of *S. nelsoniana* reflects only a small portion of its historical distribution and abundance.

Altered land use practices continue to threaten the remaining *S. nelsoniana* habitat. Areas that are not set aside as preserves or otherwise protected by state or federal governments are subject to future commercial or agricultural development. Even where federal or state regulations prohibit outright habitat destruction, encroachment of non-native pest plants and invasion of woody species, hastened by the cessation of burning, threaten prairie remnants in the Willamette Valley. While it is unclear how well *S. nelsoniana* can tolerate shade and other competitive pressures (U.S. Fish and Wildlife Service 1993, CH2M Hill 1994, Glad et al. 1994, Gisler and Meinke 1995), such changes in habitat are likely causes for some apparently precipitous declines in *S. nelsoniana* numbers at William L. Finley National Wildlife Refuge, near Corvallis, Oregon, USA (Maura Naughton, personal communication).

Habitat restoration plays a key role in the conservation and recovery of any rare species (Falk 1990, Soulé 1991, Wilson et al. 1992, Sinclair et al. 1995). Unfortunately, effective techniques for managing *S. nelsoniana* and its habitat remain unavailable. Habitat management, such as burning and/or mowing during the late summer or early fall, can improve prairie habitat by reducing the cover of woody species and promoting native species (Clark and Wilson 1996, Wilson and Clark

1997). The use of habitat management as a tool for the conservation of rare species requires not only a knowledge of how the treatment will affect the community as a whole, but also how the treatment will impact the species of concern (Lovett Doust and Lovett Doust 1995). Unfortunately, little is known about the response of *S. nelsoniana* to prescribed burning and mowing or about the species tolerance of existing woody and herbaceous plant cover.

The need to develop a habitat management strategy that would both improve the integrity of Willamette Valley prairie areas and promote the growth and reproduction of *S. nelsoniana* goes beyond managing the surrounding vegetation. Because hydrologic regime is an important determinant of wetland vegetation (Lippert and Jameson 1964, van der Valk 1981, Nelson and Anderson 1983, Moore and Keddy 1988, Welling et al. 1988, Trebino et al. 1996), maintaining the proper water regime is also a key component of wetland prairie restoration and management. Additionally, many rare plants have specific hydrologic requirements (Harvey and Meredith 1981, Lesica 1992, Davis 1993).

Because of the extreme reduction in habitat over the past 150 years, the current distribution of *S. nelsoniana* may not represent its true hydrologic tolerance. Moreover, recent proposals by land managers have suggested flooding some sites where *S. nelsoniana* is found for an additional six to eight weeks into the spring. Ideally, this management strategy would improve wetland habitat for both *S. nelsoniana* and over-wintering waterfowl. However, wetland species are often sensitive to alteration of flooding regimes (Nelson and Anderson 1983, Welling et al.

1988) and little information is available about the hydrologic tolerance of *S. nelsoniana* or how extended inundation would affect this rare species.

The two studies described in this thesis were designed to provide basic ecological information about the habitat requirements and tolerances of *S. nelsoniana* and to evaluate the effects of specific management techniques on the growth and reproduction of this rare species. Chapter 2 evaluates the effectiveness of burning and mowing as potential restoration techniques for *S. nelsoniana* habitat. Because characteristics of the surrounding vegetation were measured along with aspects of *S. nelsoniana* performance, this field study provides information not only about the direct effects of burning and mowing but also about the mechanisms behind these results, such as the tolerance of this species to shading and other competitive pressures. Chapter 3 tests the hydrologic tolerance of *S. nelsoniana* by determining its response to experimentally manipulated patterns of flooding. Concluding remarks and specific management recommendations based on the results of both studies are presented in Chapter 4. Ultimately this research tests the applied tools and provides some of the basic ecological information necessary to manage the remaining *S. nelsoniana* habitat and possibly restore populations to other areas within the Willamette Valley.

Chapter 2: Effects of Prescribed Fire and Mowing on *Sidalcea nelsoniana* and its Habitat

Abstract

Active habitat management plays a key role in the preservation of native ecosystems and the conservation of rare species. The use of habitat management as a conservation tool requires knowledge of how a treatment will impact both the community as a whole and the rare species of concern. *Sidalcea nelsoniana* Piper (Malvaceae) is a perennial plant native to wetland prairies of the Willamette Valley, Oregon and is listed as threatened with extinction under the federal Endangered Species Act. Changes in land use in the Willamette Valley over the past 150 years have resulted in the loss or degradation of most of the original prairie habitat. Additionally, the remnants of prairie that remain are threatened by the encroachment of woody species or weedy pest plants. While it is unclear how well *S. nelsoniana* can withstand such competitive pressures, conservation of this species will likely require some active manipulation of the habitat. The objective of this study was to test specific hypotheses about the response of *S. nelsoniana* to prescribed burning and mowing. During the summer of 1998, aspects of *S. nelsoniana* growth and flowering intensity were measured within 112 permanent *S. nelsoniana*-centered measurement quadrats in a natural field population at W.L. Finley National Wildlife Refuge, south of Corvallis, Oregon. Relative elevation, litter depth, canopy cover and cover of woody and other herbaceous species in two vertical strata were also measured within each quadrat. The site was divided into 15 treatment areas, with five replicates of each of the three

treatments: burning, mowing, and no manipulation. Treatments were applied during the fall of 1998 and the same measurements of *S. nelsoniana* and the surrounding vegetation were recorded during the summer of 1999. Direct treatment affects on the survival, growth and flowering intensity of *S. nelsoniana* were not apparent during the first year following treatments. Burning and mowing reduced canopy cover and increased herbaceous cover as compared to unmanipulated controls. Because perennials often respond slowly to changes in habitat, effects of these habitat alterations may be more evident in future years. Treatments were reapplied in the fall of 1999 and the performance of *S. nelsoniana* and the surrounding vegetation will be measured again during the summer of 2000.

Introduction

The preservation of pristine areas is of obvious importance for the conservation of rare species. Although many "natural" areas are protected and maintained as preserves by federal, state, or non-profit agencies, these areas are still vulnerable to invasion by non-native pest species. In addition, changes in land use, such as fire suppression, can lead to changes in the structure of the plant community. Active habitat management can be a valuable tool for maintaining or improving habitats by restoring ecological processes that have been removed. The prairies of the Willamette Valley, Oregon are prime examples of how changing land use can threaten a habitat and the rare species specific to that habitat.

According to land survey records from around the time of Euro-American settlement, much of the mid-Willamette valley was grassland vegetation, both in the form of low, wetland prairie and upland prairie (Habeck 1961, Johannessen et al. 1971). It is believed that these open areas were maintained for thousands of years by periodic fires carried out by the Kalapuya Indians. As the area was settled, these regular fires ceased (Johannessen et al. 1971). Additionally, much of the land was plowed and drained for agriculture. As a result, only a small fraction of original Willamette Valley wetland and upland prairie remains.

The existing remnants of open prairie in the Willamette Valley are often threatened by the invasion of woody species or encroachment by non-native herbaceous pest plants. It is in these areas that active management is required to preserve the native species that remain and to maintain suitable habitat for the survival of native prairie plant populations, including rare species. Previous studies have shown that habitat management, such as burning and/or mowing during the fall, can reduce the cover of woody species and promote native species (Clark and Wilson 1996, Wilson and Clark 1997).

The use of habitat management as a tool for the conservation of rare species requires not only a knowledge of how the treatment will affect the community as a whole, but also how the treatment will impact the species of concern (Lovett Doust and Lovett Doust 1995). *Sidalcea nelsoniana* Piper (Malvaceae) is a perennial herb native to wetland prairies of the Willamette Valley and some adjacent areas of the Oregon Coast Range and Cowlitz County, Washington. As of 1998, the distribution of *S. nelsoniana* was limited to only 64 sites, nearly half of which contained fewer than 100 individuals (U.S. Fish and Wildlife Service 1998). Because of this limited distribution and threats to its habitat, *S. nelsoniana* is listed as threatened with extinction under the federal Endangered Species Act and by the State of Oregon (U.S. Fish and Wildlife Service 1993, State of Oregon 1995).

The Endangered Species Act calls for the protection and recovery of population viability of listed species. Habitat restoration plays a key role in this task (Falk 1990, Soulé 1991, Wilson et al. 1992, Sinclair et al. 1995). Like much of the remaining prairie habitat in the Willamette Valley, the habitats of *S. nelsoniana* are changing because of the invasion and growth of woody plants or herbaceous pest plants like reed canarygrass (*Phalaris arundinacea*, all nomenclature follows Hitchcock and Cronquist 1973). Effective management will probably require active manipulation of *S. nelsoniana* habitat. Unfortunately, the effects of habitat manipulations on this species are untested and little conclusive information is available about the habitat requirements of this species. In particular, it is unclear how well *S. nelsoniana* adults and seedlings can tolerate shade and other competitive pressures (U.S. Fish and Wildlife Service 1993, CH2M Hill 1994, Glad et al. 1994, Gisler and Meinke 1995). The impact of management strategies to improve habitat quality is best understood by knowing both the tolerance of *S. nelsoniana* to existing woody and herbaceous plant cover and the response of *S. nelsoniana* to experimental manipulations.

Goal and Hypotheses

The goal of this study was to evaluate the effectiveness of potential restoration techniques for *S. nelsoniana* habitat. Specifically, I tested several sets of hypotheses about the effects of prescribed burning and mowing on *S. nelsoniana* and its habitat (Table 2.1). These hypotheses concern both immediate effects on the *S. nelsoniana* population (survival and growth) and future population trends (flowering intensity, seed production, and levels of seed predation by a native weevil, *Macrohoptus sidalceae* Sleeper [Gisler and Meinke 1997]).

Although the surrounding vegetation was not directly controlled in this study, both pre- and post- manipulation vegetation abundance may influence *S. nelsoniana* performance. In addition, any treatment effect on *S. nelsoniana* performance may be partially or entirely a result of the concurrent changes in the surrounding vegetation caused by manipulations. Quantifying the neighboring vegetation along with aspects of *S. nelsoniana* performance allowed me to test for effects of the manipulations and investigate the mechanisms causing these results. Ultimately, this research approach should provide information for this study site and suggest more general recommendations for *S. nelsoniana* management.

Standards of evidence. Each set of hypotheses (Table 2.1) was evaluated by considering the associated standards of evidence. For example, significantly lower survival of plants in burned and/or mowed areas compared to unmanipulated controls would support the alternative hypotheses that fire and/or mowing kills *S. nelsoniana*.

A reduction of shading intensity above *S. nelsoniana* plus an increase in growth, flowering intensity (as measured by number and height of flowering stalks and number of inflorescences), or seed production in burned and/or mowed areas compared to unmanipulated controls would support the alternative hypotheses that the treatments promoted *S. nelsoniana* performance by releasing plants from shading.

Table 2.1 Hypotheses for effects of burning and mowing on *Sidalcea nelsoniana* performance.

		Fire		*Mowing*
Survival	H_0:	Fire has no direct effect on *S. nelsoniana* survival	H_0:	Mowing has no direct effect on *S. nelsoniana* survival
	H_A:	Because fire kills *S. nelsoniana*, there will be fewer individuals after manipulation than in controls	H_A:	Because mowing kills *S. nelsoniana*, there will be fewer individuals after manipulation than in controls
Growth	H_0:	Fire has no effect on *S. nelsoniana* growth (as measured by cover)	H_0:	Mowing has no effect on *S. nelsoniana* growth
	H_{A1}:	By releasing plants from shading, fire will lead to greater *S. nelsoniana* growth than in controls	H_{A1}:	By releasing plants from shading, mowing will lead to greater *S. nelsoniana* growth than in controls
	H_{A2}:	By mineralizing nutrients, fire will lead to greater *S. nelsoniana* growth than in controls	H_{A2}:	By mineralizing nutrients via enhanced microbial decomposition, mowing will lead to greater *S. nelsoniana* growth than in controls
	H_{A3}:	By volatilizing nutrients during fire or by increasing evaporation after fire, fire will lead to lower *S. nelsoniana* growth than in controls	H_{A3}:	Mowing will lead to decreased *S. nelsoniana* growth than in controls (mechanism unknown)
Flowering Intensity	H_0:	Fire has no effect on *S. nelsoniana* flowering intensity	H_0:	Mowing has no effect on *S. nelsoniana* flowering intensity
	H_{A1}:	By releasing plants from shading, fire will lead to greater *S. nelsoniana* flowering intensity than in controls	H_{A1}:	By releasing plants from shading, mowing will lead to greater *S. nelsoniana* flowering intensity than in controls
	H_{A2}:	By mineralizing nutrients, fire will lead to greater *S. nelsoniana* flowering intensity than in controls	H_{A2}:	By mineralizing nutrients via enhanced microbial decomposition, mowing will lead to greater *S. nelsoniana* flowering intensity than in controls
	H_{A3}:	By volatilizing nutrients during fire or by increasing evaporation after fire, fire will lead to lower *S. nelsoniana* flowering intensity than in controls	H_{A3}:	Mowing will lead to decreased *S. nelsoniana* flowering intensity as compared to controls (mechanism unknown)

Table 2.1 (Continued)

		Fire		*Mowing*
Seed Production	H_0:	Fire has no effect on *S. nelsoniana* seed production	H_0:	Mowing has no effect on *S. nelsoniana* seed production
	H_{A1}:	By releasing plants from shading, fire will lead to higher *S. nelsoniana* seed production than in controls	H_{A1}:	By releasing plants from shading, mowing will lead to higher *S. nelsoniana* seed production than in controls
	H_{A2}:	By adding nutrients or by promoting pollination, fire will lead to higher *S. nelsoniana* seed production than in controls	H_{A2}:	By adding nutrients or by promoting pollination, mowing will lead to higher *S. nelsoniana* seed production than in controls
	H_{A3}:	Fire will lead to lower *S. nelsoniana* seed production than in controls (mechanism unknown)	H_{A3}:	Mowing will lead to lower *S. nelsoniana* seed production than in controls (mechanism unknown)
Weevil Damage	H_0:	Fire has no effect on weevil damage rates	H_0:	Mowing has no effect on weevil damage rates
	H_A:	Fire does have an effect on weevil damage rates (mechanism unknown)	H_A:	Mowing does have an effect on weevil damage rates (mechanism unknown)

However, an increase in *S. nelsoniana* growth, flowering intensity, or seed production without an associated reduction in shading intensity would support the alternative hypotheses that the treatments promoted *S. nelsoniana* performance by mineralizing nutrients. A decrease in *S. nelsoniana* growth, flowering intensity, or seed production would support the alternative hypotheses that the treatments decreased *S. nelsoniana* performance (see Table 2.1 for mechanisms).

Methods

Study species

Sidalcea nelsoniana Piper (Malvaceae) is a gynodioecious species that can propagate from either rhizomes or seeds. Reproductive individuals have 30 to 100 cm tall flowering stalks terminating in spikelike inflorescences of pinkish-lavender to pinkish-purple flowers (U.S. Fish and Wildlife Service 1993). Peak flowering occurs mid-June through mid-July in the Willamette Valley. The fruits are several-seeded schizocarps and mature in late July and early August. *S. nelsoniana* is most often found in wetland prairies, ash swales, streamsides, and roadside ditches. Associated vegetation includes graminoids such as *Festuca arundinacea*, *Phalaris arundinacea*, *Agrostis* spp., and *Carex* spp.; weedy forbs such as *Heracleum lanatum* and *Vicia* spp.; and woody species such as *Rosa* spp., *Rubus* spp., and *Fraxinus latifolia* (U.S. Fish and Wildlife Service 1998, personal observation). Adjacent vegetation typically senesces between late August and mid-September (personal observation).

Study site

One of the largest populations of *S. nelsoniana* is found at William L. Finley National Wildlife Refuge (NWR), 16 km south of Corvallis in the Willamette Valley, Oregon, USA. Invasion and growth of woody plants or herbaceous pest plants like *Phalaris arundinacea* are likely causes for some apparently precipitous declines in *S. nelsoniana* numbers at Finley NWR (Maura Naughton, personal communication). The study population of *Sidalcea nelsoniana* is located within the refuge in a riparian hedgerow between two agricultural fields planted with perennial rye grass (Field 5—burned swale, Figure 2.1). The hedgerow runs west to east and is approximately 750 m long by 50 m wide. The east end of the site floods to approximately 20 cm above the soil surface from November through April, while the west end of the site remains unflooded throughout the year (personal observation). The dominant vegetation of this site includes *Festuca arundinacea*, *Vicia* spp., *Rubus discolor* and *Rubus macrophyllus* at the driest end with *Phalaris arundinacea*, *Phalaris aquatica* and *Carex* spp. dominating in the wettest portion of the site. *Fraxinus latifolia* is found throughout. *Sidalcea nelsoniana* individuals are scattered throughout the length of the site, sometimes growing under full sun and sometimes under heavy shade. The soil at the site is Waldo silty clay loam, while soils in the surrounding agricultural fields are classified as Coburg silty clay loam and Amity silt loam (Soil Conservation Service 1975).

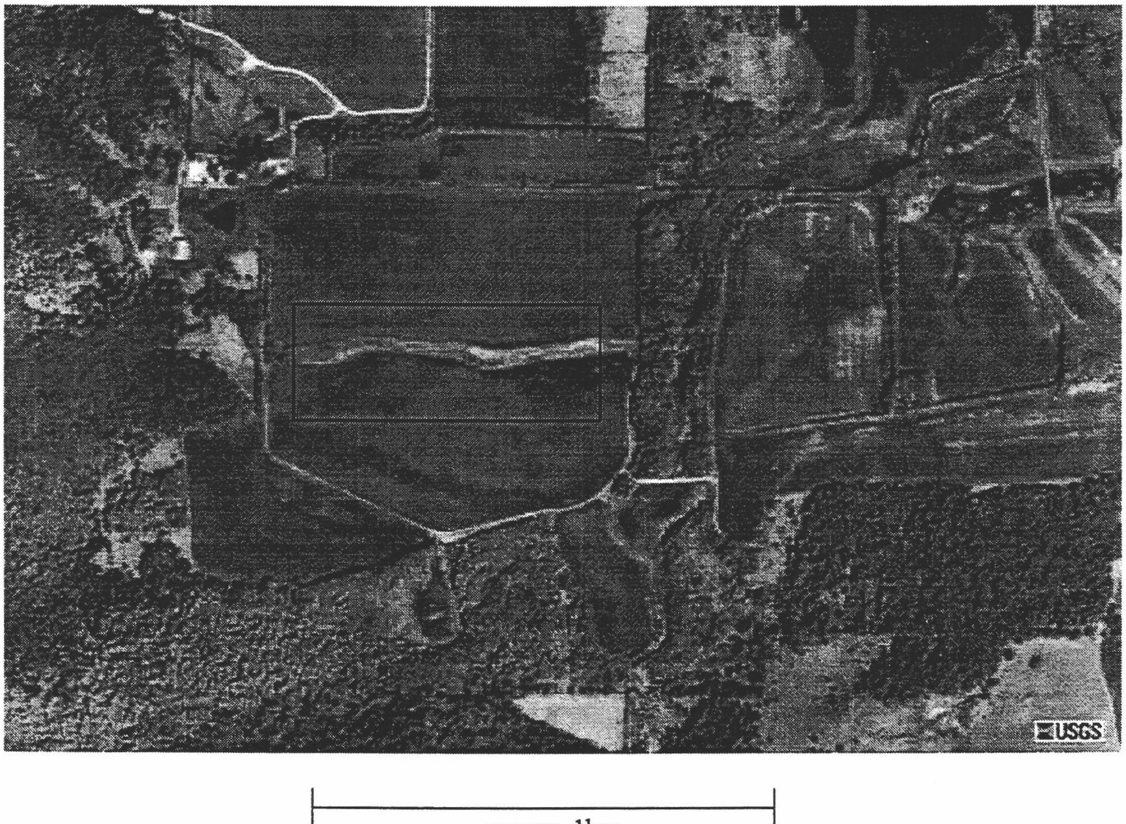

Figure 2.1 Aerial photo of a portion of W.L. Finley NWR. The *Sidalcea nelsoniana* study site was located in the drainage swale hedgerow within the outlined area (Field 5—burned swale). Image courtesy of the U.S. Geological Survey via Microsoft TerraServer (www.terraserver.microsoft.com), taken May 7, 1994 by the National Aerial Photography Program.

