Tara Goldsmith Zimmerman[1] and **Sarah Hayden Reichard**[2], University of Washington, College of Forest Resources, University of Washington Botanic Gardens, Box 354115, Seattle, Washington 98195

Factors Affecting Persistence of Wenatchee Mountains Checker-Mallow: An Exploratory Look at a Rare Endemic

Abstract

Loss of suitable habitat has historically been the primary threat to Wenatchee Mountains checker-mallow (*Sidalcea oregana* var. *calva*), a narrow endemic of Chelan County, Washington. The largest population of this federally listed endangered species is now protected from loss by Natural Area Preserve status, yet the survival of the plant is still in jeopardy. Possible threats to population growth and persistence include seed predation by weevils, succession in meadow habitats due to fire suppression, and loss of pollinator populations. This two-year exploratory study examined these threats in an effort to determine their relative impacts on the species and to guide future study. *Macrorhoptus sidalceae*, a *Sidalcea* specialist insect was identified as a primary seed predator. Seed predation by this weevil was severe; only 17% of seeds examined escaped weevil predation across all study sites. Few significant differences were found in prescribed burn experiments designed to determine effects of fire on checker-mallow individuals and on the surrounding herbaceous community. This may indicate that the species is not detrimentally affected by fire, and that prescribed fire may be a valuable management tool for habitat conservation. A second *Sidalcea* specialist insect, the bee *Diadasia nigrifrons*, was observed to be a consistent flower visitor and possibly important pollinator of the checker-mallow. These results have implications for future study and management of both the checker-mallow and other endangered species, because it is common for an imperiled species to be threatened by numerous impacts that must all be considered simultaneously for population maintenance.

Introduction

Loss of habitat is the greatest threat to biodiversity nationally and worldwide (Wilcove et al. 1998). Efforts have been made to halt species loss by conserving habitat in parks and preserves, as well as through protection of individual species under the Federal Endangered Species Act of 1973, but losses continue. Wenatchee Mountains checker-mallow, *Sidalcea oregana* var. *calva*, (hereafter referred to as WM checker-mallow), was added to the Federal Endangered Species List in December 1999. It is a herbaceous perennial narrowly endemic to the Wenatchee Mountains of Chelan County, Washington. Only five populations of this checker-mallow remain, three of which are very small. Habitat loss, degradation, and fragmentation historically have threatened the survival of WM checker-mallow (Washington Department of Natural Resources [WDNR] 2000). The largest population is now in a protected Natural Area Preserve which alleviates the historic threat of development, but new and continued threats to the plant including seed predation, meadow succession due to fire suppression, and loss of pollinators have been identified (WDNR 2000).

Seed predation has been shown to have substantial to severe effects on reproductive output in some rare species throughout the world (Menges et al. 1986, Hegazy and Eesa 1991, Windus and Snow 1993, Kaye 1999). Within the Malvaceae, and *Sidalcea* specifically, high levels of seed predation are not uncommon and may pose a threat to population growth (Dimling 1992, Gisler and Meinke 1997, Marshall and Ganders 2001). High levels of insect infestation and seed damage in WM checker-mallow fruit capsules have been repeatedly noted (Gamon 1987, WDNR 2000, Huseby 2000), but the extent of this infestation has not been quantified. The objectives of this portion of the investigation were to positively identify the seed predator and quantify the damage inflicted on WM checker-mallow seeds.

Frequent, low-intensity, late-season burns were the historic fire regime for the ponderosa pine (*Pinus ponderosa*)/Douglas-fir (*Pseudotsuga menziesii*) forests where WM checker-mallow is found (Agee 1993). Decades of fire suppression have resulted in trees and shrubs which compete with WM checker-mallow for light, water, and space encroaching on meadow habitats and forest openings. The effects

[1]Current address: Washington State University King County Extension, 919 SW Grady Way Ste 120, Renton, WA 98055