The region experiences a modified maritime climate with cool, wet winters and warm, dry summers. Average annual precipitation as recorded in Corvallis is 108.5 cm, with 93.0 cm occurring October through April. Average minimum and maximum temperatures are 0.6 C and 7.5 C in January and 10.6 C and 26.8 C in July (Oregon Climate Service).

Experimental design

Because of the spatial heterogeneity of the site and logistical constraints in applying treatments, typical experimental designs were impractical. Rather, the study was designed to investigate the performance of *S. nelsoniana* under both experimentally manipulated conditions (prescribed burning and mowing) and a range of pre-existing conditions of woody plant cover and hydrology, using General Linear Modeling (described below, McNeil et al. 1996) as the tool for statistical analysis.

During the spring of 1998, the site was surveyed and *S. nelsoniana* individuals were marked and categorized into pre-existing condition strata according to density of woody plant cover and general hydrologic conditions (Table 2.2). Flooding and woody plant cover were described categorically only for the purposes of stratifying the manipulations. Analysis of the effects of these variables on *S. nelsoniana* used actual measurements of flooding and woody plant cover (as explained below). A total of 347 *S. nelsoniana* plants were marked throughout the site. Of these, 25 were vegetative and 322 were reproductive, as indicated by the presence of flowering stalks. Only reproductive individuals were included in the study.

Table 2.2 Stratification scheme for application of experimental manipulations. Approximately 10 quadrats centered on *Sidalcea nelsoniana* plants were placed in each of the 12 combinations.

	Extensively flooded	*Not extensively flooded*
Woody plants dense	Burned	Burned
	Mowed	Mowed
	Control	Control
Woody plants not dense	Burned	Burned
	Mowed	Mowed
	Control	Control

Of the 322 marked reproductive individuals, thirty plants were randomly selected from each of the pre-existing treatment strata, for a total of 120 plants. A 0.5-m^2 quadrat was centered on each selected individual. These plant-centered quadrats were the observational units in the study. Treatment areas were delineated to be of practical size for safe and effective manipulations and to allow for buffers between treatments. Therefore, treatment areas varied in size and encompassed varying numbers of quadrats from one or more strata. Treatments were randomly assigned to each area, with slight adjustment to balance the number of quadrats in each of the 12 treatment-by-condition strata (Table 2.2).

Because of the extent of the site, three "pseudoblocks" were assigned along the length of the site. The boundaries were assigned where there was a gap of at least 20 m between the two closest *S. nelsoniana* plots and so that each pseudoblock included at least one replicate of each of the three treatments.

Vegetation measurements

Pre-manipulation conditions were recorded within each quadrat between June 26 and July 7, 1998. The same characteristics were measured for post-manipulation conditions between July 5 and July 12, 1999. Measurements of *S. nelsoniana* included size (as cover), number of flowering stalks, number of inflorescences (defined as each individual raceme branching off of the main flowering stalk) by type (pistillate or perfect) and height of the tallest flowering stalk. Measurements of the surrounding vegetation included litter depth, woody canopy cover (above 1.5 m) and cover by two species groups (herbaceous and woody less than 1.5 m in height) within two vertical strata (above and below *S. nelsoniana* mid-height [40 cm]). Average litter depth was calculated from measurements of litter depth in three locations within each quadrat. Woody canopy cover was estimated from the north side of the quadrat using a spherical densiometer, so that measurements emphasized canopy cover from the south. Cover of *S. nelsoniana* and surrounding herbaceous and woody vegetation was estimated by consensus of two investigators using calibration templates. Dominant species were also recorded for each quadrat, as a description of the plant communities in which *S. nelsoniana* is found.

Seed production measurements

Seed production and levels of weevil damage were measured during early August in 1998 and 1999. For each quadrat, two infructescences were randomly selected and the number of fruits per infructescence was recorded. One randomly selected fruit from each quadrat was examined under a dissecting microscope to determine the number of filled, undeveloped, and weevil damaged seeds using the criteria established by Gisler and Meinke (1997).

Hydrologic measurements

Because the hydrologic impact on wetland plants is largely determined by the timing and duration of flooding, hydrologic impacts on *S. nelsoniana* were characterized through the use of elevation surveys and site observations throughout the fall, winter and spring. Initially, thirty one-inch PVC pipe water wells were installed to a depth of 35 cm along the length of the study area in a 15×2 grid pattern. Depth to water table or depth of standing water was recorded every two to four weeks during the late fall, winter, and early spring 1998-1999. Unfortunately, elk removed most of the wells as the winter progressed. As an alternative measure of flooding depth, the locations of standing water were noted on subsequent sampling dates.

Relative elevation of all vegetation plots, water levels and the six remaining water wells was recorded during the summer of 1999 to the nearest tenth of a foot (approximately 3 cm) using laser level survey equipment. Elevation is often correlated with soil moisture (Nelson and Anderson 1983) and was used to quantify the relative hydrologic impact on each *S. nelsoniana* measurement plot.

Manipulations

Prescribed burning and mowing manipulations were conducted September 10-11, 1998 by U. S. Fish and Wildlife Service personnel. As discussed above, treatments were applied to groups of quadrats and ranged between 10 and 30 m in width by 25 to 50 m in length, with a buffer of at least 1 m between the treatment edge and the nearest measurement quadrat. For adequate replication, there were five areas of each manipulation and five unmanipulated areas that served as controls.

Convection burns were ignited at the southwest corner of each burn treatment area. Flames burned for 5 to 20 minutes after ignition, with average flame heights between 0.5 and 2 m. In areas with thick vegetation, flames often shot into the ash canopy. In similar prairies, experimental-scale fires have been shown to closely approximate the behavior of large-scale fires (Maret 1996).

Within each mowing treatment area, herbaceous vegetation and shrubs were mowed with a 4.5 m-wide tractor mower to approximately 15 cm above the soil surface. Large trees were cut with a chain saw and all woody brush was removed from the site.

Statistical analysis

General approach. The effects of manipulations on *S. nelsoniana* performance were analyzed by comparing the explanatory power of a series of statistical models as outlined by McNeil et al. (1996). The analysis followed a mixed design of planned manipulations, unplanned pre-existing conditions, and conditions modified by manipulations. Response variables were measurements of *S. nelsoniana* performance including survival, growth (cover), flowering intensity (number and height of flowering stalks and total number of inflorescences), and weevil damage. Seed production was not evaluated because of low seed production in 1999 (see Results and Discussion). Explanatory variables included categorical variables for treatment, pseudoblock (as defined above) and flowering type, and quantitative variables of elevation and the 1998 measurements of canopy cover, woody and herbaceous cover in two vertical strata, and litter depth. The pre-manipulation value of *S. nelsoniana* performance served as a covariate in the analyses. The individual models used are described in detail below. Some variables were transformed using either a square root or rank transformation to meet the assumptions of the statistical models.

Of the 120 plots originally measured in 1998, seven could not be relocated in 1999. Additionally, one plot was missed when manipulations were applied and was therefore excluded from the analyses. The complete data set used in the analyses consisted of 112 measurement plots.

Testing for treatment effects on S. nelsoniana *performance.* The first step in evaluating the hypotheses was to determine whether the treatments had an effect on *S. nelsoniana* performance (growth, flowering intensity, and weevil damage) after accounting for differences in the pre-existing conditions of shading, crowding, and hydrology (as measured by elevation). Each aspect of *S. nelsoniana* performance was used as the response variable in a series of models designed to test whether the treatments explained a significant amount of the variation in *S. nelsoniana* performance. The full model consisted of each explanatory variable and the covariates (Table 2.3) as well as all possible pairwise interactions among the variables. This model was compared to a restricted model from which all terms involving treatment were dropped. This restricted model therefore contained only the variables for flower type, pseudoblock, the covariates, the pre-manipulation measurements of the surrounding vegetation, and the pairwise interactions among these variables. The full and restricted models were compared using a generalized F-test (McNeil et al. 1996). An example of this approach is outlined in Appendix 2.1. If the full model (with treatment added) explained a significantly greater amount of the variation in *S. nelsoniana* performance than the restricted model, the direction and magnitude of the treatment effect was explored by comparing least square means to the controls using Dunnett's test (Day and Quinn 1989) using the statistical software package Statgraphics Plus for Windows 4.0 (Statistical Graphics Corp. 1994-1999). This analysis approach tests for both direct treatment effects and indirect effects of the

Table 2.3 Variables (and transformations) used in the general linear models testing for treatment effects on *Sidalcea nelsoniana* growth and flowering intensity. All measurements were within *S. nelsoniana*-centered quadrats. *Seed production was not tested due to extremely low seed production across all treatments in 1999. **Treatment and flower type were the only explanatory variables included in this analysis.

Response variables. *Sidalcea nelsoniana* performance after manipulation.
Vegetative cover (square root)
Number of flowering stalks (square root)
Number of inflorescences (square root)
Height of flowering stalks
Seed production *
Weevil damage**

Explanatory variables and covariates
Treatment (burning, mowing, or unmanipulated control)
Pseudoblock (1, 2, or 3 based on location along the site)
Relative elevation (rank)
Cover of herbaceous plants (<40 cm stratum) before manipulation
Cover of herbaceous plants (>40 cm stratum) before manipulation (rank)
Cover of woody plants (<40 cm stratum) before manipulation (rank)
Cover of woody plants (40 – 150 cm stratum) before manipulation (rank)
Woody canopy cover (>150 cm) before manipulation (rank)
Litter depth before manipulation
Associated measure of *S. nelsoniana* before manipulation
Flower type (pistillate or perfect)

treatment through interactions with the environment. The mechanisms (as described in the Hypotheses, Table 2.1) were explored by evaluating the outcome of the tests for treatment effects on the surrounding vegetation. Some variables were transformed before the analyses to better meet the assumptions of the statistical tests (Table 2.3).

Testing for treatment effects on the surrounding vegetation. Analyses of variance were used to test for treatment effects on litter depth, canopy cover, and woody and herbaceous cover both above and below *S. nelsoniana* mid-height. The response variable was the change in cover from 1998 to 1999, with treatment, pseudoblock, and the treatment by pseudoblock interaction as the explanatory variables. The F-ratio was calculated by comparing the treatment mean square to the mean square of the interaction with pseudoblock (Underwood 1997, Newman et al. 1997). Least square means were then compared using Tukey's test (Day and Quinn 1989) in the statistical software program Statgraphics (Statistical Graphics Corp. 1994-1999). Some variables were square root transformed before the analyses to better meet the assumptions of the statistical tests.

Results and Discussion

The characteristics of the environment and the unadjusted averages of the pre- and post- manipulation vegetation are presented first, followed by the statistical evaluation of the hypotheses (Table 2.1), statistical tests for treatment differences in the surrounding vegetation, and a discussion of mechanisms.

<u>Relative elevation and hydrologic measurements</u>

The elevation difference between the highest and lowest plots was approximately 7.1 m (Figure 2.2, Appendix 2.2). Standing water was at a relative elevation of approximately 2 m below the highest plot during the winter months (January and February 1999). Standing water in May was at a relative elevation of approximately 6 m below the highest plot.

At well installation on October 24, 1998, the water table was below the 35 cm depth of each of the wells. By mid-November 1998, all but three of the wells had a detectable water table (shallower than 35 cm), with standing water present at five of the wells. All wells in the wetter east end of the site had been removed by elk by mid-January 1999. Average depth to water table among the wells remaining in the drier, west end of the site ranged between 15 and 20 cm from December through April. Water depth data from available wells are listed in Appendix 2.3.

<u>Pre-manipulation vegetation characteristics</u>

Although quadrats were centered on *S. nelsoniana* plants, pre-manipulation cover of *S. nelsoniana* (July 1998) within each quadrat averaged only 8.6% (Table 2.4). Thus, this rare plant, even in this relatively large population, was not a dominant in the vegetation.

The number of pistillate inflorescences outnumbered the number of perfect inflorescences by 3.5 to 1 (Table 2.4), and of the quadrats measured, pistillate plants outnumbered perfect plants by nearly 4 to 1. Pistillate to perfect flower ratios in other Willamette Valley *S. nelsoniana* populations ranged between 0.2:1 and 5.0:1 (Gisler

Figure 2.2 Relative elevation of *Sidalcea nelsoniana* measurement plots in relation to their location. Relative elevation (m) by west-east location (a) and by north-south location within the following three "cross-sections" of the west-east profile: between 7 and 22 m (b), between 200 and 220 m (c) and between 485 and 520 m (d).

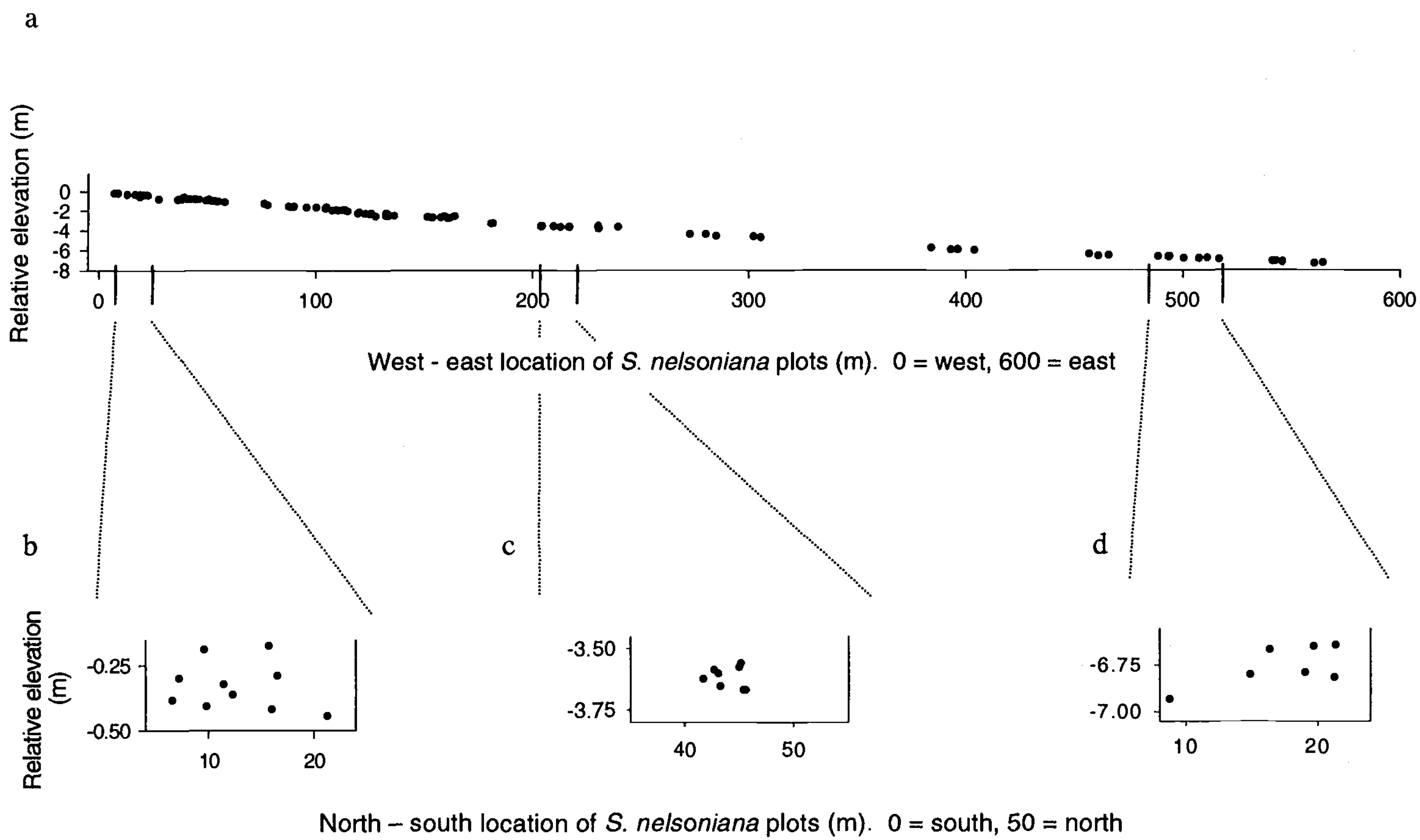
a
Relative elevation (m)
0
-2
-4
-6
-8
0
100
200
300
400
500
600
West - east location of S. nelsoniana plots (m). 0 = west, 600 = east
b
c
d
Relative elevation (m)
-0.25
-0.50
10
20
-3.50
-3.75
40
50
-6.75
-7.00
10
20
North – south location of S. nelsoniana plots (m). 0 = south, 50 = north

Figure 2.2

Table 2.4 Summary of pre-manipulation vegetation data based on 112 *Sidalcea nelsoniana*-centered quadrats measured during the summer of 1998.

Variable	Average	Standard Error	Minimum	Maximum
S. nelsoniana cover (%)	8.6	0.5	1	25
Flowering stalks	5.7	0.5	1	34
Total no. of inflorescences	27.3	2.5	0	135
Pistillate inflorescences	21.9	2.5	0	135
Perfect inflorescences	6.4	1.7	0	90
Height of tallest flowering stalk (cm)	114.7	2.3	52	180
Herbaceous cover below *S. nelsoniana* mid-height (40 cm) (%)	45.6	2.3	4	98
Herbaceous cover above 40 cm (%)	15.3	1.0	2	60
Woody cover below 40 cm (%)	3.2	0.5	0	25
Woody cover, 40 –150 cm (%)	8.7	1.4	0	75
Canopy cover (%)	23.3	2.7	0	97
Litter depth (cm)	5.4	0.3	0	21

and Meinke 1995). Pollen availability could limit seed production in populations with high ratios of pistillate to perfect flowering types.

In 1998, 11% of all carpels collected contained filled seeds, while 39% contained unfilled seeds and 51% were completely or partially destroyed by weevils. These rates are similar to the weevil infestation rates found by Gisler and Meinke (1997) across 15 *S. nelsoniana* populations.

Herbaceous cover below *S. nelsoniana* mid-height (40 cm) was often dense, and averaged 45.6% (Table 2.4). As would be expected, herbaceous cover above *S. nelsoniana* mid-height was less dense, averaging 15.3%. Woody cover below *S. nelsoniana* mid-height was relatively sparse, averaging 3.2%. Above *S. nelsoniana* mid-height (and below 1.5 m), woody cover averaged 8.7%. Average canopy cover was 23.3%. Litter depth averaged 5.4 cm deep over all measurements. The raw data for each quadrat are listed in Appendix 2.2.

Festuca arundinacea was dominant in 69 of the 120 plots (58%). *Agrostis* spp. (mostly *Agrostis tenuis*) and *Rubus* spp. were also common dominant species. The frequency of all dominant species is listed in Appendix 2.4.

Post-manipulation vegetation characteristics

One year after manipulations (1999), the average cover of *S. nelsoniana* across all quadrats remained at 8.6% (Table 2.5). Average cover of *S. nelsoniana* by treatment area (not adjusted for pre-manipulation condition) was 6.9% in burned areas, 9.4% in mowed areas and 9.6% in unmanipulated controls (Table 2.6). These averages represented an increase of less than 1% over the 1998 measurements in the

Table 2.5 Summary of post-manipulation vegetation data based on 112 *Sidalcea nelsoniana*-centered quadrats measured during the summer of 1999.

Variable	Average	Standard Error	Minimum	Maximum
S. nelsoniana cover (%)	8.6	0.6	0	29.0
Flowering stalks	5.1	0.5	0	25.0
Total no. of inflorescences	15.2	1.8	0	83.0
Pistillate inflorescences	13.0	1.7	0	83.0
Perfect inflorescences	2.3	0.7	0	50.0
Height of tallest flowering stalk (cm)	78.6	3.4	0	137.5
Herbaceous cover below *S. nelsoniana* mid-height (40 cm) (%)	69.0	1.8	10	98.0
Herbaceous cover above 40 cm (%)	43.4	2.5	1	93.0
Woody cover below 40 cm (%)	5.5	0.9	0	43.0
Woody cover, 40 – 150 cm (%)	8.6	1.6	0	83.0
Canopy cover (%)	14.5	2.3	0	90.0
Litter depth (cm)	6.0	0.3	0	22.0

Table 2.6 Raw means (in bold) and standard errors for all measurements of *Sidalcea nelsoniana* performance and the surrounding vegetation by treatment area before (1998) and after (1999) burning and mowing manipulations were applied. n = number of plots in each treatment.