[2]Author to whom correspondence should be addressed. E-mail: reichard@u.washington.edu

of fire on vegetation can vary greatly depending on fire intensity and vegetation type, though in general fire is thought to favor herbaceous plants over shrubs (Daubenmire 1968, Bartos and Mueggler 1981, Moore et al. 1982, White 1986, Nuzzo et al. 1996, Pendergrass et al. 1998, and Busse et al. 2000). Fire effects on WM checker-mallow are unknown. Anecdotal evidence suggests that plants resprouted vigorously after being burned in 1994, yet no pre-burn data exist for comparison (D. Knecht, USFS Leavenworth Ranger District, personal communication). The objectives for this second portion of the investigation were to determine the effects of fire on individual checker-mallow plants, on seedling recruitment, and on associated (and potentially competing) species within checker-mallow habitat by experimenting with prescribed fire.

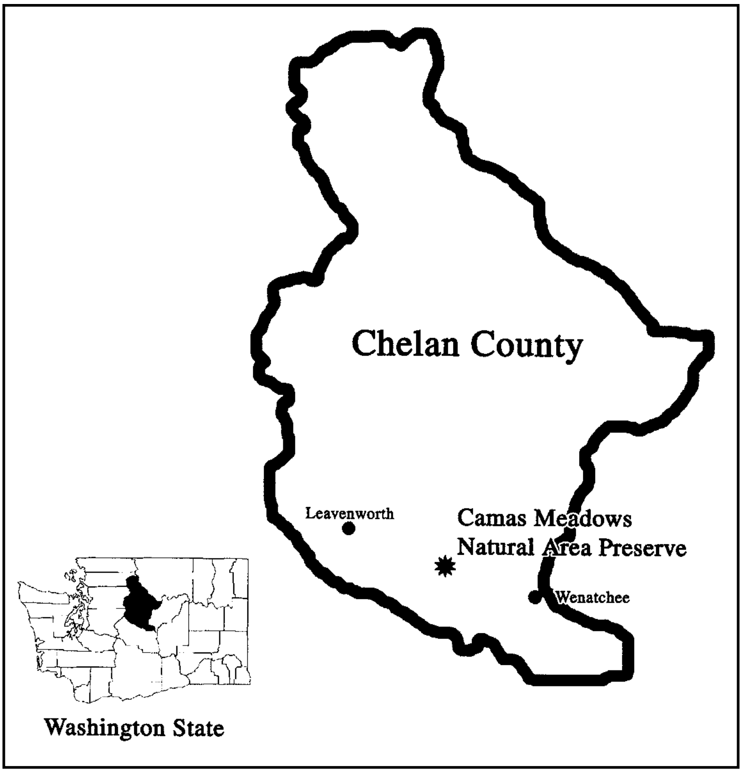

Figure 1. Location of study sites: Camas Meadows Natural Area Preserve, Chelan County, Washington.

Declines in pollinator abundance and diversity can result from habitat fragmentation, which in turn can lead to pollination limitation for plants in habitat fragments (e.g. Rathcke and Jules 1993, Aizen and Feinsinger 1994, Olesen and Jain 1994, Kremen and Ricketts 2000). This can be especially acute when plant species are rare and plant-pollinator relationships are specialized (Tepedino 1979, Kunin 1997). Very little is known about the pollination of WM checker-mallow, although bees are likely pollinators based on pollinators of other taxa in the genus and family, the sticky nature of its pollen and its floral morphology (Gamon 1987). The objective of this portion of the investigation was to observe and identify the frequent flower visitors of the checker-mallow.

Methods

Study site

All study sites are located in a large wet meadow area known as Camas Land about 16 km north of Blewett Pass, and approximately 16 km west-northwest of Wenatchee in Chelan County, Washington (Figure 1). Five of the six study sites (A, B, D, E, and F) are located within Camas Meadows Natural Area Preserve (NAP), a protected preserve which includes about 55% of the Camas Land drainage basin and spans 1333 acres (WDNR 2000). The sixth site (C) is adjacent to the NAP on land managed by the US Forest Service. All study sites are within a mile of one another, and are considered one meta-population by US Fish and Wildlife Service (Gamon, 1987).