	BURN n = 37		CONTROL n = 40		MOW n = 35	
	1998	1999	1998	1999	1998	1999
S. nelsoniana						
Cover (%)	**7.3**	**6.9**	**9.3**	**9.6**	**9.2**	**9.4**
	0.7	0.8	0.8	1.1	0.9	1.2
No. of flowering stalks	**5.2**	**4.2**	**5.1**	**5.4**	**6.9**	**5.7**
	0.7	0.5	0.6	0.9	1.1	0.8
No. of inflorescences	**24.8**	**14.1**	**28.3**	**14.5**	**31.2**	**17.7**
	4.5	2.5	4.2	3.0	5.0	3.6
Flowering stalk height (cm)	**112.4**	**80.5**	**116.5**	**80.2**	**115.0**	**74.9**
	3.6	5.8	3.5	5.6	4.8	6.3
Herbaceous cover (%)						
Below 40 cm	**42.7**	**75.4**	**44.7**	**58.7**	**49.7**	**74.1**
	3.8	2.7	3.5	3.4	4.6	2.5
Above 40 cm	**15.4**	**53.7**	**13.0**	**28.8**	**17.7**	**49.3**
	1.8	4.2	1.3	3.8	1.9	3.9
Woody cover (%)						
Below 40 cm	**3.6**	**5.1**	**4.3**	**8.4**	**1.6**	**2.6**
	0.8	1.2	1.0	1.8	0.6	1.0
40 – 150 cm	**12.0**	**6.3**	**9.7**	**15.9**	**3.9**	**2.8**
	2.9	1.6	2.7	3.8	1.1	1.1
Canopy	**23.2**	**7.3**	**23.3**	**32.7**	**23.3**	**1.3**
	4.7	1.7	4.4	5.0	5.2	0.7
Average litter depth (cm)	**4.9**	**5.5**	**5.9**	**5.2**	**5.3**	**7.5**
	0.4	0.6	0.4	0.3	0.5	0.6

mowed and unmanipulated areas and a decrease of less than 1% in the burned areas and are unlikely to be biologically significant.

The number of flowering stalks averaged 5.1 per quadrat in 1999 (Table 2.5), and the unadjusted average was also similar among treatments and years (Table 2.6). The number of inflorescences and the height of the flowering stalks generally decreased from 1998 to 1999 overall and across all three treatment groups (Table 2.5, Table 2.6). The flowering type ratio was even more skewed toward pistillate plants in 1999 (5.7:1, Table 2.5) and was higher than ratios observed by Gisler and Meinke (1995) in other Willamette Valley populations.

S. nelsoniana fruits produced an average of 7 carpels each in 1999, just as in 1998. Seeds were unavailable from 20% of the measurement plots because they had either already dispersed or because the plant did not produce fruits. Of those that produced fruits in 1999, less than 1% of the carpels collected contained filled seeds and 74% had been damaged by weevils. The remaining 25% contained undeveloped or unfilled seeds. Other *S. nelsoniana* populations also experienced high rates of weevil damage in 1999 (Steve Gisler, personal communication).

Herbaceous cover below *S. nelsoniana* mid-height was even more dense in 1999 than in 1998 across all treatments; however, the increase was most dramatic in the burned and mowed areas. Herbaceous cover above *S. nelsoniana* mid-height showed a similar trend (Table 2.5, Table 2.6). Woody cover below *S. nelsoniana* mid-height remained sparse in 1999, but showed a slight increase from 1998 in all treatments (Table 2.5, Table 2.6). The unadjusted averages of both woody cover between 40 and 150 cm and canopy cover increased between 1998 and 1999 in unmanipulated areas but decreased in burned and mowed areas (Table 2.6). The raw data for each quadrat are listed in Appendix 2.5.

Vicia spp. were dominant in more of the plots in 1999 than in 1998 (56% in 1999 compared to 4% in 1998), while *Festuca arundinacea* was dominant in fewer (35% in 1999 compared to 58% in 1998). *Agrostis* spp. and *Rubus* spp. remained common dominant species in 1999. The frequency of all dominant species is listed in Appendix 2.4.

Hypothesis tests: treatment effects on *Sidalcea nelsoniana* performance

Survival. Survival of marked plants from 1998 to 1999 was high across all treatments. Out of 112 marked individuals, 108 were still present in 1999. Survival was similar among the treatments: 97.3% in burned areas (36/37), 97.1% in mowed areas (34/35) and 95.0% in controls (38/40). These results support the null hypotheses that neither fire nor mowing have a direct effect on *S. nelsoniana* survival (Table 2.1).

Growth. Treatment did not explain a significant amount of the variation in *S. nelsoniana* cover after accounting for the covariates and pre-existing conditions of hydrology and surrounding vegetation ($p = 0.15$, generalized F-test, Table 2.7). This supports the null hypotheses that neither fire nor mowing has an effect on *S. nelsoniana* growth during the first year after manipulations (Table 2.1).

Number of flowering stalks. Treatment did not explain a significant amount of the variation in the number of *S. nelsoniana* flowering stalks after accounting for the covariates and pre-existing conditions of hydrology and surrounding vegetation ($p = 0.79$, generalized F-test, Table 2.7). These results support the null hypotheses that fire

Table 2.7 Summary of statistical models used to test for treatment effects on *Sidalcea nelsoniana* performance. df: numerator and denomenator degrees of freedom used to calculate generalized F-statistic (McNeil et al 1996). F: generalized F-statistic (see Appendix 1). p: probability that the difference in R^2 between the models with and without treatment could have occurred by chance. * Performance variable was square root transformed before analyses.

Performance variable	R^2		df	F	p
	Full model (includes treatment and all pairwise interactions)	Restricted model (terms with treatment removed)			
Cover *	89.4%	71.4%	24, 22	1.55	0.15
No. of flowering stalks *	88.0%	78.7%	24, 22	0.71	0.79
No. of inflorescences *	82.3%	63.5%	24, 22	0.97	0.53
Flowering stalk height	84.8%	74.2%	24, 22	0.64	0.86

and mowing do not affect the number of *S. nelsoniana* flowering stalks during the first year after manipulations (Table 2.1).

Flowering stalk height. Treatment did not explain a significant amount of the variation in the height of *S. nelsoniana* flowering stalks after accounting for the covariates and pre-existing conditions of hydrology and surrounding vegetation ($p = 0.86$, generalized F-test, Table 2.7). This supports the null hypotheses that neither fire nor mowing affects the height of *S. nelsoniana* flowering stalks the first year following manipulations (Table 2.1).

Number of inflorescences. Treatment did not explain a significant amount of the variation in the number of *S. nelsoniana* inflorescences after accounting for the covariates and pre-existing conditions of hydrology and surrounding vegetation ($p = 0.53$, generalized F-test, Table 2.7). This supports the null hypotheses that fire and mowing do not have an effect on the number of *S. nelsoniana* inflorescences produced during the first year following manipulations (Table 2.1).

Seed production. Because of the small number of seeds produced overall (less than 1% of the total carpels collected contained filled seeds), I did not test for treatment differences in seed production. However, the low seed production across all treatments seems to support the null hypotheses that fire and mowing do not affect *S. nelsoniana* seed production (Table 2.1).

Weevil damage. Statistical analyses of weevil damage were done using only those individuals for which fruits were available. In 1999, weevils had damaged one or more carpels in 84% of the fruits collected, or 74% of the total carpels collected. The percentage of carpels damaged by weevils did not differ significantly among treatments after adjusting for the flower type of the individual ($F = 0.35$ for treatment, $p = 0.70$). This supports the null hypotheses that neither fire nor mowing have a direct effect on weevil damage in *S. nelsoniana* (Table 2.1).

Treatment effects on the surrounding vegetation

Canopy cover. Treatments had significant effects on canopy cover one year after application (p=0.004, Table 2.8, Figure 2.3). Canopy cover increased slightly in the unmanipulated areas from 1998 to 1999, whereas canopy cover significantly decreased in both the burned and especially the mowed areas (Figure 2.3). The more pronounced decrease in the mowed areas is not surprising since trees were actually removed from the mowed areas and would be unlikely to sprout to canopy height in just one season. Trees in the burned areas were not removed and a few leafed out again where the fire was not intense enough to kill the entire tree (personal observation).

Woody cover between 40 and 150 cm. Although both the raw and square-root adjusted means show a decrease in woody cover between 40 and 150 cm in the burned and mowed areas and an increase in the controls (Table 2.6, Figure 2.3), the treatment effect was not statistically significant (p=0.257, Table 2.9). The vegetation in this category is primarily shrubs such as rose and blackberry, which often resprout after manipulations (Wilson and Clark 1997). In addition, many of the ash trees that were cut in the mowed treatments resprouted to approximately 1 m in height, adding cover

Table 2.8 Analysis of Variance for treatment effects on canopy cover. The response variable is the square root of the 1999 canopy cover minus the square root of the 1998 canopy cover. [1] F-ratio based on Treatment × Pseudoblock mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	2	79.22	28.5 [1]	0.004
Pseudoblock	2	0.24	0.1 [2]	0.947
Treatment × Pseudoblock	4	2.78	0.7 [2]	0.631
Residual	103	4.31		
Total	111			

R^2 = 43.5 %

R^2 (adjusted for df) = 39.1 %

Table 2.9 Analysis of Variance for treatment effects on woody cover above *Sidalcea nelsoniana* mid-height. The response variable is the square root of the 1999 cover minus the square root of the 1998 cover. [1] F-ratio based on Treatment × Pseudoblock mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	2	3.73	2.0 [1]	0.257
Pseudoblock	2	3.90	1.6 [2]	0.207
Treatment × Pseudoblock	4	1.92	0.8 [2]	0.536
Residual	103	2.44		
Total	111			

R^2 = 19.1 %

R^2 (adjusted for df) = 12.8 %

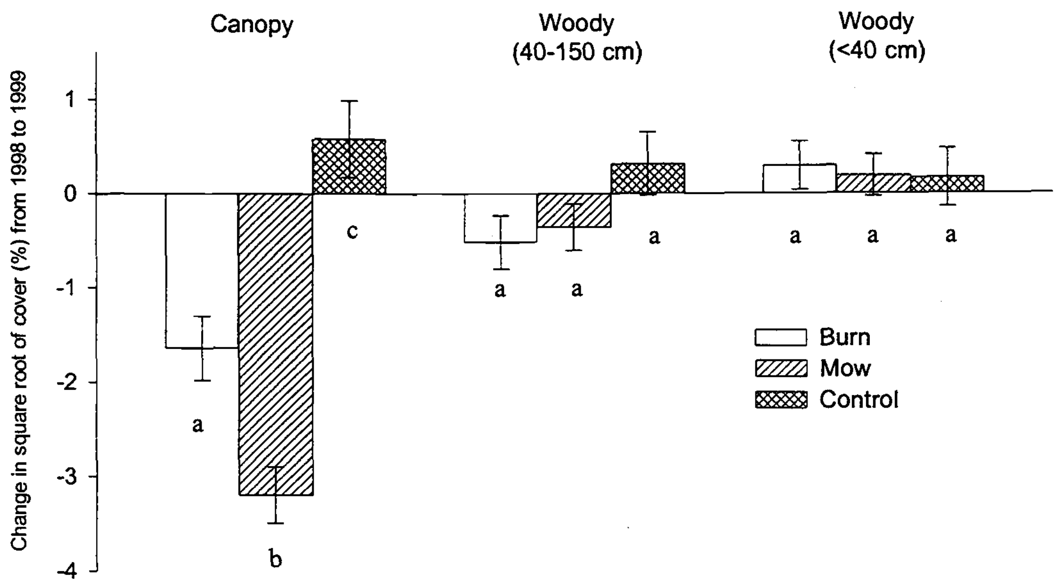

Figure 2.3 Least square means and standard errors for change in canopy cover and woody cover above and below *S. nelsoniana* mid-height from 1998 to 1999 by treatment. Values are the square root of the 1998 cover measurement subtracted from the square root of the 1999 cover measurement. Treatments that share the same letter are not statistically different from one another (Tukey's HSD, $\alpha = 0.05$).

to the woody above 40 cm category (personal observation). If repeated applications of the treatments diminished resprouting, differences in woody shrub cover would likely be more pronounced.

Woody cover below 40 cm. Woody cover below 40 cm increased slightly in all areas and was not significantly affected by the manipulations (p=0.936, Table 2.10, Figure 2.3). Once again, repeated applications of the treatment may eventually kill the woody vegetation and reduce the cover in this category.

Herbaceous cover above 40 cm. Herbaceous cover above 40 cm was significantly affected by the treatments (p=0.019, Table 2.11). While herbaceous cover increased in all areas from 1998 to 1999, the increase was significantly greater in burned and mowed plots than in unmanipulated controls (Figure 2.4). The increase in the burned treatment was most pronounced, but did not differ significantly from the mow treatment (Figure 2.4). The more frequent occurrence of *Vicia* spp. as dominants in the plots during 1999 likely accounted for much of this increase (Appendix 2.4, personal observation).

Herbaceous cover below 40 cm. The increase in herbaceous cover below 40 cm in 1999 was also affected by the treatments (p=0.037, Table 2.12); however, only the burned treatment was significantly greater than the control (Figure 2.4). Although herbaceous cover also increased more in the mowed areas than in controls, this increase was intermediate to and not significantly different from either the control or the burned areas (Figure 2.4).

Litter depth. Treatment had no significant effect overall on average litter depth (p=0.451 for treatment, Table 2.13). Although there was a significant interaction

Table 2.10 Analysis of Variance for treatment effects on woody cover below *Sidalcea nelsoniana* mid-height. The response variable is the square root of the 1999 cover minus the square root of the 1998 cover. [1] F-ratio based on Treatment × Pseudoblock mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	2	0.11	0.1 [1]	0.936
Pseudoblock	2	0.52	0.4 [2]	0.667
Treatment × Pseudoblock	4	1.57	1.2 [2]	0.306
Residual	103	1.28		
Total	111			

R^2 = 7.4 %

R^2 (adjusted for df) = 0.2 %

Table 2.11 Analysis of Variance for treatment effects on herbaceous cover above *Sidalcea nelsoniana* mid-height. The response variable is the cover in 1999 minus the cover in 1998. [1] F-ratio based on Treatment × Pseudoblock mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	2	3678.70	12.5 [1]	0.019
Pseudoblock	2	3664.89	7.1 [2]	0.001
Treatment × Pseudoblock	4	293.51	0.6 [2]	0.684
Residual	103	513.20		
Total	111			

R^2 = 29.1 %

R^2 (adjusted for df) = 23.6 %

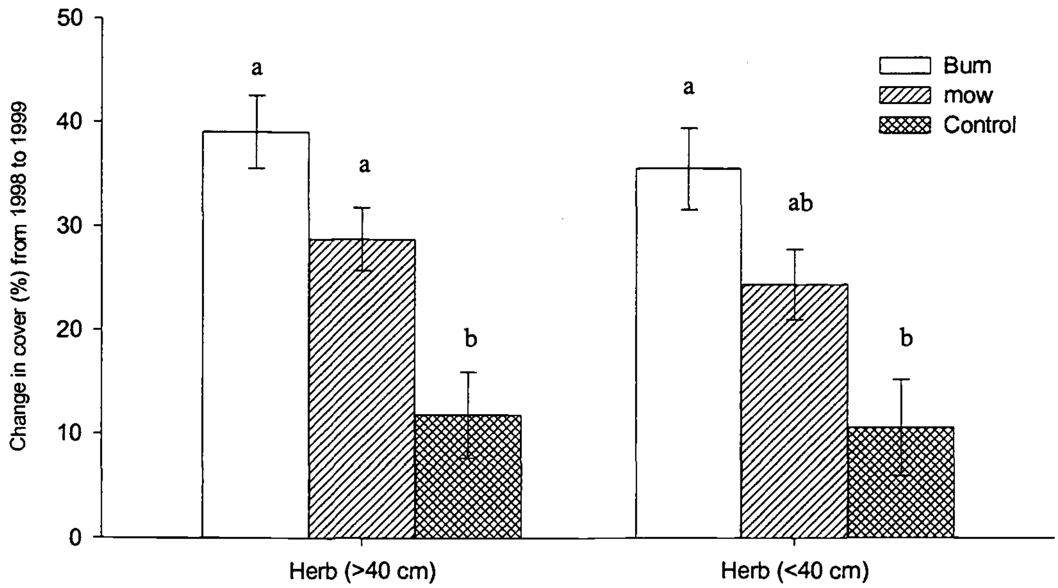

Figure 2.4 Least square means and standard errors for change in herbaceous cover above and below *S. nelsoniana* mid-height from 1998 to 1999 by treatment. Values were not transformed for the analyses and are the 1998 measure subtracted from the 1999 measure of cover. Treatments that share the same letter are not statistically different from one another (Tukey's HSD, $\alpha = 0.05$).

Table 2.12 Analysis of Variance for treatment effects on herbaceous cover below *Sidalcea nelsoniana* mid-height. The response variable is the cover in 1999 minus the cover in 1998. [1] F-ratio based on Treatment × Pseudoblock mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio		p
Treatment	2	3079.16	8.4	1	0.037
Pseudoblock	2	4502.07	10.3	2	< 0.001
Treatment × Pseudoblock	4	366.32	0.8	2	0.504
Residual	103	436.95			
Total	111				

R^2 = 28.7 %

R^2 (adjusted for df) = 23.2 %

Table 2.13 Analysis of Variance for treatment effects on average litter depth. The response variable is the 1999 average litter depth in cm minus the 1998 average litter depth for each plot. [1] F-ratio based on Treatment × Pseudoblock mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio		p
Treatment	2	33.26	1.0	1	0.452
Pseudoblock	2	81.37	6.1	2	0.003
Treatment × Pseudoblock	4	34.09	2.6	2	0.043
Residual	103	13.34			
Total	111				

R^2 = 23.1 %

R^2 (adjusted for df) = 17.1 %

between treatment and pseudoblock (Table 2.13), graphical inspection of this interaction showed no clear trend of treatment effect on litter depth.

Mechanisms

Although burning and mowing did not significantly affect *S. nelsoniana* performance during the first year after manipulations, both fire and mowing did alter the surrounding vegetation. However, the specific changes that occurred in this first year after treatments may have acted in opposing directions to result in no net change in *S. nelsoniana* growth and flowering intensity.

As in other studies (e.g. Clark and Wilson 1996), both fire and mowing were effective at reducing woody cover as compared to controls. Because *S. nelsoniana* plants are often found growing in full sun, it seems unlikely that a reduction in woody cover would be harmful to *S. nelsoniana* performance. Therefore, this reduction in shading should either promote or have no effect on *S. nelsoniana* performance.

The large increase in herbaceous cover in burned and mowed plots compared to controls in the first year after treatments is less well documented (but see Kost and De Steven 2000). Because herbaceous cover also increased in the controls, some of the increase was likely due to year to year variation in climate (such as the unusually wet winter and spring in 1999). However, herbaceous cover increased significantly more in the treated areas. Thus, the herbaceous vegetation may have been stimulated by the increased light in burned and mowed areas. It is also possible that the additional increase was a response to nutrient mineralization caused by the burning and mowing treatments. If nutrients were mineralized by the treatments, *S. nelsoniana* would be expected to increase as well (see Hypotheses Table 2.1). However, if the increased nutrients were utilized more efficiently by the surrounding vegetation, competition may have limited *S. nelsoniana* performance.

Although it is difficult to tell from this data set how the surrounding vegetation affects *S. nelsoniana* performance, many species respond positively to a suppression of the surrounding vegetation (Howe 1999). Therefore, it seems likely that a decrease in canopy cover or the surrounding vegetation would lead to decreased competition for light and/or nutrients and result in an increase in *S. nelsoniana* growth and/or flowering intensity. Similarly, an increase in the surrounding vegetation could lead to increased competition and decreased *S. nelsoniana* performance. If only one of these changes had occurred, the results may be easier to interpret. However, while canopy cover significantly decreased in the burned and mowed areas, herbaceous cover significantly increased. *S. nelsoniana* plants that may have been able to take advantage of an opened canopy might have instead been outcompeted by other herbaceous plants.

Conclusions and Management Implications

It is not surprising that direct treatment effects were not apparent during the first year after manipulations. Experimental habitat manipulations often do not produce strong patterns until several years after treatment application (Wilson and Clark, in prep.). The characteristics of the surrounding vegetation in 1998 (before manipulations) explained much of the variation in *S. nelsoniana* performance in 1999

(Table 2.7, R^2 values of restricted models). This suggests that the characteristics of the surrounding vegetation in 1999, the environment as altered by the manipulations, may be very important in influencing the performance of *S. nelsoniana* in future years. Because neither burning nor mowing killed *S. nelsoniana*, or significantly harmed the growth or reproduction of the species, treatments were reapplied during September 1999 and measurements of *S. nelsoniana* and the surrounding vegetation will be recorded again during the summer of 2000.

While the impact of the reduction in woody cover on *S. nelsoniana* performance is unclear at this point, reduction in woody cover is a key goal in the restoration and management of any prairie area, as few species can survive under thick shrub cover. Furthermore, because shrubs and trees often resprout after treatment (Wilson and Clark 1997, Frenkel and Heinitz 1987) treatments must be repeated regularly for the most efficient reduction in woody cover (Wilson and Clark 1997).

Additionally, there may be some delay between the mineralization of nutrients caused by fire and/or mowing and the ability of *S. nelsoniana* to take up these resources and utilize them for increased growth or flowering intensity. The constraints of working with a protected species prevented this study from comparing below ground productivity among the three treatment conditions. Perhaps in this first year after manipulations, the increased resources were primarily stored below ground and did not result in a biologically or statistically meaningful increase in above-ground cover. As woody cover is further reduced by repeated applications of the treatment, conditions may become more favorable for additional above-ground production that would enable *S. nelsoniana* to better compete with the surrounding herbaceous vegetation.

Many mechanisms seem to influence *S. nelsoniana* performance in this system. With repeated treatment application, one or more of these processes may emerge as being more important than the others and the relationship between fire, mowing and the growth and flowering intensity of mature *S. nelsoniana* individuals may become more clear. Furthermore, additional management efforts may be necessary to control the surrounding herbaceous vegetation and reduce the competitive pressure on *S. nelsoniana*. These results reinforce the importance of careful long term monitoring in any habitat management program.

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APPENDICES

Appendix 2.1 Hypothetical example illustrating the General Linear Model approach to hypothesis testing.

Symbols

S_{99}	cover of *S. nelsoniana* in 1999
S_{98}	cover of *S. nelsoniana* in 1998 (covariate)
T_i	treatment (1=burning, 2=mowing, 3=control)
E	elevation
H_1	cover of herbaceous plants below *S. nelsoniana* mid-height
H_2	cover of herbaceous plants below *S. nelsoniana* mid-height
W_1	cover of herbaceous plants below *S. nelsoniana* mid-height
W_2	cover of herbaceous plants below *S. nelsoniana* mid-height
C	canopy cover
L	litter depth (cm)

Hypotheses

H_0: Treatment is not important to *S. nelsoniana* cover in 1999

H_1: Treatment is needed to understand *S. nelsoniana* cover in 1999

Models

Model 0 (corresponding to H_0 true):

$$S_{99} = \mu + S_{98} + E + H_1 + H_2 + W_1 + W_2 + C + L + \varepsilon$$

Model 1 (corresponding to H_1 true):

$$S_{99} = \mu + S_{98} + T_i + E + H_1 + H_2 + W_1 + W_2 + C + L + (T_i{*}H_1) + (T_i{*}H_2) + (T_i{*}W_1) + (T_i{*}W_2) + (T_i{*}C) + (T_i{*}L) + \varepsilon$$

Generalized F test statistic

$$F = \frac{(R_1^2 - R_0^2)/(df_1 - df_0)}{(1 - R_1^2)/(N - 1 - df_1)}$$

where R_0^2 and R_1^2 are the coefficients of determination from models 0 and 1, respectively. If $F > F_{crit}$, then H_0 is rejected: treatment *is* needed to understand *S. nelsoniana* cover in 1999.

Appendix 2.2 Pre-manipulation and elevation data for 120 *Sidalcea nelsoniana*-centered quadrats. Pre-manipulation conditions of *S. nelsoniana* and the surrounding vegetation were recorded between June 26 and July 7, 1998. Relative elevation was measured during the summer of 1999. Plots for which there is no elevation data were not found during the 1999 sampling period and were excluded from the analyses of treatment effects and the calculations of raw means presented in the text. * Plot was missed when treatments were applied and was therefore excluded from the analyses.

Appendix 2.2

Species abbreviations used in Appendix 2.2

Agr	*Agrostis* spp. (mostly *Agrostis tenuis*, some *Agrostis exarata*)
Alo	*Alopecurus* spp.
Bro	*Bromus* spp.
Car	*Carex* spp.
Cir	*Cirsium* spp.
Dagl	*Dactylus glomerata*
Elpa	*Eleocharis palustris*
Fear	*Festuca arundinacea*
Frla	*Fraxinus latifolia*
Gal	*Galium* spp.
Hela	*Heracleum lanatum*
Hola	*Holcus lanatus*
Jun	*Juncus* spp.
OEG	Other exotic (non-native) grass species
Pavi	*Parentucellia viscosa*
Phaq	*Phalaris aquatica*
Phar	*Phalaris arundinacea*
Ros	*Rosa* spp.
Rub	*Rubus* spp. (mostly *R. discolor*, some R. *ursinus* and R. *laciniatus*)
Sine	*Sidalcea nelsoniana*
Sta	*Stachys* spp.
Syal	*Symphoricarpos albus*
Vic	*Vicia* spp.

Appendix 2.2 (Continued)

Plot #	0	5	8	10	12	13	16	18	19	21	25	27	36
Pseudoblock	1	1	1	1	1	1	1	1	1	1	1	1	1
Relative elevation (m)	-0.2	-0.2	-0.3	-0.4	-0.4	-0.3	-0.3	-0.4	-0.4	-0.4	-0.6	-0.7	-0.8
Sidalcea nelsoniana													
cover (%)	7.0	23.0	4.0	6.5	11.0	15.5	19.0	9.0	15.0	4.5	11.5	6.0	11.0
No. flowering stalks	3.0	9.0	3.0	4.0	5.0	3.0	6.0	6.0	2.0	1.0	5.0	2.0	4.0
No. pistillate inflorescences	9.0	50.0	0.0	6.0	15.0	5.0	12.0	25.0	0.0	10.0	0.0	0.0	30.0
No. perfect inflorescences	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	4.0	2.0	0.0
Total no. inflorescences	9.0	50.0	3.0	6.0	15.0	5.0	12.0	25.0	39.0	10.0	4.0	2.0	30.0
Inflorescence height (cm)	89.5	137.0	93.0	90.0	90.0	100.0	128.0	125.0	148.5	141.0	97.5	68.0	157.0
Herbaceous cover (%)													
below 40 cm	65.0	77.0	75.0	53.0	98.0	87.0	90.0	78.0	72.0	55.0	70.0	68.0	35.0
above 40 cm	25.0	30.0	35.0	28.0	33.0	19.0	10.0	20.0	36.0	26.5	35.0	21.0	10.0
Woody cover (%)													
below 40 cm	0.0	0.0	0.0	13.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5
above 40 cm	0.0	0.0	0.0	26.0	16.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	2.0
canopy	0.0	45.0	0.0	4.0	7.0	3.0	0.0	41.0	0.0	42.0	0.0	0.0	1.0
Litter depth (cm)													
position a	0.5	5.0	6.0	2.0	3.0	2.0	2.0	3.0	5.0	5.0	2.0	5.0	2.5
position b	7.0	2.0	1.5	7.0	8.0	4.0	4.0	4.0	2.0	4.0	1.5	7.0	4.0
position c	2.0	4.5	4.0	3.0	7.0	2.5	5.0	11.0	3.5	5.0	4.0	6.0	7.0
Average litter depth (cm)	3.2	3.8	3.8	4.0	6.0	2.8	3.7	6.0	3.5	4.7	2.5	6.0	4.5
Dominant Species	Fear	Fear	Fear	Hela Syal Fear	Fear Rub	Cir Fear	Fear	Fear	Fear Sine Sta Vic	Fear Vic	Fear	Fear Agr Vic	Fear Ros

Appendix 2.2 (Continued)

Plot #	39	41	42	49	50	51	100	102	103	106	109	113	122
Pseudoblock	1	1	1	1	1	1	1	1	1	1	1	1	1
Relative elevation (m)	na	-0.8	-0.8	na	-0.8	-0.6	-0.6	-0.9	-0.8	-0.8	-0.8	-0.8	-0.9
Sidalcea nelsoniana													
cover (%)	22.0	18.0	8.0	4.5	5.0	12.0	6.0	8.0	6.5	13.0	2.0	9.0	7.0
No. flowering stalks	16.0	11.0	6.0	2.0	3.0	8.0	6.0	7.0	1.0	5.0	2.0	7.0	9.0
No. pistillate inflorescences	48.0	77.0	0.0	0.0	6.0	13.0	54.0	36.0	4.0	23.0	7.0	2.0	0.0
No. perfect inflorescences	0.0	0.0	40.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	35.0
Total no. inflorescences	48.0	77.0	40.0	6.0	6.0	13.0	54.0	36.0	4.0	23.0	7.0	16.0	35.0
Inflorescence height (cm)	126.0	138.0	146.0	111.0	98.0	106.0	131.0	124.0	94.5	113.0	93.0	106.0	116.0
Herbaceous cover (%)													
below 40 cm	40.0	22.0	12.0	12.0	45.0	84.0	97.0	45.0	68.0	20.0	75.0	22.0	25.0
above 40 cm	10.0	7.0	13.0	5.0	12.0	18.0	26.0	15.0	11.0	7.0	22.0	30.0	11.0
Woody cover (%)													
below 40 cm	10.0	0.5	6.5	14.0	17.0	0.0	0.0	4.0	0.0	17.0	1.0	13.0	17.0
above 40 cm	16.5	1.0	12.0	30.0	10.0	0.0	0.0	6.0	11.0	27.0	13.0	50.0	50.0
canopy	19.0	7.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0	9.0	25.0	93.0	13.0
Litter depth (cm)													
position a	2.5	3.5	1.0	15.0	2.5	1.0	5.0	4.0	11.0	1.5	7.0	2.0	1.5
position b	16.0	6.0	1.0	7.0	1.0	1.5	8.0	5.0	10.0	10.0	6.0	7.0	5.5
position c	14.0	0.5	0.5	10.0	1.0	2.0	2.5	4.0	5.0	7.0	2.0	14.0	0.0
Average litter depth (cm)	10.8	3.3	0.8	10.7	1.5	1.5	5.2	4.3	8.7	6.2	5.0	7.7	2.3
Dominant Species	Hola Rub	Fear	Syal Hola	Rub	Agr Rub	Fear	Fear	Fear	Fear	Fear Rub	Fear Rub	Rub OEG	Syal

Appendix 2.2 (Continued)

Plot #	129	137	138	140	143	144	145	148	157	158	159	160	161
Pseudoblock	1	1	1	1	1	1	1	1	2	2	2	2	2
Relative elevation (m)	-1.1	-1.0	-1.1	-0.9	-0.9	-0.9	-0.9	-0.8	-1.3	-1.2	-1.3	-1.4	-1.5
Sidalcea nelsoniana													
cover (%)	1.0	11.0	4.0	17.0	11.5	4.5	5.0	7.5	5.0	8.0	3.0	2.5	10.0
No. flowering stalks	1.0	3.0	1.0	4.0	6.0	3.0	6.0	6.0	2.0	10.0	1.0	1.0	7.0
No. pistillate inflorescences	4.0	9.0	2.0	14.0	43.0	22.0	43.0	0.0	3.0		0.0	1.0	29.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0		12.0	0.0	0.0
Total no. inflorescences	4.0	9.0	2.0	14.0	43.0	22.0	43.0	5.0	3.0	0.0	12.0	1.0	29.0
Inflorescence height (cm)	120.0	146.0	120.0	124.0	147.0	106.0	98.0	87.0	88.0	93.0	72.0	131.0	108.0
Herbaceous cover (%)													
below 40 cm	90.0	70.0	52.0	18.0	13.0	48.0	23.0	53.0	47.0	15.0	43.0	13.0	50.0
above 40 cm	20.0	18.0	2.0	7.0	7.0	5.5	10.0	26.0	18.0	12.0	14.0	18.5	20.0
Woody cover (%)													
below 40 cm	0.0	3.0	9.0	7.0	3.0	0.0	8.0	3.5	8.0	5.5	0.0	2.0	0.0
above 40 cm	0.0	0.0	8.0	3.0	18.0	1.5	37.0	43.0	6.0	32.0	0.0	52.0	0.0
canopy	59.0	17.0	91.0	17.0	0.0	44.0	41.0	6.0	0.0	8.0	4.0	34.0	0.0
Litter depth (cm)													
position *a*	10.0	7.0	0.5	1.5	0.5	6.0	4.0	10.0	0.0	3.0	8.0	1.0	4.5
position b	3.0	9.0	3.0	13.0	0.5	2.0	21.0	7.0	1.0	5.0	4.0	6.0	3.0
position c	6.0	7.0	1.0	8.0	8.0	9.0	11.0	3.0	3.0	3.5	5.0	0.0	8.0
Average litter depth (cm)	6.3	7.7	1.5	7.5	3.0	5.7	12.0	6.7	1.3	3.8	5.7	2.3	5.2
Dominant Species	Hela Agr OEG	Fear Bro	Agr Frla	Bro Fear	Rub	Hola OEG	Rub Agr	Fear OEG Frla Gal	Hela Fear	Rub Hela	Fear	Syal	Fear Vic Cir

Appendix 2.2 (Continued)

Plot #	165	168	169	170	171	173	175	177	180	185	187	191	193
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Relative elevation (m)	-1.6	-1.5	-1.9	-1.7	-1.8	-1.8	-1.6	-1.7	-1.6	-2.3	-2.3	-2.3	-2.2
Sidalcea nelsoniana													
cover (%)	3.5	8.0	8.0	6.0	15.0	9.5	20.0	7.5	5.0	6.0	2.5	8.0	5.0
No. flowering stalks	2.0	5.0	3.0	2.0	8.0	4.0	17.0	7.0	2.0	4.0	1.0	8.0	1.0
No. pistillate inflorescences	12.0	5.0	9.0	9.0	4.0	42.0	127.0	37.0	24.0	2.0	5.0	25.0	16.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	24.0	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0
Total no. inflorescences	12.0	5.0	9.0	9.0	28.0	42.0	127.0	37.0	24.0	17.0	5.0	25.0	16.0
Inflorescence height (cm)	131.5	107.0	122.0	109.0	103.0	134.0	133.0	116.0	130.0	150.5	102.0	132.5	125.5
Herbaceous cover (%)													
below 40 cm	50.0	25.0	40.0	24.0	55.0	45.0	29.0	4.0	11.0	26.0	57.0	75.0	78.0
above 40 cm	9.0	3.0	8.5	13.0	17.0	15.0	11.0	10.0	3.5	8.0	12.0	24.5	27.0
Woody cover (%)													
below 40 cm	4.0	3.5	8.0	1.0	1.5	0.0	25.0	15.0	14.0	11.0	16.0	8.0	0.0
above 40 cm	7.5	16.0	17.5	5.0	5.0	0.0	27.0	75.0	41.0	4.0	1.5	0.5	0.0
canopy	43.0	29.0	78.0	13.0	0.0	0.0	0.0	17.0	0.0	35.0	27.0	10.0	6.0
Litter depth (cm)													
position a	7.0	4.5	3.0	3.0	1.0	7.0	12.0	1.5	10.0	5.5	6.0	5.0	10.0
position b	6.0	4.0	6.0	5.0	2.0	11.0	2.0	2.0	9.0	13.0	5.0	5.0	10.0
position c	6.0	3.0	5.0	4.0	4.0	13.0	8.0	3.0	10.0	4.0	5.0	6.0	6.5
Average litter depth (cm)	6.3	3.8	4.7	4.0	2.3	10.3	7.3	2.2	9.7	7.5	5.3	5.3	8.8
Dominant Species	Syal Fear	Syal OEG	Fear Rub	Fear	Fear Sta	Fear Vic	Sine Rub	Rub	Rub Syal	Fear Frla	Dagl Fear	Fear	Fear

Appendix 2.2 (Continued)

Plot #	194	196	199	204	205	207	209	210	211	214	218	221	223
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Relative elevation (m)	-2.3	-2.1	-1.9	-1.9	-2.0	-1.9	-2.1	-2.6	-2.6	-2.5	-2.5	-2.6	-2.3
Sidalcea nelsoniana													
cover (%)	15.0	7.0	13.0	12.0	21.0	7.0	4.5	9.0	9.0	11.0	3.0	10.0	8.0
No. flowering stalks	7.0	3.0	4.0	3.0	7.0	3.0	1.0	2.0	10.0	3.0	2.0	3.0	9.0
No. pistillate inflorescences	4.0	30.0	16.0	0.0	23.0	10.0	12.0	0.0	46.0	8.0	10.0	9.0	27.0
No. perfect inflorescences	48.0	0.0	0.0	18.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0
Total no. inflorescences	52.0	30.0	16.0	18.0	23.0	10.0	12.0	14.0	46.0	8.0	10.0	9.0	27.0
Inflorescence height (cm)	156.0	134.0	99.0	107.0	133.0	82.0	112.0	125.0	116.0	126.0	118.0	102.0	120.0
Herbaceous cover (%)													
below 40 cm	25.0	70.0	70.0	50.0	45.0	42.0	32.0	68.0	46.0	54.0	82.0	86.0	58.0
above 40 cm	8.0	15.0	12.5	25.0	10.0	7.0	20.0	15.0	20.0	8.5	6.0	3.0	10.0
Woody cover (%)													
below 40 cm	12.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	5.0
above 40 cm	2.0	6.0	0.0	0.0	48.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	20.0
canopy	46.0	73.0	0.0	3.0	92.0	0.0	0.0	24.0	30.0	66.0	46.0	62.0	50.0
Litter depth (cm)													
position a	16.0	3.0	2.5	4.0	2.5	3.5	7.0	5.0	5.0	5.0	0.5	9.0	5.0
position b	7.0	8.0	7.0	4.0	8.0	3.0	16.0	8.0	9.0	6.0	5.0	8.0	6.0
position c	5.5	20.0	5.0	4.0	4.0	11.0	10.0	4.0	11.0	2.0	4.0	7.0	2.0
Average litter depth (cm)	9.5	10.3	4.8	4.0	4.8	5.8	11.0	5.7	8.3	4.3	3.2	8.0	4.3
Dominant Species	Fear Frla	Fear Frla	Fear	Fear	Fear Frla	Fear	Fear	Fear	Fear	Agr Fear	Fear Hola	Agr Fear Hola Alo	Agr Fear

Appendix 2.2 (Continued)

Plot #	227	228	229	231	233	235	236	237	238	239	240	241	242
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Relative elevation (m)	-2.3	-2.3	-2.6	-2.7	-2.7	-2.8	na	-2.7	-2.7	-2.7	-2.7	-2.7	-2.6
Sidalcea nelsoniana													
cover (%)	6.0	16.0	8.0	5.5	4.0	12.5	6.0	8.0	7.0	19.0	4.5	8.0	17.0
No. flowering stalks	8.0	5.0	5.0	2.0	5.0	13.0	2.0	7.0	9.0	5.0	3.0	4.0	11.0
No. pistillate inflorescences	67.0	45.0	36.0	14.0	42.0	33.0	5.0	28.0	0.0	66.0	6.0	18.0	96.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	72.0	0.0	0.0	0.0	0.0
Total no. inflorescences	67.0	45.0	36.0	14.0	42.0	33.0	5.0	28.0	72.0	66.0	6.0	18.0	96.0
Inflorescence height (cm)	125.5	134.5	125.0	115.0	131.0	160.0	121.0	110.0	132.0	159.0	110.5	141.0	144.0
Herbaceous cover (%)													
below 40 cm	50.0	18.0	80.0	35.0	89.0	50.0	68.0	87.0	52.0	49.0	32.0	35.0	25.0
above 40 cm	12.5	3.5	20.0	22.0	21.0	47.0	17.0	24.0	3.0	5.0	8.0	7.5	5.0
Woody cover (%)													
below 40 cm	6.0	18.0	0.0	2.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	4.0
above 40 cm	2.5	47.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	1.0	5.0
canopy	0.0	1.0	0.0	0.0	6.0	13.0	86.0	24.0	17.0	23.0	94.0	79.0	90.0
Litter depth (cm)													
position a	9.0	4.5	10.0	5.0	9.0	8.0	8.0	9.0	9.0	6.0	5.0	8.0	5.0
position b	7.0	14.0	11.0	5.0	9.0	7.0	8.0	12.0	5.0	9.0	9.0	4.0	6.5
position c	8.0	9.0	3.0	7.0	10.0	13.0	3.0	8.0	5.5	9.0	7.0	14.0	7.0
Average litter depth (cm)	8.0	9.2	8.0	5.7	9.3	9.3	6.3	9.7	6.5	8.0	7.0	8.7	6.2
Dominant Species	Fear	Rub	Agr	Fear	Fear	Fear	Fear	Fear	Fear	Fear	Agr	Fear	Sine
	Alo	Fear		OEG		Agr	Agr	Agr	Agr	Sine	Fear	Frla	Frla
							Frla			Frla	Frla		Fear