The climate of this area is typified by the warm, dry summers and cold, moderately wet winters found elsewhere on the eastern flank of the Cascade Range, but the topography and hydrology are unusual. Camas Land is a shallow, flat basin surrounded by a gradually sloped rim. Elevation ranges from 850 m to 1025 m. This basin is a wet meadow typically saturated until late spring or early summer that then quickly dries. Vegetation within the basin is a mixture of introduced pasture grasses, native meadow grasses, and forbs. WM checker-mallow occurs throughout Camas Land in a patchy distribution which may have been more continuous in the past, though currently the suitable habitat is quite fragmented (Gamon 1987). It is most commonly found in seasonally saturated areas, including areas of the basin, along intermittent streams, and in depressions in forest openings. It is also found along forest edges and shrub borders. The entire meta-population is estimated to contain 11,000 individuals (USFWS, 2004).

Experimental Design

Seed Predation

We collected fruits systematically in order to quantify the weevil infestation in WM checker-mallow fruits and to positively identify the weevil species involved. The method described here is adapted from Gisler and Meinke (1997). On 7 August, 2002, at each of sites A, C, D, and E, we randomly chose ten plants from all individuals with maturing fruits. From each plant, we collected one raceme with ripe or nearly ripe fruits. All fruits and seeds were dissected and examined under magnification to determine the number of parasitized, undeveloped, and undamaged mature seeds. We scored seeds as parasitized if they showed damage to the seed coat and loss of tissue in combination with the presence of frass or if an actual weevil larva or adult was present in the schizocarp. Undeveloped seeds were small, distinctively shriveled and dried up. Specimens of the weevils were identified and vouchers stored by Dr. Charles O'Brien of Florida A & M University. We tallied totals over each location, and all undamaged seeds were returned to their source sites.

Fire Effects

We treated small plots with prescribed fire to determine the effects of burning on existing WM checker-mallow individuals, seedling recruitment, and potentially competing associated species. Within sites C, D, and E, we established eight 4 m^2 plots along each side of a 37 m transect. We positioned the plots one m from the transect line, and three m from adjacent plots. Between 21 July and 30 July 2001, we recorded the following measurements in a 1 m^2 sampling plot within each treatment plot as indicators of recruitment, vigor, and competing community effects: percent cover WM checker-mallow; percent cover of all associated vegetation within sampling plot; and number of WM checker-mallow individuals. On the longest reproductive stem in each plot, we measured length of stem, number of reproductive units (flowers and fruits) on stem, and length and width of third leaf from ground. On 15 October 2001, half of all the 4 m^2 plots were burned by the USFS Leavenworth Ranger District fire crew, using a small propane torch and in some cases flares. Burned and unburned plots were paired along the transect and the side of the transect to be burned was chosen randomly for each pair. On 25 and 26 July 2002, the above parameters were re-measured nine months post-burn.

Pollinator Observations

We made opportunistic observations of insects visiting WM checker-mallow flowers during 2001 and 2002 to determine which insects were frequent visitors. Due to permit constraints, voucher specimens of just a small number of insect visitors were collected by netting, and therefore represent a fraction of the observed pollinator diversity. All collected specimens were identified and are housed at Utah State University.

Statistical Analyses

Seed Predation

We analyzed seed predation data with a Chi Square test to determine whether the proportion of weevil damaged seeds varied significantly from site to site.

Fire Effects

We analyzed the fire effects data using SPSS 10.0.5 statistical package (SPSS Inc. 1999). Treatment results were blocked by site. Leafy aster (*Aster foliaceus*), sulfur cinquefoil (*Potentilla recta*), lupine (*Lupinus* sp.), cinquefoil (*Potentilla gracilis*) and graminoids had high percent cover on at least two sites. Percent cover data for WM checker-mallow and these five associated species were transformed by *natural log (x+1)* for normality and analyzed using GLM (general linear model) with ANOVA, including 2001 pre-treatment data as a covariate to account for possible pre-burn plot differences. Because the associated species chosen for analysis were selected based on prominence rather than specific hypotheses, a Bonferroni correction was applied to that portion of the analysis (Miller 1981). This correction dictates a more stringent significance level, so that to get an an overall significance level of 5% ($\alpha = 0.05$) for the five associated species tested, significance should be declared for any one species with a *P*-value below 1% ($P \leq 0.01$) (Miller 1981). We also analyzed the number of WM checker-mallow individuals with 2001 pre-treatment data as a covariate, while reproductive units on the tallest reproductive individual per plot, leaf area index (product of leaf length and leaf width), and longest reproductive stem length were analyzed without the covariate factor to determine fire effects on individuals and their reproductive potential. The covariate factor was removed from the model because the tallest stem per plot was not necessarily the same plant in 2001 as in 2002.

Results

Climatic Data

The second driest year on record occurred in Washington in 2001 (Washington State Department of Ecology [WSDOE] 2001). Winter precipitation levels were 60% of average. Drought effects were evident at Camas Meadows NAP and likely had some effect on 2001 results. At all sites, some WM checker-mallow individuals in each part of the current study became dry and senesced before fruits were formed and in some cases before all flowers had opened. During the 2002 summer season (a normal precipitation year), this type of response was not seen and all vegetation appeared to be more lush than in 2001.

Seed Predation

Weevils collected from flowers (early season) and schizocarps (late season) were identified as *Macrorhoptus sidalceae*, a species described from British Columbia, Canada. It has been collected previously on *Sidalcea hendersonii* (Sleeper 1957) and *S. nelsoniana* (Gisler and Meinke 1997).

We examined 3576 seeds under magnification. The proportion of seeds damaged by weevils varied significantly from site to site ($P < 0.001$) and accounted for 62-78% of all seeds, while intact undamaged seeds made up 9% to 26% of the total at a given site. The proportion of undeveloped seeds was relatively constant across sites (Figure 2) ranging from 12% to 13%. Overall, only 17% (595 of 3576) of seeds collected and examined in 2002 were undamaged. It appeared that weevil larvae made their way from one seed to another within a fruit, so that over time a fruit infested with

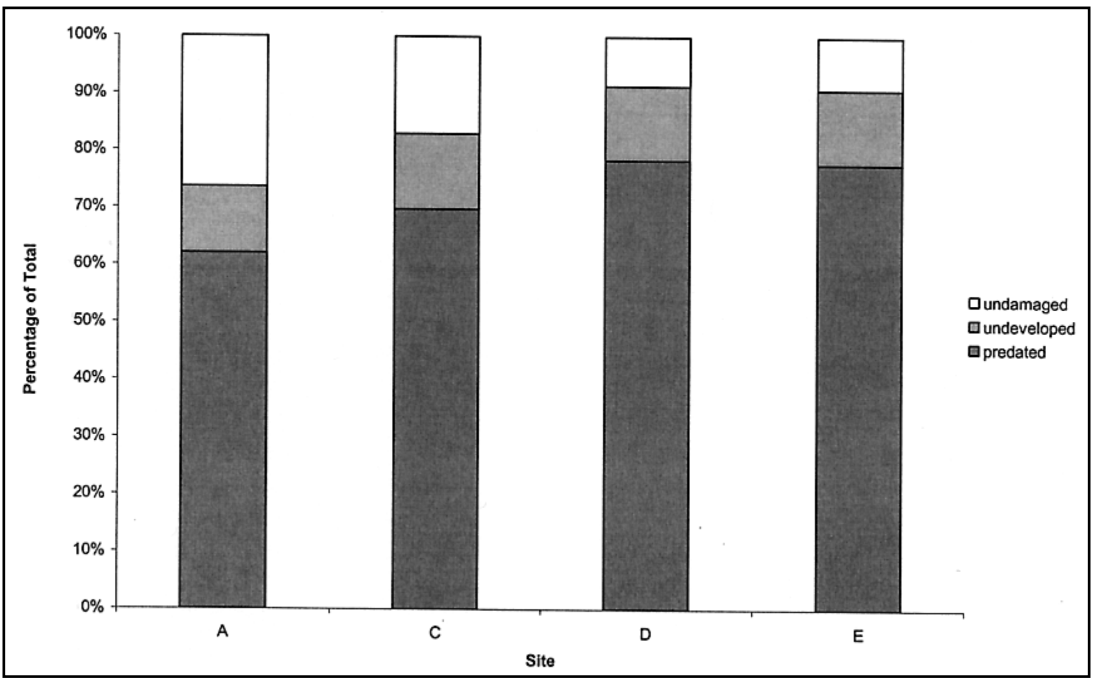

Figure 2. Seed predation and survival results shown as percentage of total by site.

one weevil larva could be left with only 2 or fewer intact seeds out of 6 to 9 potential seeds.