Appendix 2.2 (Continued)

Plot #	244	245	246	248	249	250	251	252	253	254	255	257	259
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Relative elevation (m)	-3.3	-3.3	na	na	-3.6	-3.6	-3.6	-3.7	-3.6	-3.7	-3.7	-3.6	-3.7
Sidalcea nelsoniana													
cover (%)	12.0	2.5	3.0	6.0	10.0	2.5	7.0	7.5	3.5	25.0	7.0	11.0	11.0
No. flowering stalks	18.0	1.0	2.0	2.0	7.0	1.0	13.0	8.0	11.0	34.0	11.0	12.0	10.0
No. pistillate inflorescences	103.0	6.0	27.0	11.0	53.0	8.0	52.0	64.0	41.0	29.0	0.0	8.0	135.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0	75.0	82.0	0.0
Total no. inflorescences	103.0	6.0	27.0	11.0	53.0	8.0	52.0	64.0	41.0	51.0	75.0	90.0	135.0
Inflorescence height (cm)	173.0	110.0	162.0	124.0	126.0	102.0	110.0	134.5	141.0	130.0	105.0	141.0	137.5
Herbaceous cover (%)													
below 40 cm	48.0	47.0	77.0	75.0	40.0	68.0	27.0	50.0	72.0	10.0	40.0	84.0	66.0
above 40 cm	12.5	13.0	32.0	12.0	4.0	18.0	20.0	26.0	20.0	25.0	13.0	32.0	18.0
Woody cover (%)													
below 40 cm	1.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	2.0	8.0
above 40 cm	0.0	20.0	0.0	0.0	2.5	0.0	0.0	0.0	3.0	0.0	9.0	0.3	3.0
canopy	0.0	0.0	0.0	0.0	48.0	23.0	70.0	13.0	97.0	0.0	1.0	48.0	8.0
Litter depth (cm)													
position a	8.0	2.0	11.0	7.0	6.0	2.5	4.0	5.0	1.0	12.0	1.5	3.0	2.0
position b	5.0	8.0	8.0	8.0	5.0	5.0	3.0	5.0	3.0	13.0	2.0	2.0	5.0
position c	7.0	9.0	10.0	4.0	11.0	3.0	4.0	3.5	8.0	5.0	1.0	7.0	4.0
Average litter depth (cm)	6.7	6.3	9.7	6.3	7.3	3.5	3.7	4.5	4.0	10.0	1.5	4.0	3.7
Dominant Species	Agr	Fear	Fear	Fear	Agr	Agr	Hola	Agr	Rub	Phar	Hola	Hela	Fear
	Fear	Rub	Hela			Holo	Hela		Agr	Sine	Hela	Fear	
	Sine		Hola				Sine		Hela			Sine	

Appendix 2.2 (Continued)

Plot #	260	261	265	266	268	269	270	271	273	275	277	280	282
Pseudoblock	2	2	2	2	2	2	2	2	23	3	3	3	3
Relative elevation (m)	-3.6	-3.9	-4.6	-4.4	na	-4.4	-4.6	-4.7	-5.9	-5.9	-6.5	-6.7	-6.8
Sidalcea nelsoniana													
cover (%)	7.0	7.5	2.0	6.0	10.0	4.0	12.0	11.0	7.5	10.0	7.5	3.0	12.0
No. flowering stalks	6.0	5.0	1.0	7.0	11.0	18.0	5.0	7.0	2.0	9.0	1.0	1.0	4.0
No. pistillate inflorescences	32.0	16.0	4.0	37.0	18.0	8.0	73.0	20.0	2.0	32.0	0.0	9.0	15.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0
Total no. inflorescences	32.0	16.0	4.0	37.0	18.0	8.0	73.0	20.0	2.0	32.0	5.0	9.0	15.0
Inflorescence height (cm)	110.0	101.0	87.0	131.0	102.0	103.0	180.0	135.5	52.0	89.5	84.0	136.0	87.2
Herbaceous cover (%)													
below 40 cm	68.0	50.0	12.5	23.0	17.5	55.0	16.5	16.0	37.0	13.0	30.0	33.0	18.0
above 40 cm	15.0	5.0	60.0	15.0	5.0	8.0	5.0	2.0	6.0	6.0	2.0	5.0	10.0
Woody cover (%)													
below 40 cm	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0	4.0	1.0	3.0	2.0	3.0
above 40 cm	0.0	0.0	0.0	0.0	1.5	0.0	23.0	21.0	1.0	13.0	16.0	52.0	2.0
canopy	0.0	38.0	9.0	44.0	39.0	68.0	33.0	79.0	10.0	4.0	0.0	0.0	0.0
Litter depth (cm)													
position *a*	6.0	3.0	16.0	11.0	3.0	3.0	4.0	3.0	0.0	0.5	1.0	4.0	10.0
position b	4.0	2.0	8.0	16.0	3.5	4.0	1.0	4.0	0.0	4.0	1.0	2.0	10.0
position c	4.0	1.0	2.0	5.0	3.0	3.0	7.0	4.0	2.0	20.0	3.0	3.0	7.0
Average litter depth (cm)	4.7	2.0	8.7	10.7	3.2	3.3	4.0	3.7	0.7	8.2	1.7	3.0	9.0
Dominant Species	Fear	Fear	Phar	Phar Jun	Hola Pavi	Hola	Ros	Syal	Phar Car	Ros Phar	Ros Car Agr	Ros	Phaq Hola Sine Pavi

Appendix 2.2 (Continued)

Plot #	292	297	315	317	330	336	338	342	348	356	361	401*	403
Pseudoblock	3	3	3	3	3	3	3	3	3	3	3	3	3
Relative elevation (m)	-6.8	-6.8	-6.6	-6.7	-6.9	na	-7.1	-7.1	-7.2	-7.3	-7.3	-5.8	-6.0
Sidalcea nelsoniana													
cover (%)	3.0	6.0	4.5	4.0	15.0	5.0	8.5	8.0	1.5	5.5	2.5	6.0	6.0
No. flowering stalks	1.0	8.0	2.0	2.0	11.0	2.0	4.0	5.0	2.0	1.0	1.0	11.0	3.0
No. pistillate inflorescences	3.0	0.0	0.0	12.0	52.0	13.0	0.0	9.0	3.0	1.0	1.0	0.0	3.0
No. perfect inflorescences	0.0	90.0	5.0	8.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	11.0	0.0
Total no. inflorescences	3.0	90.0	5.0	20.0	52.0	13.0	14.0	9.0	3.0	1.0	1.0	11.0	3.0
Inflorescence height (cm)	73.0	107.0	84.0	118.0	96.0	101.0	92.0	93.0	76.0	70.0	75.0	120.0	75.0
Herbaceous cover (%)													
below 40 cm	53.0	30.0	35.0	39.0	20.0	20.0	12.0	25.0	45.0	16.0	23.0	72.0	12.0
above 40 cm	9.0	6.0	13.0	13.0	10.0	23.0	12.0	18.0	13.0	9.0	5.5	7.5	2.0
Woody cover (%)													
below 40 cm	1.0	0.0	0.0	3.0	0.0	11.0	0.0	1.0	0.0	0.0	0.0	3.0	0.0
above 40 cm	0.0	0.0	2.5	12.5	0.0	4.5	0.0	2.5	1.0	0.0	0.0	0.0	1.5
canopy	23.0	0.0	81.0	0.0	0.0	7.0	23.0	3.0	37.0	5.0	74.0	86.0	56.0
Litter depth (cm)													
position a	0.5	7.0	2.0	1.5	0.0	6.0	12.0	2.5	2.5	1.0	4.0	3.0	0.5
position b	2.0	3.5	4.0	3.0	5.0	8.0	2.0	5.0	3.0	2.0	5.0	15.0	0.5
position c	7.0	5.0	8.0	2.0	10.0	4.0	13.0	2.0	1.0	4.0	3.0	10.0	0.0
Average litter depth (cm)	3.2	5.2	4.7	2.2	5.0	6.0	9.0	3.2	2.2	2.3	4.0	9.3	0.3
Dominant Species	Car	Car Sine Phaq	Car Frla	Car Agr	Sine Phaq	Phaq Phar	Phaq	Pavi Phaq	Pavi	Phaq	Pavi Car Hola	Phar	Car Frla

Appendix 2.2 (Continued)

Plot #	411	506	509	MEAN	ST DEV	MINIMUM	MAXIMUM
Pseudoblock	3	3	3				
Relative elevation (m)	-5.9	-6.6	-6.4	-2.8	2.1	-7.3	-0.2
Sidalcea nelsoniana							
cover (%)	12.5	5.0	17.5	8.6	5.0	1.0	25.0
No. flowering stalks	16.0	7.0	15.0	5.7	4.9	1.0	34.0
No. pistillate inflorescences	54.0	0.0	32.0	21.5	25.9	0.0	135.0
No. perfect inflorescences	0.0	61.0	0.0	6.1	17.0	0.0	90.0
Total no. inflorescences	54.0	61.0	32.0	27.3	27.0	0.0	135.0
Inflorescence height (cm)	115.0	93.0	85.0	115.1	23.9	52.0	180.0
Herbaceous cover (%)							
below 40 cm	10.0	30.0	14.0	45.8	24.4	4.0	98.0
above 40 cm	40.0	20.0	20.0	15.2	10.0	2.0	60.0
Woody cover (%)							
below 40 cm	0.0	0.0	0.0	3.3	5.2	0.0	25.0
above 40 cm	0.0	0.0	0.0	8.5	14.8	0.0	75.0
canopy	0.0	0.0	0.0	23.7	29.1	0.0	97.0
Litter depth (cm)							
position a	7.0	4.0	15.0	4.9	3.7	0.0	16.0
position b	5.0	2.0	10.0	5.9	3.8	0.0	21.0
position c	5.0	2.0	4.0	5.8	3.8	0.0	20.0
Average litter depth (cm)	5.7	2.7	9.7	5.5	2.7	0.3	12.0
Dominant Species	Phar	Phar Elpa	Car Phar				

Appendix 2.3. Depth to water table and depth of standing water (cm) recorded from 30 shallow water wells along *Sidalcea nelsoniana* site at Finley NWR. Negative values are depth to water table, positive values are depth of standing water. Well number refers to position along the transect from west to east (approximately 40 m intervals). Row 1 wells are closer to the agricultural field, row 2 wells are closer to the creek. NA indicates no detectable water table (water table deeper than 35cm). X indicates well pulled by elk or otherwise missing and no longer usable. Relative elevation was recorded in July 1999.

Well no.	Row	11/24/98	12/1/98	12/10/98	1/21/99	2/4/99	2/26/99	4/13/99	5/12/99	Rel. Elev. (cm)
1	1	-16	-16.5	-27	-13	-14	-17	NA	NA	0.0
1	2	-34.5	-34	-38.5	-30	-32	-37.5	NA	NA	-4.2
2	1	-17.5	-20	-27.5	-18	-16	-19	NA	NA	X
2	2	-21.5	-23	-35	-17	-19	-29	NA	NA	X
3	2	-19.5	-14.5	-25.5	-5.5	-8	-11.5	-24	-38	X
3	1	NA	NA	NA	X	X	X	X	X	X
4	1	-25.5	-26	NA	-19.5	-21	-24	NA	NA	-14.9
4	2	-31.5	-27.5	-36	2	0.5	-14	-34.5	NA	-17.2
5	1	NA	NA	NA	X	X	X	X	X	X
5	2	NA	NA	NA	-33	-35.5	NA	NA	NA	-23.2
6	1	-34	NA	NA	-27.5	-26.5	NA	NA	NA	X
6	2	-12	-15.5	-29.5	X	X	X	X	X	X
7	2	-21.5	-19.5	-27	-15	-15.5	-20	-28.5	-34	-33.2
7	1	-27	-30.5	-33	X	X	X	X	X	X
8	1	-20.5	-18.5	-31	-14	-13	X	X	X	X
8	2	-14.5	-8	-13.5	X	X	X	X	X	X
9	1	-5.5	-0.5	-7	X	X	X	X	X	X
9	2	0.5	7	1.5	X	16.5	14	3.5	X	X
10	1	-0.5	2.5	-4	X	X	X	X	X	X
10	2	17.5	19	11	X	X	X	X	X	X
11	1	-6.5	6	-5	X	X	X	X	X	X
11	2	7	12	7	X	X	X	X	X	X
12	1	-7.5	0	X	X	X	X	X	X	X
12	2	-0.5	2	X	X	X	X	X	X	X
13	2	-8.5	-0.5	X	X	X	X	X	X	X
13	1	12	18	X	X	X	X	X	X	X
14	2	-7	-5	X	X	X	X	X	X	X
14	1	0.5	X	X	X	X	X	X	X	X
15	1	-11	-5.5	-4.5	X	X	X	X	X	X
15	2	-6.5	-4	-0.5	X	X	X	X	X	X
AVERAGE:		-11.5	-8.1	-17.1	-17.3	-15.3	-17.6	-20.9	-36.0	

Appendix 2.4 Frequency of dominant species within *Sidalcea nelsoniana*-centered quadrats before (1998) and after (1999) manipulations. Each quadrat may have more than one dominant species (if no species has >50% cover). Note that *S. nelsoniana* was not considered as a possible dominant in 1999, even when it had high cover within the plot.

	Number of Plots		% of Plots	
	1998	**1999**	**1998**	**1999**
Festuca arundinacea	69	40	57.5	35.4
Agrostis spp.	21	31	17.5	27.4
Rubus spp.	17	17	14.2	15.0
Fraxinus latifolia	13	1	10.8	1.0
Holcus lanatus	12	12	10.0	10.6
Parentucellia viscosa	11	6	9.2	5.3
Sidalcea nelsoniana	11	na	9.2	na
Phalaris arundinacea	10	9	8.3	8.0
Heracleum lanatum	9	10	7.5	8.9
Carex spp.	9	8	7.5	7.1
Phalaris aquatica	7	4	5.8	3.5
Symphoricarpos albus	7	8	5.8	7.1
Rosa spp.	5	5	4.2	4.4
Vicia spp.	5	63	4.2	55.8
Cirsium spp.	2	3	1.7	2.7
Stachys spp.	2	4	1.7	3.5
Bromus spp.	2	3	1.7	2.7
Alopecurus spp.	2	0	1.7	0
Eleocharis palustris	1	1	0.8	1.0
Juncus spp.	1	3	0.8	3.7
Galium spp	1	3	0.8	2.7
Dactylus glomerata	1	0	0.8	0
Other Exotic Grasses	6	0	5.0	0

Appendix 2.5 Post-manipulation data for 120 *Sidalcea nelsoniana*-centered quadrats. Post-manipulation conditions of *S. nelsoniana* and the surrounding vegetation were recorded between July 5 and July 12, 1999. Seven plots were not found during the 1999 sampling period and one was missed when treatments were applied. These plots are indicated with "na" in the data column and were excluded from the analyses.

Appendix 2.5

Species abbreviations used in Appendix 2.5

Agex	*Agrostis exarata*
Agte	*Agrostis tenuis*
Alo	*Alopecurus* spp.
Besy	*Beckmannia syzigachne*
Bro	*Bromus* spp.
Car	*Carex* spp.
Chr	*Chrysanthemum* spp.
Cir	*Cirsium* spp.
Dagl	*Dactylus glomerata*
Elpa	*Eleocharis palustris*
Fear	*Festuca arundinacea*
Frla	*Fraxinus latifolia*
Gal	*Galium* spp.
Ger	*Geranium* spp.
Hela	*Heracleum lanatum*
Hola	*Holcus lanatus*
Jun	*Juncus* spp.
Lope	*Lolium perenne*
Myo	*Myosotis* spp.
OEG	Other exotic (non-native) grass species
Pavi	*Parentucellia viscosa*
Phaq	*Phalaris aquatica*
Phar	*Phalaris arundinacea*
Ros	*Rosa* spp.
Rudi	*Rubus discolor*
Rula	*Rubus laciniatus*
Ruur	*Rubus ursinus*
Sta	*Stachys* spp.
Syal	*Symphoricarpos albus*
Vic	*Vicia* spp.

Appendix 2.5 (Continued)

Plot #	0	5	8	10	12	13	16	18	19	21	25	27	36
Pseudoblock	1	1	1	1	1	1	1	1	1	1	1	1	1
Treatment	C	C	C	M	M	M	M	M	M	M	B	B	B
Sidalcea nelsoniana													
cover (%)	9.0	7.5	4.5	2.0	5.0	14.0	23.5	10.0	5.0	11.0	5.0	4.5	10.0
No. flowering stalks	5.0	17.0	4.0	2.0	4.0	8.0	13.0	6.0	4.0	8.0	2.0	1.0	6.0
No. pistillate inflorescences	17.0	6.0	0.0	0.0	22.0	34.0	42.0	24.0	0.0	28.0	0.0	0.0	31.0
No. perfect inflorescences	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	8.0	3.0	0.0
Total no. inflorescences	17.0	6.0	3.0	0.0	22.0	34.0	42.0	24.0	3.0	28.0	8.0	3.0	31.0
Inflorescence height (cm)	86.0	96.0	58.5	78.0	75.5	108.0	113.0	75.5	94.0	97.5	83.5	73.5	121.5
Herbaceous cover (%)													
below 40 cm	75.0	37.0	65.0	85.0	88.0	87.0	68.0	90.0	70.0	80.0	90.0	95.0	74.0
above 40 cm	75.0	7.0	37.0	70.0	55.0	40.0	27.0	20.0	25.0	40.0	35.0	75.0	57.0
Woody cover (%)													
below 40 cm	0.0	0.0	0.0	20.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
above 40 cm	0.0	0.0	0.0	18.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
canopy	0.0	52.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Litter depth (cm)													
position a	6.0	3.0	7.0	7.0	12.0	16.0	9.0	10.0	9.0	10.0	6.0	13.0	12.0
position b	10.0	5.0	12.0	8.0	11.0	12.0	14.0	9.0	6.0	8.0	17.0	15.0	14.0
position c	12.0	7.0	6.0	5.0	9.0	8.0	11.0	11.0	5.0	9.0	10.0	12.0	8.0
Average litter depth (cm)	9.3	5.0	8.3	6.7	10.7	12.0	11.3	10.0	6.7	9.0	11.0	13.3	11.3
Grazing													
No. of stems grazed	1.0	16.0	2.0	0.0	0.0	0.0	1.0	0.0	4.0	0.0	0.0	0.0	0.0
Dominant Species	Vic	Fear	Vic Fear	Syal Hela Vic	Vic Fear	Fear Vic	Fear Hola	Vic Fear	Vic Fear	Vic Hela	Vic Fear	Vic Fear	Vic Cir Ros

Appendix 2.5 (Continued)

Plot #	39	41	42	49	50	51	100	102	103	106	109	113	122
Pseudoblock	1	1	1	1	1	1	1	1	1	1	1	1	1
Treatment	B	B	B	M	M	M	B	B	B	B	B	B	B
Sidalcea nelsoniana													
cover (%)	*na*	5.0	3.0	*na*	5.0	7.0	4.0	6.0	3.0	15.0	16.0	6.0	10.0
No. flowering stalks	*na*	13.0	1.0	*na*	2.0	7.0	1.0	8.0	2.0	9.0	7.0	5.0	6.0
No. pistillate inflorescences	*na*	17.0	0.0	*na*	6.0	11.0	7.0	28.0	11.0	40.0	57.0	0.0	0.0
No. perfect inflorescences	*na*	0.0	0.0	*na*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	22.0
Total no. inflorescences	*na*	17.0	0.0	*na*	6.0	11.0	7.0	28.0	11.0	40.0	57.0	7.0	22.0
Inflorescence height (cm)	*na*	89.0	57.0	*na*	83.5	95.5	102.0	102.5	94.0	100.0	102.5	88.5	88.0
Herbaceous cover (%)													
below 40 cm	*na*	75.0	55.0	*na*	88.0	68.0	70.0	82.0	80.0	95.0	82.0	33.0	30.0
above 40 cm	*na*	17.0	17.0	*na*	40.0	45.0	70.0	33.0	65.0	60.0	70.0	14.0	25.0
Woody cover (%)													
below 40 cm	*na*	2.0	20.0	*na*	15.0	0.0	0.0	9.0	0.0	3.0	4.0	20.0	20.0
above 40 cm	*na*	0.0	10.0	*na*	20.0	0.0	0.0	0.0	0.0	1.5	12.0	7.0	13.5
canopy	*na*	12.0	1.0	*na*	0.0	0.0	0.0	0.0	0.0	0.0	15.0	32.0	4.0
Litter depth (cm)													
position a	*na*	1.5	7.0	*na*	10.0	12.0	20.0	2.0	4.0	3.0	14.0	0.5	1.5
position b	*na*	2.0	13.0	*na*	9.0	12.0	18.0	3.0	3.0	4.0	16.0	2.0	2.0
position c	*na*	0.0	7.0	*na*	14.0	7.0	13.0	5.0	3.0	4.0	12.0	5.0	3.0
Average litter depth (cm)	*na*	1.2	9.0	*na*	11.0	10.3	17.0	3.3	3.3	3.7	14.0	2.5	2.2
Grazing													
No. of stems grazed	*na*	0.0	1.0	*na*	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Dominant Species	*na*	Hola Vic Chr	Vic Syal	*na*	Vic Ruur	Fear	Vic Hola	Vic Fear Ger	Cir Vic Agte	Vic Cir	Vic Rudi	Vic Ruur	Syal Vic Hela

Appendix 2.5 (Continued)

Plot #	129	137	138	140	143	144	145	148	157	158	159	160	161
Pseudoblock	1	1	1	1	1	1	1	1	2	2	2	2	2
Treatment	B	B	B	B	B	B	B	B	B	B	B	B	C
Sidalcea nelsoniana													
cover (%)	2.0	2.5	0.3	15.0	12.0	5.5	5.0	7.0	6.0	17.0	6.0	5.0	3.0
No. flowering stalks	2.0	5.0	0.0	7.0	7.0	7.0	4.0	4.0	5.0	4.0	5.0	2.0	2.0
No. pistillate inflorescences	4.0	0.0	0.0	7.0	11.0	22.0	7.0	1.0	9.0	10.0	0.0	6.0	3.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	24.0	0.0	0.0
Total no. inflorescences	4.0	0.0	0.0	7.0	11.0	22.0	7.0	7.0	9.0	10.0	24.0	6.0	3.0
Inflorescence height (cm)	83.0	30.5	0.0	75.0	75.0	101.5	89.5	100.0	94.0	101.5	95.0	122.0	56.0
Herbaceous cover (%)													
below 40 cm	88.0	75.0	98.0	55.0	58.0	95.0	55.0	70.0	75.0	85.0	80.0	83.0	55.0
above 40 cm	50.0	40.0	20.0	33.0	22.0	83.0	45.0	16.0	30.0	65.0	55.0	65.0	20.0
Woody cover (%)													
below 40 cm	0.0	0.0	2.0	2.0	15.0	0.0	25.0	2.5	4.0	8.0	0.0	16.0	0.0
above 40 cm	0.0	0.0	3.0	0.0	28.0	0.0	30.0	2.5	7.5	12.0	0.0	12.0	0.0
canopy	16.0	2.0	10.0	8.0	0.0	1.0	11.0	2.0	0.0	6.0	0.0	9.0	0.0
Litter depth (cm)													
position a	5.5	2.5	2.5	0.5	0.0	5.0	2.0	2.0	5.0	3.0	7.0	7.0	2.5
position b	2.0	2.5	2.0	1.5	2.0	7.0	2.0	1.0	4.0	5.0	2.0	9.0	2.0
position c	6.0	3.0	0.5	2.5	6.0	8.0	3.5	4.0	6.0	6.0	6.0	10.0	5.0
Average litter depth (cm)	4.5	2.7	1.7	1.5	2.7	6.7	2.5	2.3	5.0	4.7	5.0	8.7	3.2
Grazing													
No. of stems grazed	0.0	5.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Dominant Species	Vic Agte Sta	Vic Agte	Vic	Vic Lope	Rudi Sta Vic	Vic Gal	Rula Vic Agte	Hola Gal	Vic Agex	Hela Vic Bro	Vic	Hela Vic Agte	Sta Agte

Appendix 2.5 (Continued)

Plot #	165	168	169	170	171	173	175	177	180	185	187	191	193
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Treatment	C	C	C	C	C	C	C	C	C	C	C	C	C
Sidalcea nelsoniana													
cover (%)	6.0	9.0	7.0	9.0	29.0	3.0	17.0	9.0	6.5	20.0	14.0	28.0	6.5
No. flowering stalks	1.0	1.0	2.0	3.0	13.0	2.0	19.0	3.0	6.0	7.0	4.0	15.0	2.0
No. pistillate inflorescences	0.0	6.0	2.0	31.0	64.0	2.0	18.0	4.0	5.0	0.0	30.0	78.0	2.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	22.0	0.0	0.0	0.0
Total no. inflorescences	0.0	6.0	2.0	31.0	78.0	2.0	18.0	4.0	5.0	22.0	30.0	78.0	2.0
Inflorescence height (cm)	33.0	105.0	88.5	106.5	122.5	51.5	84.0	65.5	93.5	96.5	119.0	132.0	75.0
Herbaceous cover (%)													
below 40 cm	87.0	40.0	38.0	55.0	50.0	77.0	33.0	30.0	12.5	25.0	65.0	82.0	91.0
above 40 cm	38.0	5.0	3.0	5.0	35.0	45.0	13.0	3.0	12.0	4.5	45.0	72.0	50.0
Woody cover (%)													
below 40 cm	20.0	25.0	20.0	6.5	2.0	0.0	18.0	35.0	35.0	43.0	16.0	1.0	0.0
above 40 cm	18.0	40.0	83.0	15.0	0.0	0.0	12.0	19.0	62.0	12.0	15.0	13.0	0.0
canopy	45.0	38.0	90.0	31.0	0.0	0.0	0.0	46.0	0.0	72.0	54.0	44.0	4.0
Litter depth (cm)													
position a	3.5	4.0	12.0	3.0	6.0	7.0	3.5	6.5	7.0	2.5	4.0	4.0	3.0
position b	5.0	7.0	0.5	2.5	6.0	8.0	8.0	5.5	10.0	3.0	6.0	6.0	2.5
position c	4.0	3.5	1.5	6.0	6.5	11.0	9.0	3.0	13.0	1.5	4.0	7.0	8.0
Average litter depth (cm)	4.2	4.8	4.7	3.8	6.2	8.7	6.8	5.0	10.0	2.3	4.7	5.7	4.5
Grazing													
No. of stems grazed	1.0	0.0	2.0	0.0	1.0	0.0	19.0	1.0	2.0	1.0	0.0	0.0	0.0
Dominant Species	Vic Syal Agte	Syal Fear	Rudi Fear	Fear Syal	Agex Vic	Vic Fear	Gal Ruur	Rudi Ruur	Ruur Syal	Ruur Sta	Vic Ruur Fear	Vic Agte	Fear Vic

Appendix 2.5 (Continued)

Plot #	194	196	199	204	205	207	209	210	211	214	218	221	223
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Treatment	C	C	C	C	C	C	C	C	C	C	C	C	C
Sidalcea nelsoniana													
cover (%)	25.0	8.0	12.0	0.0	7.0	0.8	6.0	6.5	10.5	9.0	6.0	9.0	8.0
No. flowering stalks	25.0	2.0	7.0	0.0	1.0	0.0	3.0	2.0	18.0	5.0	3.0	5.0	4.0
No. pistillate inflorescences	9.0	17.0	20.0	0.0	1.0	0.0	25.0	3.0	33.0	5.0	3.0	4.0	4.0
No. perfect inflorescences	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total no. inflorescences	59.0	17.0	20.0	0.0	1.0	0.0	25.0	3.0	33.0	5.0	3.0	4.0	4.0
Inflorescence height (cm)	137.5	137.0	88.0	0.0	69.0	0.0	86.5	63.0	96.0	89.0	84.0	56.5	97.0
Herbaceous cover (%)													
below 40 cm	33.0	75.0	55.0	65.0	77.0	65.0	83.0	80.0	81.0	75.0	70.0	65.0	58.0
above 40 cm	4.0	50.0	42.0	13.5	10.0	22.5	70.0	48.0	80.0	50.0	9.0	24.0	7.0
Woody cover (%)													
below 40 cm	13.0	14.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	2.5	2.0	0.0	24.0
above 40 cm	14.0	9.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	3.5	0.0	2.0	43.0
canopy	60.0	62.0	6.0	23.0	85.0	0.0	0.0	33.0	44.0	72.0	62.0	76.0	78.0
Litter depth (cm)													
position a	6.0	8.0	5.0	6.0	8.0	4.0	12.0	4.5	4.5	3.5	2.5	4.0	5.5
position b	0.0	6.0	5.0	1.5	2.5	5.5	6.0	8.0	2.5	5.0	3.0	4.0	6.0
position c	5.0	2.0	15.0	2.0	3.0	2.0	3.5	1.0	3.0	4.0	3.5	4.0	4.5
Average litter depth (cm)	3.7	5.3	8.3	3.2	4.5	3.8	7.2	4.5	3.3	4.2	3.0	4.0	5.3
Grazing													
No. of stems grazed	17.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
Dominant Species	Ruur	Vic	Fear	Fear	Agte	Fear	Vic	Vic	Vic	Agte	Agte	Fear	Rudi
	Agte	Hela	Hela	Agte	Hela	Agte	Fear	Fear	Fear			Hola	Agte
		Fear	Vic		Frla	Agex	Agte					Agte	

Appendix 2.5 (Continued)

Plot #	227	228	229	231	233	235	236	237	238	239	240	241	242
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Treatment	C	C	M	M	M	M	M	M	M	M	M	M	M
Sidalcea nelsoniana													
cover (%)	13.0	10.0	2.5	3.5	8.0	15.0	*na*	6.5	6.0	17.0	5.5	11.0	18.0
No. flowering stalks	3.0	9.0	2.0	4.0	4.0	9.0	*na*	4.0	7.0	7.0	3.0	5.0	14.0
No. pistillate inflorescences	10.0	14.0	2.0	5.0	7.0	19.0	*na*	5.0	0.0	68.0	0.0	16.0	67.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	0.0	0.0	*na*	0.0	12.0	0.0	0.0	0.0	0.0
Total no. inflorescences	10.0	14.0	2.0	5.0	7.0	19.0	*na*	5.0	12.0	68.0	0.0	16.0	67.0
Inflorescence height (cm)	80.5	118.0	78.0	81.5	89.0	95.0	*na*	65.0	81.0	128.0	45.0	122.0	96.0
Herbaceous cover (%)													
below 40 cm	60.0	83.0	95.0	83.0	90.0	90.0	*na*	82.0	86.0	73.0	82.0	75.0	70.0
above 40 cm	57.0	75.0	90.0	75.0	53.0	88.0	*na*	57.0	65.0	80.0	50.0	66.0	60.0
Woody cover (%)													
below 40 cm	1.0	20.0	0.0	4.0	0.0	0.0	*na*	2.0	2.5	0.0	0.0	0.0	0.0
above 40 cm	2.5	30.0	0.0	5.0	0.0	0.0	*na*	0.0	3.5	0.0	0.0	0.0	0.0
canopy	0.0	21.0	0.0	0.0	0.0	0.0	*na*	0.0	0.0	0.0	6.0	11.0	23.0
Litter depth (cm)													
position a	7.5	7.0	9.0	9.0	11.0	11.5	*na*	9.0	12.0	22.0	8.0	5.0	8.0
position b	15.0	8.0	7.0	12.0	12.0	14.0	*na*	11.0	10.0	13.0	3.0	12.0	6.0
position c	6.0	8.0	11.0	10.0	10.5	9.0	*na*	8.0	3.0	15.0	5.0	7.0	7.0
Average litter depth (cm)	9.5	7.7	9.0	10.3	11.2	11.5	*na*	9.3	8.3	16.7	5.3	8.0	7.0
Grazing													
No. of stems grazed	0.0	8.0	0.0	0.0	0.0	0.0	*na*	0.0	0.0	0.0	0.0	0.0	0.0
Dominant Species	Vic Hola	Vic Rudi	Vic Fear	Fear Vic	Fear	Fear Bro	*na*	Fear Vic	Vic Fear	Vic Fear	Vic Fear Agte	Vic Hela Fear	Vic Fear

Appendix 2.5 (Continued)

Plot #	244	245	246	248	249	250	251	252	253	254	255	257	259
Pseudoblock	2	2	2	2	2	2	2	2	2	2	2	2	2
Treatment	M	M	M	M	B	B	B	M	M	M	M	M	B
Sidalcea nelsoniana													
cover (%)	21.0	4.0	*na*	*na*	17.5	2.0	9.0	20.0	1.5	28.0	5.5	19.0	12.0
No. flowering stalks	23.0	1.0	*na*	*na*	11.0	1.0	9.0	8.0	4.0	15.0	4.0	12.0	7.0
No. pistillate inflorescences	29.0	10.0	*na*	*na*	46.0	3.0	17.0	83.0	1.0	32.0	0.0	0.0	43.0
No. perfect inflorescences	0.0	0.0	*na*	*na*	0.0	0.0	0.0	0.0	0.0	1.0	20.0	48.0	0.0
Total no. inflorescences	29.0	10.0	*na*	*na*	46.0	3.0	17.0	83.0	1.0	33.0	20.0	48.0	43.0
Inflorescence height (cm)	89.0	91.5	*na*	*na*	109.0	83.5	97.0	118.0	42.5	122.0	84.0	95.5	115.5
Herbaceous cover (%)													
below 40 cm	75.0	82.0	*na*	*na*	85.0	90.0	75.0	78.0	77.0	45.0	77.0	40.0	76.0
above 40 cm	55.0	16.5	*na*	*na*	80.0	87.0	93.0	78.0	25.0	70.0	60.0	15.0	85.0
Woody cover (%)													
below 40 cm	0.0	7.0	*na*	*na*	2.0	0.0	0.0	0.0	2.0	0.0	1.0	2.0	7.0
above 40 cm	0.0	27.0	*na*	*na*	27.0	0.0	0.0	0.0	2.5	0.0	1.5	2.5	4.0
canopy	0.0	0.0	*na*	*na*	12.0	23.0	41.0	0.0	0.0	0.0	0.0	1.0	0.0
Litter depth (cm)													
position a	10.0	4.5	*na*	*na*	5.5	9.0	8.0	6.5	6.0	3.0	7.0	5.0	2.0
position b	8.0	8.5	*na*	*na*	7.0	5.5	3.0	8.5	4.0	3.5	8.0	0.0	5.5
position c	6.5	7.5	*na*	*na*	6.0	3.0	6.0	6.0	5.0	5.0	9.0	7.0	2.5
Average litter depth (cm)	8.2	6.8	*na*	*na*	6.2	5.8	5.7	7.0	5.0	3.8	8.0	4.0	3.3
Grazing													
No. of stems grazed	0.0	0.0	*na*	*na*	0.0	0.0	1.0	2.0	3.0	6.0	0.0	2.0	0.0
Dominant Species	Fear Agte	Fear Rudi	*na*	*na*	Agte Hela Rudi	Vic Agte	Vic Phar	Agte	Agte	Hola Phar	Hola Ger Vic	Bro	Vic Hola

Appendix 2.5 (Continued)

Plot #	260	261	265	266	268	269	270	271	273	275	277	280	282
Pseudoblock	2	2	2	2	2	2	2	2	23	3	3	3	3
Treatment	B	B	B	B	B	B	C	C	M	M	C	B	C
Sidalcea nelsoniana													
cover (%)	13.0	8.5	0.3	5.5	*na*	5.0	7.0	13.0	3.5	8.0	14.0	4.0	2.5
No. flowering stalks	5.0	4.0	0.0	2.0	*na*	1.0	5.0	7.0	0.0	7.0	4.0	1.0	1.0
No. pistillate inflorescences	38.0	15.0	0.0	18.0	*na*	1.0	25.0	21.0	0.0	10.0	0.0	3.0	1.0
No. perfect inflorescences	0.0	0.0	0.0	0.0	*na*	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0
Total no. inflorescences	38.0	15.0	0.0	18.0	*na*	1.0	25.0	21.0	0.0	10.0	10.0	3.0	1.0
Inflorescence height (cm)	106.0	88.0	0.0	131.0	*na*	40.0	128.0	117.0	0.0	66.5	68.0	81.0	26.0
Herbaceous cover (%)													
below 40 cm	85.0	87.0	65.0	80.0	*na*	80.0	10.0	30.0	70.0	35.0	40.0	47.0	40.0
above 40 cm	82.0	72.5	80.0	87.0	*na*	88.0	1.0	3.0	55.0	75.0	7.0	20.0	30.0
Woody cover (%)													
below 40 cm	0.0	0.0	0.0	0.0	*na*	0.0	15.0	12.0	0.0	13.0	9.0	13.0	0.0
above 40 cm	0.0	8.0	0.0	0.0	*na*	0.0	72.0	55.0	0.0	13.0	40.0	35.0	0.0
canopy	0.0	26.0	0.0	15.0	*na*	10.0	62.0	79.0	3.0	0.0	0.0	0.0	0.0
Litter depth (cm)													
position a	5.0	2.0	2.5	9.0	*na*	3.0	14.0	4.0	1.0	1.0	3.0	3.0	12.0
position b	8.0	4.0	2.0	12.0	*na*	12.0	2.0	2.0	0.5	2.0	2.0	5.0	3.0
position c	6.5	0.5	5.0	6.0	*na*	11.0	3.0	1.0	5.0	3.0	5.0	6.0	6.0
Average litter depth (cm)	6.5	2.2	3.2	9.0	*na*	8.7	6.3	2.3	2.2	2.0	3.3	4.7	7.0
Grazing													
No. of stems grazed	0.0	0.0	0.0	0.0	*na*	0.0	1.0	0.0	0.0	3.0	0.0	0.0	0.0
Dominant Species	Fear Vic	Vic Hola Fear	Phar Vic	Phar Agte Voc	*na*	Vic Fear Hola	Ros	Syal	Phar Car Myo	Phar Ros	Car Ros	Ros Agte	Hola Pavi

Appendix 2.5 (Continued)