Gisler and Meinke (1997) found *Sidalcea nelsoniana* to also harbor *Macrorhoptus sidalceae*. They determined that although other more common *Sidalcea* species were present in the vicinity of *S. nelsoniana*, *M. sidalceae* favored the rare *S. nelsoniana* over other related species. Camas Meadows NAP does not contain other *Sidalcea* species for this kind of comparison, but this does appear to be another case where a threatened species is heavily impacted by this weevil.

Although infestation levels in the current study varied significantly by site, none of the four study sites had more than 25% intact seeds. This low level of seed survival may impact seedling recruitment and population growth. Further study of site variation will be necessary to better understand differing infestation levels. Related factors such as germination requirements and extent of soil seed bank will require study to fully understand the implications of the observed level of seed loss.

Fire Effects

When we recorded post-treatment data in July 2002, burn plots and non-burn plots were not visually distinguishable from each other. Vegetation in most plots appeared comparatively vigorous and lush, as opposed to 2001 when all vegetation seemed to be affected by drought.

Mean percent cover of WM checker-mallow ranged from 2.8% at site D in the control to 34.4% at site C in the control. There was no statistically significant treatment effect on percent cover WM checker-mallow or on the five associated species analyzed.

Mean number of WM checker-mallow individuals per plot ranged from 4.3 at site D, to 9.9 at site C. There was no significant treatment effect on number of individuals per plot.

Mean leaf area index on the longest reproductive stem per plot ranged from 24.7 cm² at site D in control plots to 109.8 cm² at site C in burn plots. Individuals in the burn plots had a significantly higher leaf area index than those in control plots (ANOVA: $F_{1,28} = 4.270$, $P = 0.048$), indicating a possible increase in growth and vigor. However, neither mean stem length nor mean number of reproductive units, both measured on the longest reproductive stem per plot, were significantly different between treatments.

Although experimental data does not show fire to be clearly beneficial here, there is no indication that fire is detrimental to the system either. Fire has been slowly re-introduced to selected areas throughout the eastern Cascades as a management tool to thin underbrush and to remove dense woody species. Further study of its effect on WM checker-mallow is warranted in order to determine whether it will be an appropriate management tool for Camas Meadows NAP.

Pollinator Observations

A variety of bumble bees and solitary bees were observed visiting WM checker-mallow flowers, including the following species: *Diadasia nigrifrons, Bombus (Pyrobombus) bifarius, Bombus (Pyrobombus) vandykei, Bombus (Pyrobombus) mixtus, Bombus (Psithyrus) insularis, Hoplitis albifrons argentifrons, Osmia densa, Osmia malina,* and *Osmia (Acanthosmiodes)* sp. *Diadasia nigrifrons*, a frequently observed visitor, is a *Sidalcea* specialist bee (Linsley and MacSwain 1957, Kuta 2003). Because WM checker-mallow is the only *Sidalcea* taxon found in the Camas Land area, *D. nigrifrons* likely relies heavily on this plant. Further characterization of the relationship between WM checker-mallow, *D. nigrifrons*, and other potential pollinators may be an important step toward understanding reproduction and population dynamics for this endangered plant.

Conclusions

The high level of schizocarp infestation by *M. sidalceae* warrants additional study into the impact of the seed damage on germination and recruitment. Similar studies have found seed predation to enhance germination of slightly damaged seeds by breaking the impermeable seed coat (Karban and Lowenberg 1992), while others have found seed predation to detrimentally effect the soil seed bank (Hendrix 1988). Further study will be needed to determine the impact of seed predation on WM checker-mallow population growth and persistence. Any management of this potentially predatory insect should be balanced with the protection of the *Sidalcea* specialist pollinator, *D. nigrifrons*.