Plot #	292	297	315	317	330	336	338	342	348	356	361	401	403
Pseudoblock	3	3	3	3	3	3	3	3	3	3	3	3	3
Treatment	C	C	B	B	B	B	M	M	M	M	M	M	M
Sidalcea nelsoniana													
cover (%)	0.0	5.0	3.0	3.5	0.0	*na*	7.0	9.0	2.5	4.0	0.0	*na*	5.0
No. flowering stalks	0.0	1.0	0.0	2.0	0.0	*na*	3.0	2.0	2.0	0.0	0.0	*na*	0.0
No. pistillate inflorescences	0.0	0.0	0.0	1.0	0.0	*na*	0.0	6.0	0.0	0.0	0.0	*na*	0.0
No. perfect inflorescences	0.0	1.0	0.0	0.0	0.0	*na*	3.0	0.0	0.0	0.0	0.0	*na*	0.0
Total no. inflorescences	0.0	1.0	0.0	1.0	0.0	*na*	3.0	6.0	0.0	0.0	0.0	*na*	0.0
Inflorescence height (cm)	0.0	53.0	0.0	59.0	0.0	*na*	36.0	79.0	0.0	0.0	0.0	*na*	0.0
Herbaceous cover (%)													
below 40 cm	85.0	65.0	76.0	95.0	70.0	*na*	55.0	60.0	77.0	65.0	50.0	*na*	93.0
above 40 cm	18.0	33.0	57.0	70.0	25.0	*na*	11.0	33.5	28.0	45.0	3.5	*na*	35.0
Woody cover (%)													
below 40 cm	0.0	0.0	0.0	2.0	0.0	*na*	0.0	21.0	0.0	0.0	0.0	*na*	0.0
above 40 cm	0.0	0.0	2.0	15.0	0.0	*na*	0.0	0.0	0.0	0.0	0.0	*na*	4.0
canopy	67.0	0.0	15.0	0.0	0.0	*na*	0.0	0.0	0.0	0.0	0.0	*na*	0.0
Litter depth (cm)													
position a	1.0	6.0	5.0	1.0	5.0	*na*	7.0	6.0	2.0	8.0	1.0	*na*	1.0
position b	2.0	3.0	3.0	0.0	2.0	*na*	3.0	3.0	3.0	4.0	3.5	*na*	4.0
position c	3.0	4.0	0.0	6.0	4.0	*na*	3.0	5.0	2.0	9.0	6.0	*na*	2.5
Average litter depth (cm)	2.0	4.3	2.7	2.3	3.7	*na*	4.3	4.7	2.3	7.0	3.5	*na*	2.5
Grazing													
No. of stems grazed	0.0	0.0	0.0	0.0	0.0	*na*	0.0	0.0	2.0	0.0	0.0	*na*	0.0
Dominant Species	Car	Phaq	Vic	Vic	Jun	*na*	Phaq	Pavi	Agte	Jun	Pavi	*na*	Agte
		Pavi	Car	Car	Besy		Pavi	Phaq	Pavi	Phaq	Car		Car
								Agte	Jun	Vic			Myo

Appendix 2.5 (Continued)

Plot #	411	506	509	MEAN	ST DEV	MINIMUM	MAXIMUM
Pseudoblock	3	3	3				
Treatment	M	C	C				
Sidalcea nelsoniana							
cover (%)	16.0	7.5	15.0	8.6	6.4	0.0	29.0
No. flowering stalks	6.0	2.0	4.0	5.1	4.9	0.0	25.0
No. pistillate inflorescences	6.0	0.0	11.0	13.0	18.0	0.0	83.0
No. perfect inflorescences	0.0	4.0	0.0	2.3	7.8	0.0	50.0
Total no. inflorescences	6.0	4.0	11.0	15.4	18.6	0.0	83.0
Inflorescence height (cm)	95.5	53.0	90.0	78.6	35.7	0.0	137.5
Herbaceous cover (%)							
below 40 cm	65.0	82.0	55.0	69.0	19.5	10.0	98.0
above 40 cm	73.0	10.0	17.0	43.4	26.5	1.0	93.0
Woody cover (%)							
below 40 cm	0.0	0.0	0.0	5.5	9.0	0.0	43.0
above 40 cm	0.0	0.0	0.0	8.6	16.6	0.0	83.0
canopy	0.0	0.0	0.0	14.5	24.1	0.0	90.0
Litter depth (cm)							
position a	2.0	2.0	10.0	6.1	4.1	0.0	22.0
position b	2.0	4.0	3.0	6.0	4.3	0.0	18.0
position c	12.0	5.0	4.0	6.0	3.4	0.0	15.0
Average litter depth (cm)	5.3	3.7	5.7	6.0	3.3	1.2	17.0
Grazing							
No. of stems grazed	0.0	2.0	0.0	1.0	3.0	0.0	19.0
Dominant Species	Phar Myo	Elpa Myo	Car Phar				

Chapter 3: Response of *Sidalcea nelsoniana* to Experimentally Determined Flooding Regimes

Abstract

Wetland vegetation is often sensitive to site hydrology, so maintaining the proper flooding regime is a key component of wetland restoration and management projects. It is especially important to understand the hydrologic requirements of any rare species that may be present. *Sidalcea nelsoniana* is native to wetland prairies of the Willamette Valley, Oregon and is listed as threatened with extinction under the federal Endangered Species Act. Land use changes in the past 150 years have resulted in the loss of more than 99% of the habitat for *S. nelsoniana*, so its current distribution might not reflect its complete range of hydrologic tolerance. Moreover, recent proposals by land managers have suggested flooding some sites where *S. nelsoniana* is found for an additional six to eight weeks into the spring in order to improve wetland habitat. The purpose of this study was to evaluate the flooding tolerance of *S. nelsoniana* and to predict the effect of increased flooding duration on its performance. Rhizome fragments were collected from mature individuals and transplanted into 15-cm pots exposed to four artificially maintained flooding conditions: drained soil, saturated soil with no standing water, standing water from mid-November until mid-April, and standing water from mid-November through mid-June. Differences among treatments were most notable starting in April. Plants with drained soil did not survive as the spring rains declined and the soil dried. All plants flooded past April died by mid-June. Plants in saturated soils without standing water and those that were flooded until

mid-April were the most successful, and did not differ significantly in survival; number, height, and cover of leaves; and number and height of flowering stems. These two treatments most closely match conditions found in a nearby *S. nelsoniana* field site and in many other Willamette Valley wetland prairies. These results suggest that the current distribution of *S. nelsoniana* approximately matches its hydrologic tolerance and that extending the flooding regime of a *S. nelsoniana* site so that standing water remains beyond mid-April may be detrimental to populations of this protected species.

Introduction

With the rapid decline in wetland habitat that has occurred over the past 150 years in North America, restoration of degraded areas and proper management of existing habitat is critical to the preservation of this resource. Because hydrologic regime is an important determinant of wetland vegetation (Lippert and Jameson 1964, van der Valk 1981, Nelson and Anderson 1983, Moore and Keddy 1988, Welling et al. 1988, Trebino et al. 1996), a key part of the restoration and management of wetland prairie habitat is maintaining the proper water regime. Additionally, many rare plants in wetland habitats have specific hydrologic requirements (Harvey and Meredith 1981, Lesica 1992, Davis 1993). The objective of this study is to gain a better understanding of the hydrologic requirements of one protected rare plant by determining its tolerance to experimentally manipulated patterns of flooding.

Sidalcea nelsoniana Piper (Malvaceae) (Nelson's checker-mallow) is a perennial herb native to wetland prairies and streamsides of the Willamette Valley, Oregon and some adjacent areas of the Oregon Coast Range and Cowlitz County, Washington (U.S. Fish and Wildlife Service 1993). Land use changes over the past 150 years have altered or obliterated more than 99% of wetland prairie habitat in the Willamette Valley and limit the current distribution of *S. nelsoniana* to just 64 sites, many with fewer than 100 individuals (U.S. Fish and Wildlife Service 1998). Although the historic distribution of *S. nelsoniana* is poorly known, such dramatic habitat loss suggests that the current distribution may not indicate its complete range of hydrologic tolerance. Remaining populations are often threatened by encroachment of woody species, road management activities, and continuing agricultural and commercial development (U.S. Fish and Wildlife Service 1993). Because of its limited distribution and declining habitat, *S. nelsoniana* is listed under the federal Endangered Species Act as threatened with extinction (U.S. Fish and Wildlife Service 1993). *S. nelsoniana* is also listed as threatened by the State of Oregon (State of Oregon 1995)

One of the largest populations of *S. nelsoniana* occurs at William L. Finley National Wildlife Refuge near Corvallis, Oregon. Within the refuge, many of the sites in which *S. nelsoniana* are found have been altered by past agricultural practices, leading to proposals to improve wetland habitat by increasing flooding duration for an additional six to eight weeks into the spring and early summer. Ideally, this management strategy would also have beneficial results for over-wintering waterfowl.

Unfortunately, little is known about the hydrologic tolerance of *S. nelsoniana* or how extended inundation would affect this species.

This experimental study was designed to evaluate the flooding tolerance of *S. nelsoniana* and to predict the effect of increased flooding duration on the performance of *S. nelsoniana* grown from rhizome fragments. Treatments were designed to represent a range of hydrologic conditions and included well-drained soil, saturated soil with no standing water, flooded until mid-April, and flooded until mid-June. Treatments were applied within a small plastic wading pool, as described below.

This study tested two sets of hypotheses. The first set concerns shoot emergence and survival.

H_0: Flooding regime has no effect on the emergence of *S. nelsoniana* shoots from rhizomes or on the survival of emerged shoots.

H_{A1}: Increased duration of flooding will cause the rhizomes to rot, thus decreasing the number of *S. nelsoniana* shoots that emerge or survive.

H_{A2}: Increased duration of flooding will increase the number of *S. nelsoniana* shoots that emerge and/or survive because the emergence phase will be shifted to later in the season when temperatures are warmer.

A decrease in the number of surviving shoots in the flooded treatments along with signs of rotting in flooded rhizomes would support H_{A1}. An increase in the number of surviving shoots with increased duration of flooding would support H_{A2}.

The second set of hypotheses addresses *S. nelsoniana* performance, as measured by maximum leaf height, number of emerged leaves, final leaf area, and number and height of flowering stems.

H_0: Flooding regime has no effect on *S. nelsoniana* performance.

H_{A1}: Increased duration of flooding will lead to increased *S. nelsoniana* performance because the growing season will be shifted to a warmer, more productive time of year.

H_{A2}: Increased duration of flooding will lead to decreased *S. nelsoniana* performance because plants will be released from flooding later, become established later, and therefore have a shorter growing season.

H_{A3}: Increased duration of flooding will lead to decreased *S. nelsoniana* performance because plants will be released from flooding when spring rains have decreased and therefore will be limited by water availability, or because increased flooding will rot rhizomes.

Increased performance (i.e. more leaves, taller plants) combined with later emergence in treatments with increased duration of flooding would suggest that growing conditions are more favorable and thus support H_{A1}. A similar trend in performance among all treatments but delayed with longer flooding would suggest that performance is decreased because shoots experience a shorter growing season (H_{A2}). Decreased performance in individuals released from flooding later would indicate that growing conditions are less favorable, possibly limited by water availability (H_{A3}).

Methods

Study species

Sidalcea nelsoniana is a gynodioecious species that can propagate from either rhizomes or seeds. Reproductive individuals have 30 to 100 cm tall flowering stalks terminating in spikelike inflorescences of pinkish-lavender to pinkish-purple flowers (U.S. Fish and Wildlife Service 1993). Peak flowering occurs mid-June through mid-July in the Willamette Valley, with fruits maturing in late July and early August. *S. nelsoniana* is most often found in wetland prairies, ash swales, streamsides, and roadside ditches. Associated vegetation includes graminoids such as *Festuca arundinacea*, *Phalaris arundinacea*, *Agrostis* spp., and *Carex* spp.; weedy forbs such as *Heracleum lanatum* and *Vicia* spp.; and woody species such as *Rosa* spp., *Rubus* spp., and *Fraxinus latifolia* (U.S. Fish and Wildlife Service 1993, personal observation, nomenclature follows Hitchcock and Cronquist 1973). Adjacent vegetation typically senesces between late August and mid-September (personal observation).

Study site

The study was located approximately 500 m from a large *S. nelsoniana* field population at William L. Finley National Wildlife Refuge (NWR), 16 km south of Corvallis, Oregon, USA. This location was chosen to closely simulate natural growing conditions of temperature, photoperiod, and precipitation. The region experiences a modified maritime climate, with warm dry summers and cool wet winters. Average annual precipitation as recorded in Corvallis is 108.5 cm, with 93.0 cm occurring October through April. Mean temperature ranges from a minimum of 0.6 C in January to a maximum of 26.8 C in July (Oregon Climate Service).

Experimental design

During the flowering season of 1998, *S. nelsoniana* individuals from two populations were marked for possible collection. During October 1998, rhizome fragments were collected from 12 of these marked individuals, with each individual often yielding several rhizome fragments. Rhizome fragments were used as the propagules in this experiment because of their success in other transplant experiments (Anonymous 1986, 1987) and because they are more likely to simulate the response of mature individuals. Eighteen fragments were collected from six plants along McFarland Road at the southern border of Finley NWR. Twenty-two fragments were collected from six plants at the Oregon State University Poultry Farm along Harrison Blvd. in Corvallis, OR.

Rhizomes were given a unique identification code and weighed before transplanting. Fragments weighed between 1.7 and 37.1 g with a mean of 5.8 g. Fragments larger than 7.5 g were cut into smaller pieces and re-weighed. Each rhizome fragment was transplanted into a 15-cm pot filled with 10 cm of native wetland soil similar to that found at many *S. nelsoniana* sites (a silty clay loam collected from Cattail Dike at Finley NWR). Rhizomes were planted at a depth of 2-3 cm below the soil surface. Transplanted rhizomes were stored in a temperature-controlled greenhouse for up to two weeks before experimental conditions were applied. Of those fragments weighing between 3.0 and 7.0 g, sixteen from each of the two populations were randomly selected for use in the experimental study, for a total of 32 experimental units.

Within each of the two populations, each potted rhizome fragment was randomly assigned to one of the four flooding treatments, yielding eight replicates of each treatment. Pots were transported to Finley NWR on November 10, 1998 and randomly arranged within a 122 cm diameter by 30 cm deep plastic wading pool. Treatments were applied as follows:

- Drained (*Dr*): pots elevated above the surface of the water on concrete blocks.
- Saturated Soil (*SS*): pots placed on concrete blocks so that the water level was approximately at the soil surface from November 20 through April 15. After April 15, the pots were elevated above the water surface and allowed to drain.
- Flooded until April (*FA*): pots placed on the bottom of the pool until April 15, 1999 and then elevated above the water surface on concrete blocks.
- Flooded until June (*FJ*): pots placed on the bottom of the pool until June 23, 1999 and then elevated above the water surface on concrete blocks.

To maintain a relatively constant water level, the pool was filled with water so that excess precipitation flowed over the edge. Unfortunately, the lack of a water source nearby confounded the practicality of flushing the water in the system on a regular basis. Although algal and microbial growth may have affected the condition of the flooded plants, the use of an algicide in the water may have had other unknown effects on *S. nelsoniana*. The pool was monitored throughout the winter and there was no sign of harm due to excess algal or microbial growth.

Pots were weeded and rotated 90 degrees at each measurement interval. Pots were randomly re-arranged within the pool on April 15 and June 23, 1999. All pots were top watered every two weeks between June 10 and July 14, 1999.

Measurements

Every two to four weeks from November 10, 1998 through July 14, 1999 the number of emerged leaves and the height of the tallest leaf was recorded for each pot. All basal and cauline leaves were included in the leaf count. Leaf height was measured to the junction of the blade and the petiole on the tallest fully emerged leaf (including cauline leaves). Survival was recorded as the persistence of green leaves above the soil surface. Number and height of flowering stems were also recorded when present. Absolute leaf area cover was estimated for each surviving individual on July 14, 1999 using templates of known size.

Statistical analysis

Performance characteristics as recorded on July 13-14, 1999 were analyzed using a multi-factor analysis of variance (ANOVA) in the statistical software program Statgraphics Plus for Windows 4.0 (Statistical Graphics Corp. 1994-1999). A separate ANOVA was performed for each of the growth characteristics measured (leaf height, number of leaves, leaf area cover, stem height and number of stems). Main effects included treatment and source population (McFarland Rd. or OSU Poultry Farm).

Height and number of leaves as recorded before treatments were applied (November 10, 1998) were used as covariates in their respective analyses. Rhizome weight was used as a covariate in the analyses of leaf area cover and flowering characteristics. Rhizome fragments that did not emerge over the course of the study were assumed to be statistically non-variable and were excluded from the analyses.

Results

<u>Survival</u>

When potted rhizomes were transported to the experimental pool on November 10, 1998, basal leaves had emerged in all but five pots. By November 17, 1998 leaves had emerged from seven out of eight rhizome fragments in each of the *FJ* and *FA* treatments and from all eight in the *Dr* and *SS* treatments. The two rhizome fragments that had not emerged by this time remained dormant for the duration of the study, and thus were deleted from the analyses. Survival remained constant through the winter for the *FA*, *FJ*, and *SS* treatments but declined slightly for the *Dr* treatment (Figure 3.1a). By mid-May, there were no surviving individuals in the *Dr* treatment. Survival in the *FJ* treatment declined sharply after mid-May, with only one individual surviving on June 10 and no surviving individuals by June 23. Survival in the *FA* treatment held steady at seven individuals until mid-April and then declined to six individuals for the duration of the study. All eight *SS* individuals survived for the duration of the experiment.

Figure 3.1 Performance of *Sidalcea nelsoniana* rhizome fragments exposed to altered flooding regimes. Arrows indicate when *FA* treatment was released from flooding. a) Survival as a proportion of maximum number emerged. b) Average maximum leaf height of surviving individuals. c) Average number of emerged leaves per surviving individual.

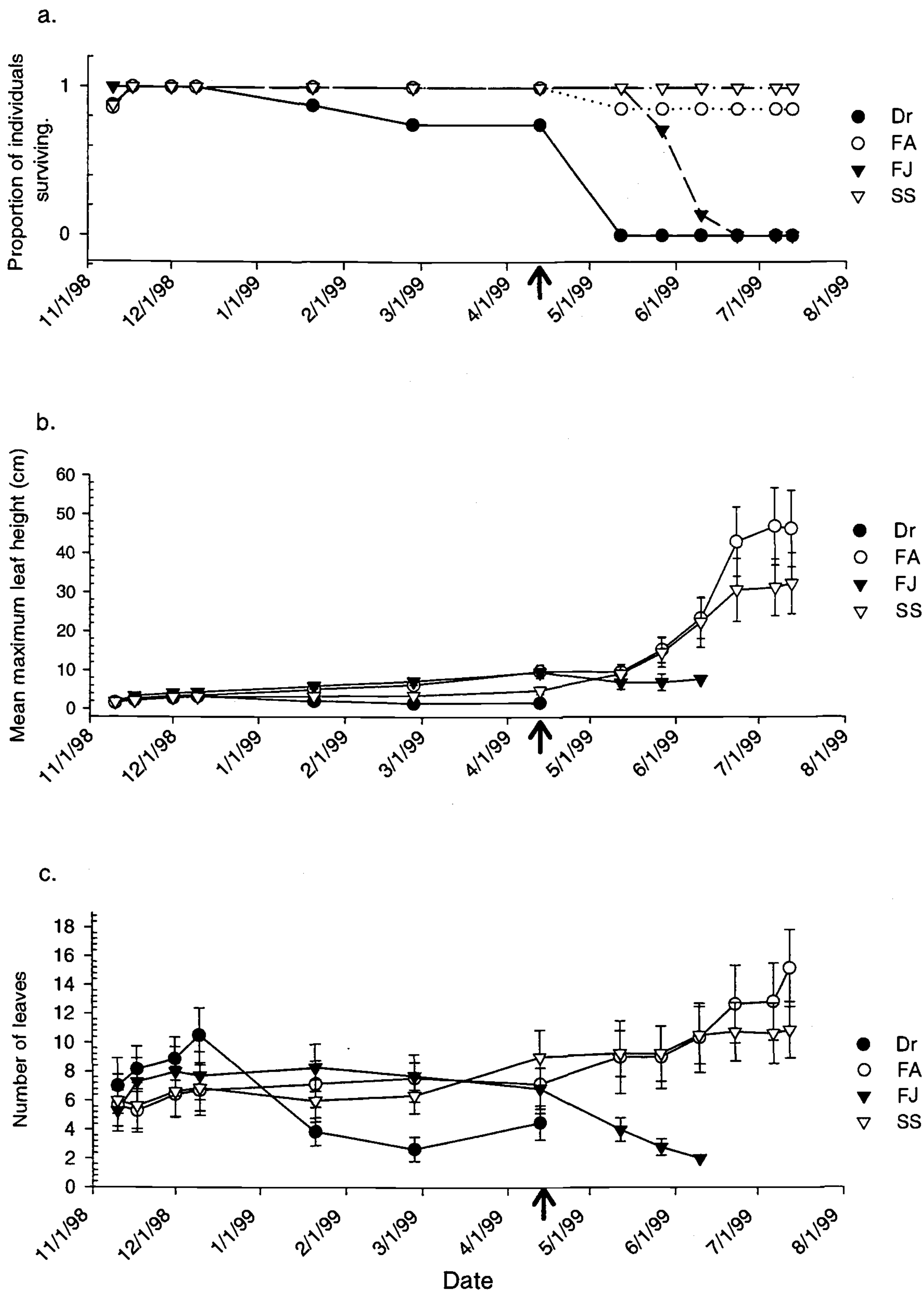

a.
Proportion of individuals surviving.
1
0
11/1/98
12/1/98
1/1/99
2/1/99
3/1/99
4/1/99
5/1/99
6/1/99
7/1/99
8/1/99
Dr
FA
FJ
SS
b.
Mean maximum leaf height (cm)
60
50
40
30
20
10
0
c.
Number of leaves
18
16
14
12
10
8
6
4
2
0
Date

Figure 3.1

Leaf height

Average maximum leaf height of surviving individuals increased gradually from November to mid-April for the *FJ*, *FA* and *SS* treatments (Figure 3.1b). The *FA* and *FJ* treatment means were similar and followed a similar trajectory until mid-April, while the *SS* treatment increased at a slightly slower rate. The *SS* treatment increased in height rapidly after mid-April. The mean maximum height of the *FA* treatment showed little change immediately after being released from flooding on April 15, but increased rapidly from mid-May through the rest of the experiment, following a similar trajectory as the *SS* treatment. The *FJ* treatment mean declined slightly after mid-April and then remained steady until no surviving individuals remained. The mean height of the *Dr* treatment reached a maximum of 3.2 cm in December and then declined for the remainder of the study.

The final mean leaf height of surviving individuals as recorded on July 13, 1999 after accounting for source population and height on November 10 (before treatment) was 31.0 ± 1.5 cm for the *SS* treatment and 43.2 ± 1.6 cm for the *FA* treatment. All individuals in the *FJ* and *Dr* treatments had died. There was not a significant difference between the *SS* and *FA* treatments ($p = 0.11$, Table 3.1).

Number of leaves

Average number of leaves on surviving individuals remained similar throughout the winter among the *FA*, *FJ*, and *SS* treatments. The average number of leaves in the *Dr* treatment declined sharply between mid-December and mid-January

Table 3.1 Analysis of Variance for maximum leaf height as recorded on July 13, 1999 for individuals in the *SS* and *FA* treatments. [1] F-ratio based on Treatment × Population mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	1	536.0	32.0 [1]	0.111
Population	1	882.3	2.1 [2]	0.181
Pre-treatment height	1	2590.0	6.1 [2]	0.033
Treatment × Population	1	16.8	0.1 [2]	0.847
Residual	10	426.6		
Total	14			

R^2 = 48.8 %

R^2 (adjusted for d.f.) = 28.4 %

Table 3.2 Analysis of Variance for number of leaves as recorded on July 13, 1999 for individuals in the *SS* and *FA* treatments. [1] F-ratio based on Treatment × Population mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	1	12.6	1.1 [1]	0.485
Population	1	55.9	1.7 [2]	0.218
Pre-treatment no. of leaves	1	230.9	7.1 [2]	0.024
Treatment × Population	1	11.5	0.4 [2]	0.565
Residual	10	32.4		
Total	14			

R^2 = 49.5 %

R^2 (adjusted for d.f.) = 29.3 %

and remained lower than the other three treatments until there were no longer any surviving individuals (Figure 3.1c).

The number of leaves continued to increase gradually in both the *FA* and *SS* treatments after mid-April when *FA* plants were elevated above the surface of the water. The number of leaves declined steadily in the *FJ* treatment after mid-April (Figure 3.1c). The final mean number of leaves per surviving individual as recorded on July 13, 1999 after accounting for source population and the number of leaves on November 10 (before treatment) was 13.0 ± 1.3 for the *FA* treatment and 11.2 ± 1.2 for the *SS* treatment. There was not a significant difference between the *FA* and *SS* treatments ($p = 0.49$, Table 3.2).

Leaf area cover

Average final leaf area cover after accounting for source population and initial rhizome weight was 92.5 ± 20.9 cm^2 for surviving plants in the *FA* treatment and 61.0 ± 17.0 cm^2 for surviving plants in the *SS* treatment. The two treatments were not significantly different from each other ($p = 0.45$, Table 3.3).

Flowering intensity

Only those individuals in the *SS* and *FA* treatments produced flowering stems. Flowering stems first appeared between the May 11 and May 27, 1999 sampling dates. No new stems were produced after the June 23 sampling date. Out of six surviving individuals in the *FA* treatment, five produced flowering stems. Five out of eight individuals produced flowering stems in the *SS* treatment. The number of stems

Table 3.3 Analysis of Variance for leaf area cover as recorded on July 13, 1999 for surviving individuals in the *SS* and *FA* treatments. [1] F-ratio based on Treatment × Population mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	1	3114.0	1.4 [1]	0.452
Population	1	896.3	0.7 [2]	0.439
Initial rhizome weight	1	3574.2	2.6 [2]	0.140
Treatment × Population	1	2299.1	1.7 [2]	0.227
Residual	9	1364.4		
Total	13			

R^2 = 41.6 %

R^2 (adjusted for d.f.) = 15.7 %

Table 3.4 Analysis of Variance for number of stems as recorded on July 13, 1999 for surviving individuals in the *SS* and *FA* treatments. [1] F-ratio based on Treatment × Population mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio	p
Treatment	1	0.5	0.9 [1]	0.519
Population	1	0.4	0.7 [2]	0.425
Pre-treatment no. of leaves	1	2.6	4.2 [2]	0.070
Treatment × Population	1	0.5	0.9 [2]	0.379
Residual	9	0.6		
Total	13			

R^2 = 45.6 %

R^2 (adjusted for d.f.) = 21.4 %

produced per individual after accounting for source population, size before treatment application (number of leaves on November 10), and any treatment by population interaction was 1.2 ± 0.3 in the *FA* treatment and 0.8 ± 0.3 in the *SS* treatment. The two treatments were not significantly different from each other (p = 0.52, Table 3.4).

Of those plants that produced stems, the average heights were 69.2 ± 10.1 cm for the *FA* treatment and 59.4 ± 11.9 cm for the *SS* treatment, after accounting for source population, initial size (number of leaves on November 10), and any treatment by population interaction. There was no difference in flowering stem height between the two treatments (p = 0.65, Table 3.5).

Discussion

Evaluation of hypotheses

Survival and emergence of shoots from rhizomes. Because shoots had emerged from all rhizomes (except the two that never produced shoots) within one week of applying the experimental treatments, the flooding regime did not act upon the emergence of *S. nelsoniana* shoots from rhizomes. However, survival of these emerged shoots was affected by flooding regime, with high survival of plants in the *FA* and *SS* treatments, and no survival to the end of the study for plants in the *Dr* and *FJ* treatments. Decreased survival in the *FJ* treatment supports the hypothesis that increased flooding duration beyond mid-April will lead to decreased survival of *S. nelsoniana*. In addition, decreased survival in the *Dr* treatment suggests that

Table 3.5 Analysis of Variance for flowering stem height as recorded on July 13, 1999 for surviving individuals in the *SS* and *FA* treatments. [1] F-ratio based on Treatment × Population mean square. [2] F-ratio based on residual mean square.

Source	df	Mean Square	F-ratio		p
Treatment	1	184.4	0.4	1	0.485
Population	1	419.4	2.8	2	0.218
Pre-treatment no. of leaves	1	571.3	3.8	2	0.024
Treatment × Population	1	487.6	3.2	2	0.565
Residual	9	151.2			
Total	13				

R^2 = 73.8 %

R^2 (adjusted for d.f.) = 52.9 %

S. nelsoniana will not survive periods of extreme drought during the early growing season. Because these treatments represent opposite extremes of the flooding regime, the patterns are likely due to different mechanisms, discussed below.

Performance. Flooding regime also affected *S. nelsoniana* performance. While much of this difference was due to differences in survival (the *FA* and *SS* plants survived, while the *Dr* and *FJ* plants did not), there were subtle differences in leaf height and number of leaves among treatments prior to the rapid decreases in survival of the *FJ* and *Dr* treatments. In mid-April, for example, leaf height was slightly greater for those plants in the *FA* and *FJ* treatments than for those in the *SS* and *Dr* treatments. This suggests that flooding may have stimulated petiole elongation, as in some other flood tolerant species (Blom et al. 1990).

Once released from flooding, the *FA* individuals rapidly increased in height, while the height of those plants that remained flooded (*FJ*) did not change. The number of leaves per surviving individual also decreased in the *FJ* treatment after mid-April, while the number of leaves in the *FA* and *SS* treatments gradually increased. These trends, combined with decreased survival in the *FJ* treatment support the hypothesis that increasing the flooding duration until mid-June will lead to poorer *S. nelsoniana* performance.

Mechanisms

Decreased survivorship and performance in the Dr *treatment.* The slight decline in survivorship and sharp decline in number of leaves that occurred during the early winter months in the *Dr* treatment was likely due to an unusually cold weather system that affected the Pacific Northwest between December 19 and 25, 1998. Temperatures remained below freezing for 96 hours (Oregon Climate Service 1998) and a layer of ice formed at the surface of the pool. While the pots in the *FA*, *FJ*, and even the *SS* treatments were insulated to some degree by the surrounding water, the elevated plants in the *Dr* treatment were exposed to the cold air.

Those individuals that survived through the cold spell persisted into spring, and even showed a slight increase in number of leaves between late February and mid-April. However, survivorship decreased sharply in April, apparently due to drought as natural precipitation declined. The effects of extreme temperatures and drought on these experimental plants may not be indicative of field conditions since plants growing in the field would be surrounded by a greater volume of soil, which would increase both insulation from extreme temperatures and water holding capacity. Had the plants in the pots been watered regularly throughout the spring, they may have survived.

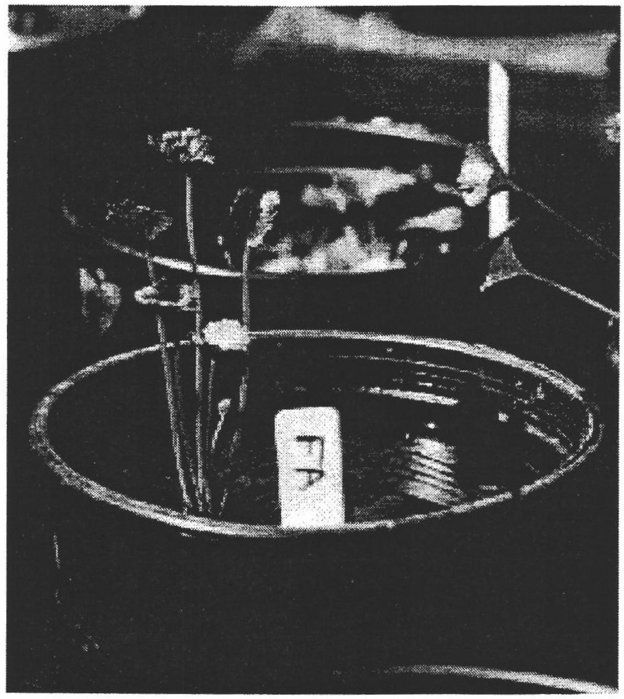
Decreased survivorship and performance in the FJ *treatment.* While the decrease in survival of the *FJ* individuals during May could be a result of rotting rhizomes, as the hypotheses suggest, there may also be a physiological mechanism that is sufficient to allow the plants to survive inundation until April, but not later into the spring. Blom et al. (1990) explored one such mechanism in several *Rumex* species. In those species that were "flood tolerant," flooding actually stimulated petiole and stem elongation. Plants were more likely to survive prolonged and deep inundation if their leaves protruded above the water surface.

Pronounced differences in leaf morphology between flooded and non-flooded plants in this study suggest that a similar mechanism may be present in *S. nelsoniana*. In mid-April, the leaf blades of the *FA* and *FJ* individuals were relatively small and had long petioles, placing the leaves at or just below the surface of the water (Figure 3.2a). In contrast, the leaf blades of the *SS* individuals were larger and had shorter petioles (Figure 3.2b). Four weeks after they were released from flooding, the *FA* leaf morphology more closely resembled the broader leaf blades of the *SS* individuals, while the leaf blades of the surviving *FJ* individuals remained small with long petioles. The rapid decline in survival of the *FJ* individuals after mid-April suggests that petiole elongation is not sufficient to allow *S. nelsoniana* individuals to withstand inundation into mid-June.

Slightly better performance in the FA *treatment (compared to* SS*).* Although the *FA* and *SS* treatments did not result in statistically significant differences in mean maximum leaf height or number of emerged leaves, the *FA* treatment performed slightly better than the *SS* treatment in both cases (Figures 1b and 1c). This suggests that *S. nelsoniana* individuals may not only tolerate but perhaps even benefit from a certain amount of flooding and that flooding is only harmful if it persists into late spring.

Ecological and management implications

The performance of *S. nelsoniana* under the experimental flooding conditions of this study suggests that the current distribution of *S. nelsoniana* does approximately represent its range of hydrologic tolerance and that there is a limit to how much a)



b)

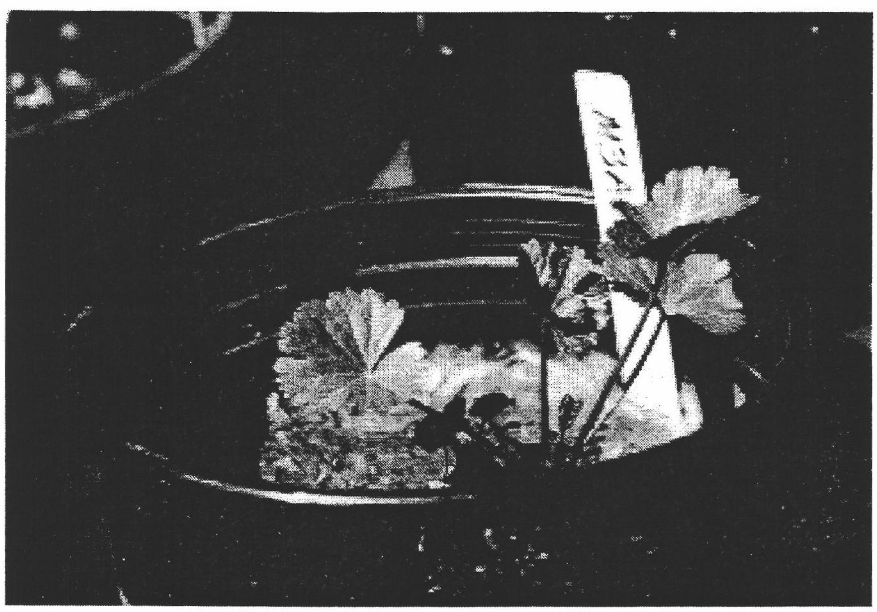


Figure 3.2 Leaf morphology of *SS* and *FA* individuals on April 15, 1999. After being under 10 cm of water through the winter, the leaf blades of the *FA* individuals were small with long petioles (a). In contrast, those plants that were not under water (*SS* treatment) had larger leaf blades and shorter petioles (b).

flooding this wetland prairie species can tolerate. Survivorship and performance were greatest in the *SS* and *FA* treatments, both conditions that exist naturally at many *S. nelsoniana* sites. For example, portions of a nearby *S. nelsoniana* site remained under shallow water from November through April, while other areas of the same site had wet soils but no standing water at any time throughout the winter (personal observation). These treatments also most closely resemble the seasonal moisture patterns typical in the Willamette Valley. Winter rains and clay soils result in standing water and high water tables throughout the winter months in wetland prairie areas. As precipitation decreases in the spring, these sites dry out and little or no standing water remains during the late spring and summer months (Finley 1995).

In contrast, it is not known whether the flooding regime represented by the *FJ* treatment existed historically in *S. nelsoniana* sites. However, the rapid decline in survivorship and growth between April and June for plants that remained flooded suggests that sites which remained flooded into late spring would be unsuitable for *S. nelsoniana*.

While *S. nelsoniana* individuals may be able to survive a certain amount of inundation, changing the flooding regime of a site can alter the entire plant community at that site (Harris and Marshall 1963, van der Valk 1981, Nelson and Anderson 1983, Moore and Keddy 1988). This may affect *S. nelsoniana* indirectly by intensifying the competitive interactions with associated species. For example, increased inundation could increase the likelihood or severity of encroachment by *Phalaris arundinacea* (reed canary grass), a persistent problem with prolonged flooding in wetland prairies.

Although there are obvious differences between this experimental study and conditions of potential field sites for *S. nelsoniana*, these results suggest that the current distribution of *S. nelsoniana* does approximate its natural hydrologic tolerance and that inundating a *S. nelsoniana* site into June may be detrimental to this listed species. Therefore, extreme caution should be exercised when managing for high water levels past mid-spring, the historical end of the flooding season in the Willamette Valley.

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Chapter 4: Conclusions and Management Recommendations

Active habitat management, combined with an understanding of the environmental requirements and ecological relationships of target species, can be a valuable tool in the preservation of native ecosystems and the conservation of rare species. The two studies presented in this thesis increase the understanding of the ecology of *Sidalcea nelsoniana* Piper (Malvaceae), a federally threatened species, by providing new information about its habitat tolerances and suggesting directions for future habitat management efforts targeted at conserving this rare species.

Prescribed fire and mowing are common management practices in many prairie areas, including those in the Willamette Valley, Oregon. These tools can be effective at reducing woody species and promoting native species (Clark and Wilson 1996, Wilson and Clark 1997). Although burning and mowing did not significantly affect the performance of *S. nelsoniana* in the first year following manipulations, the treatments were effective at reducing canopy cover, a desired goal for prairie restoration and management.

While the treatments reduced woody canopy cover, burning and mowing actually promoted the surrounding herbaceous vegetation. This increased competition may have limited *S. nelsoniana* performance in the burned and mowed areas. Therefore, any beneficial effect of reduced shading (from reduced canopy cover) could have been offset by increased competitive pressure from the surrounding vegetation.

It is not surprising that neither prescribed fire nor mowing had any significant effect on the performance of *S. nelsoniana* during the first year after treatments, since experimental habitat manipulations often do not produce strong patterns until several years following treatment applications (Wilson and Clark, in prep.). Since the characteristics of the surrounding vegetation before manipulations explained much of the variation in *S. nelsoniana* performance during the following year, it seems likely that the vegetation as altered by the manipulations may be very important in influencing the performance of *S. nelsoniana* in future years.

Survival was high across all treatments and neither burning nor mowing significantly harmed the growth or reproduction of this species. Therefore, future treatment applications are unlikely to be harmful and treatments should be repeated as necessary to control woody species. However, if the treatments continue to increase the surrounding herbaceous vegetation, additional management may be required to specifically address this issue and limit the adverse effects of competition on *S. nelsoniana*. New research may be needed to determine the most effective strategy for achieving this goal. Because it may take several years for patterns to emerge, long term monitoring of the performance of *S. nelsoniana* and the surrounding vegetation at this site should be a top priority.

Since wetland vegetation is often sensitive to changes in hydrology, management efforts at this and other *S. nelsoniana* sites must also focus on maintaining the proper water regime. *S. nelsoniana* individuals grown from rhizome fragments were most successful in the experimental conditions of saturated soil with no standing water and under standing water until mid-April. These flooding conditions most closely match the range of field conditions and seasonal moisture patterns found in many Willamette Valley wetland prairies and *S. nelsoniana* sites. This suggests that the current distribution of *S. nelsoniana* approximately represents its range of hydrologic tolerance.

Individuals that were flooded past mid-April had died by mid-June. These results suggest that this species does not possess the adaptations necessary to survive prolonged inundation into the spring growing season. Flooding a *S. nelsoniana* site beyond mid-April may be harmful to this protected species and should be avoided. In addition, changing the flooding regime of a site can alter the entire plant community (Harris and Marshall 1963, van der Valk 1981, Nelson and Anderson 1983, Moore and Keddy 1988) and possibly intensify competitive interactions among species. Extreme caution should be exercised when altering the hydrology of existing and proposed *S. nelsoniana* sites, and water levels should be maintained within the range of conditions currently found in Willamette Valley wetland prairies.

These studies demonstrate the importance of understanding the ecological requirements and tolerances of target species in any conservation effort. While burning and mowing are often effective management tools for maintaining open prairie habitat, their effects on non-woody species may be less clear, especially during the first year after treatments. For this reason, careful long term monitoring is crucial in any habitat management program. Finally, while extended inundation may have beneficial results for other wetland flora and fauna, certain rare species have specific hydrologic requirements and may be adversely affected by such management practices.

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