Though the results of this study should be considered preliminary, they do indicate a need for further study of fire effects on WM checker-mallow. There is some indication that fire may promote increased vigor in WM checker-mallow, and though other parameters measured indicated no difference between burned and unburned plots, fire may be a useful management tool to reach other goals, especially if it can be confirmed that it has no negative effects. Further experimentation may be particularly useful in regard to effects of differing fire intensity. Intensity of prescribed fire was not measured here, but will be an important factor when comparing future results to the historic fire regime. Fire may prove to be a useful tool for weed control, for woody species reduction, and for promotion of native forbs and grasses including WM checker-mallow. Each of these possibilities, however, will require targeting experiments over multiple years to determine the full effects of burning.

Acknowledgements

Funding for this study was provided in part by the US Forest Service, USDA McIntire-Stennis Program, and the Northwest Horticultural Society's Elisabeth Carey Miller Scholarship. Assistance with insect identification was provided by Robbin Thorp of University of California at Davis, Terry Griswold of Utah State University, Evan Sugden of University of Washington, Sedonia Sipes of Southern Illinois University, and Charles O'Brien of Florida A & M University. We thank the botanists and the fire crew at the Leavenworth Ranger District for their field assistance. We thank Robert Gara, James Agee, Martha Groom, Vincent Tepedino, and Kelly Amsberry for comments on earlier drafts of this manuscript.

Literature Cited

Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, D.C.

Aizen, M. A., and P. Feinsinger. 1994. Forest fragmentation, pollination, and plant reproduction in a Chaco dry forest, Argentina. Ecology 75:330-351.

Bartos, D. L., and W. F. Mueggler. 1981. Early succession in aspen communities following fire in western Wyoming. Journal of Range Management 34:315-318.

Busse, M. D., S. A. Simon, and G. M. Riegel. 2000. Tree growth and understory responses to low-severity prescribed burning in thinned *Pinus ponderosa* forests of central Oregon. Forest Science 46:258-268.

Daubenmire, R. 1968. Ecology of fire in grasslands. Advances in Ecological Research 5: 209-266.

Dimling, J. F. 1992. Analysis of the biotic factors affecting the seed set of a rare Pacific Northwest endemic: *Sidalcea malvaeflora* (D.C.) Gray ex. Benth. *elegans* (Greene) C.L. Hitchc. Northwest Science 66:35-39.

Gamon, J. 1987. Report on the status of *Sidalcea oregana* (Nutt.) Gray var. *calva* Hitchc. Unpublished report on file at Washington Natural Heritage Program, Olympia, Washington.

Gisler, S. D., and R. J. Meinke. 1997. Reproductive attrition by pre-dispersal seed predation in Sidalcea nelsoniana (Malvaceae): Implications for the recovery of a threatened species. Pages 56-61 *In* T. N. Kaye, A. Liston, R. M. Love, D. L. Luoma, R. J. Meinke, and M. V. Wilson (editors), Conservation and management of native plants and fungi. Native Plant Society of Oregon, Corvallis, Oregon.

Hegazy, A. K., and N. M. Eesa. 1991. On the ecology, insect seed-predation, and conservation of a rare and endemic plant species: *Ebenus armitagei* (Leguminosae). Conservation Biology 5:317-324.

Hendrix, S. D. 1988. Herbivory and its impact on plant reproduction. Pages 246-263 *In* J. Lovett Doust and L. Lovett Doust (editors), Plant reproductive ecology: patterns and strategies. Oxford University Press, New York.

Huseby, P. 2000. A preliminary study of seed germination in *Sidalcea oregana* var. *calva*. Unpublished study on file at the Center for Urban Horticulture, University of Washington, Seattle, Washington.

Karban R., and G. Lowenberg. 1992. Feeding by seed bugs and weevils enhances germination of wild *Gossypium* species. Oecologia 92:196-200.

Kaye, T. N. 1999. From flowering to dispersal: Reproductive ecology of an endemic plant, *Astragalus australis* var. *olympicus* (Fabaceae). American Journal of Botany 86:1248-1256.

Kremen, C., and T. Ricketts. 2000. Global perspectives on pollination disruptions. Conservation Biology 14:1226-1228.

Kunin, W. E. 1997. Population biology and rarity: on the complexity of density-dependence in insect-plant interactions. Pages 150-173 *In* W. E. Kunin and K. J. Gaston (editors), The Biology of Rarity: causes and consequences of rare-common differences. Chapman and Hall Press, London.

Kuta, K. A. 2003. The foraging behavior of a solitary bee, *Diadasia nigrifrons* (Hymenoptera: Anthophoridae) on *Sidalcea oregana* spp. *oregana*. M.S. Thesis, Utah State University, Logan, Utah.

Linsley, E. G., and J. W. MacSwain. 1957. The nesting habits, flower relationships and parasites of some North American species of *Diadasia* (Hymenoptera; Anthophoridae). The Wasmann Journal of Biology 15:199-235.

Marshall M., and F. R. Ganders. 2001. Sex-biased seed predation and the maintenance of females in a gynodioecious plant. American Journal of Botany 88:1437-1443.

Menges, E. S., D. M. Waller, and S. C. Gawler. 1986. Seed set and seed predation in *Pedicularis furbishiae*, a rare endemic of the St. John River, Maine. American Journal of Botany 73:1168-1177.

Miller, R. G. 1981. Simultaneous Statistical Inference. Springer-Verlag, New York.

Moore, W. H., B. F. Swindel, W. S. Terry. 1982. Vegetative response to prescribed fire in a North Florida flatwoods forest. Journal of Range Management 35:386-389.

Nuzzo, V. A., W. McClain, and T. Strole. 1996. Fire impact on groundlayer flora in a sand forest 1990-1994. American Midland Naturalist 136:207-221.

Olesen, J. M., and S. K. Jain. 1994. Fragmented plant populations and their lost interactions. Pages 417-426 *In* V. Loeschcke, J. Tomiuk, and S. K. Jain (editors), Conservation Genetics. Birkhäuser Verlag, Basel, Switzerland.

Pendergrass, K. L., P. M. Miller, and J. B. Kauffman. 1998. Prescribed fire and the response of woody species in Willamette Valley wetland prairies. Restoration Ecology 6:303-311.

Rathcke, B. J., and E. S. Jules. 1993. Habitat fragmentation and plant-pollinator interactions. Current Science 65:273-277.

Sleeper, E. L. 1957. Notes on the genus *Macrorhoptus Leconte* (Coleoptera; Curculionidae, Anthonominae). The Ohio Journal of Science 57(2):70-74.

SPSS Inc. 1999. SPSS for Windows, release 10.0.5.

Tepedino, V. J. 1979. The importance of bees and other insect pollinators in maintaining floral species composition. Great Basin Naturalist Memoirs 3:139-150.

Received 29 February 2004
Accepted for publication 31 July 2005

U.S. Fish and Wildlife Service. 2004. Recovery plan for *Sidalcea oregana* var. *calva* (Wenatchee Mountains Checker-mallow). U.S. Fish and Wildlife Service, Portland, Oregon x + 52 pp.

Washington Department of Natural Resources. 2000. Management Plan for Camas Meadows Natural Area Preserve. Unpublished report on file at Washington Department of Natural Resources, Ellensburg, Washington.

Washington State Department of Ecology. 2001. 2001 drought response: report to the legislature. Ecology Publication No. 01-11-017. Olympia, Washington.

White, A. S. 1986. Prescribed burning for oak savanna restoration in Central Minnesota. USDA Forest Service Research paper No. NC-266. North Central Forest Experiment Station, St. Paul, Minnesota.

Wilcove D. S., D. Rothstein, J. Dubrow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607-615.

Windus, J. L., and A. A. Snow. 1993. Fruit set and seed predation in an Ohio population of *Gentiana saponaria*. American Midland Naturalist 129:346-351.