



Monitoring Lemhi Penstemon (*Penstemon lemhiensis*) and Spotted Knapweed (*Centaurea stoebe*) Populations in Big Hole National Battlefield

2009-2014

Natural Resource Report NPS/UCBN/NRR—2016/1143



ON THE COVER

Photograph of Lemhi penstemon in bloom below the visitor center at Big Hole National Battlefield.
Photograph courtesy of Michael Durham (www.durmphoto.com).

Monitoring Lemhi Penstemon (*Penstemon lemhiensis*) and Spotted Knapweed (*Centaurea stoebe*) Populations in Big Hole National Battlefield

2009-2014

Natural Resource Report NPS/UCBN/NRR—2016/1143

Thomas J. Rodhouse

National Park Service
Upper Columbia Basin Network
63095 Deschutes Market Road
Bend, OR 97701

March 2016

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on an established, peer-reviewed methodology (Stucki et al. 2013) and a forthcoming protocol (Rodhouse et al. *in revision*) and were analyzed and interpreted within the guidelines of the manuscript and protocol.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Upper Columbia Basin Network website (<http://science.nature.nps.gov/im/units/ucbn/index.cfm>) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Rodhouse, T. J. 2016. Monitoring Lemhi penstemon (*Penstemon lemhiensis*) and spotted knapweed (*Centaurea stoebe*) in Big Hole National Battlefield: 2009-2014. Natural Resource Report NPS/UCBN/NRR—2016/1143. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	v
Executive Summary	vii
Acknowledgments.....	x
Introduction.....	1
Methods.....	3
Study Site	3
Climate During the Study Period	4
Study Species.....	7
Lemhi penstemon	7
Spotted knapweed.....	9
Management Hypotheses and Objectives.....	10
Monitoring Hypotheses and Objectives	11
Objectives	13
Study Design	13
The History of monitoring Lemhi penstemon and spotted knapweed in the battlefield.....	13
Target Populations and Sampling Frames	14
Response Design	16
Prescribed Fire Experimental Design	19
Data Analysis.....	21
Results.....	25
Spatially Extensive Plots and Visitor Center Census	25
Intensive Plots	28
Discussion	31
Literature Cited	33

Figures

	Page
Figure 1. Map of Big Hole National Battlefield, located in southwestern Montana (inset).	2
Figure 2. (a) A pioneer sketch of the Horse pasture drawn by Granville Stewart in 1878 (courtesy of the Montana Historical Society Collection, X1968.43.17), and (b) NPS photo of the Horse pasture in 2011.	4
Figure 3. Long-term records of average January temperature in the town of Wisdom, 10 miles east of the Battlefield, indicates that long stretches of subfreezing temperatures are typical in the upper Big Hole Valley.	5
Figure 4. Precipitation during the study period was generally above average, particularly during later winter and spring, as illustrated here for March totals.	6
Figure 5. A pattern of above average precipitation and below average temperatures during the first several years of study, followed by a period of above average precipitation (although with missing data) and above average temperatures in the later period of study, was recorded in Wisdom.....	7
Figure 6. Lemhi penstemon in flower at Big Hole National Battlefield. Photo courtesy of Michael Durham, reproduced with permission.....	8
Figure 7. A pollen wasp (<i>Pseudomasaris vespoides</i>) feeding on a Lemhi penstemon corolla in Big Hole National Battlefield. Photo courtesy of Michael Durham, reproduced with permission.	9
Figure 8. Spotted knapweed with its characteristic dark (spotted) involucre bracts.....	10
Figure 9. A conceptual model of Lemhi penstemon population change, or growth rate, represented by λ . Abundance, the state variable at each annual time step, is represented by N . Population change is governed by the vital rates survival (ϕ) and successful reproduction, or fecundity (γ).	12
Figure 10. Hillslope sampling frame strata and a spatially-balanced random sample of belt transect origin locations from 2012. New samples of locations for placing temporary belt transects have been used each survey year since 2009, a 1- n (never revisit) design (following notation from McDonald 2003).	15
Figure 11. Map of permanent intensive study plots.....	17
Figure 12. Diagram for counting Lemhi penstemon and spotted knapweed plants in the 42 permanent intensive study plots.	18
Figure 13. The diagram for estimating ground cover in intensive study plots with a point-intercept frame.	19
Figure 14. The 4 proposed experimental burn blocks superimposed on to the Howitzer Hill and Horse Pasture long-term Lemhi penstemon and spotted knapweed monitoring study areas.....	20

Contents (continued)

	Page
Figure 15. The perimeter of the first experimental burn in block 1, completed in September 2014. Nine intensive study plots were included in the perimeter.	21
Figure 16. Population estimates (<i>N</i>) for spotted knapweed and established Lemhi penstemon plants in the Howitzer Hill and Horse Pasture hillslope study area of BIHO, 2009-2014.	27
Figure 17. Regression coefficient estimates for population trend models of A) established Lemhi penstemon plants, B) Lemhi penstemon basal rosettes, C) Lemhi penstemon inflorescences, and D) spotted knapweed populations from extensive plot surveys conducted in the Howitzer Hill and Horse Pasture hillslope study area of BIHO, 2009-2014.....	28
Figure 18. Regression coefficient estimates for Lemhi penstemon established plants, rosettes, flowers, and seedlings for intensive plots.....	29
Figure 19. Regression coefficient plot for Lemhi penstemon established plant turnover between 2012-2013 and 2013-2014.....	30

Executive Summary

Lemhi penstemon (*Penstemon lemhiensis*) is a rare regional endemic forb found only in a single county in Idaho and in four counties in Montana, including Beaverhead County where Big Hole National Battlefield (BIHO) is located. The species is thought to be at risk as a result of habitat loss and altered fire regimes, as well as from infestations of spotted knapweed (*Centaurea stoebe*). The species is thought to be particularly dependent on bare soil microsites for germination and to be easily outcompeted by both native (e.g., steppe bunchgrasses) and non-native (e.g., spotted knapweed) vegetation. Monitoring of Lemhi penstemon in the Battlefield began in 2007 with a census performed by student volunteers and staff that identified two subpopulations on the Howitzer Hill and Horse Pasture hillslopes. This information revealed that the Battlefield was home to a very large (the largest reported, NatureServe [2015]) population and was used to guide development of the sampling design which was implemented and modified during field work beginning in 2009 and conducted annually since. A third smaller subpopulation was discovered in 2011 near the Battlefield Visitor Center and has been incorporated into the monitoring program. Monitoring of the spotted knapweed population that is spatially coincident with the penstemon population has also been incorporated into the program since 2009. A protocol has been developed to guide monitoring that was submitted to the Pacific West Region for peer review in September 2014; reviewer comments were provided in September 2015 and the protocol is now being revised. Monitoring objectives are focused on evaluating status and trend of Lemhi penstemon and spotted knapweed population sizes within the context of long-term changes in vegetation cover and climate, and NPS management actions. Monitoring is explicitly integrated in to long-term goals of the NPS cultural landscape management program for the Battlefield. A replicated asymmetrical before-after-control-impact study design (Underwood 1994) has been superimposed on to the monitoring program to support causal inferences about fire effects on penstemon and knapweed populations. Information about weed control efforts are also being included in monitoring and analyses. The study design includes the use of three methodologies: 1) annual plant surveys beginning in 2009 across the Battlefield hillslopes using large spatially-balanced random samples (e.g., $n=300$) of temporary (i.e., a new sample is used each year) 50 m x 2 m (100 m²) belt transects (referred to as [spatially-] extensive plots) to estimate net changes in the population sizes of established (excluding seedlings) penstemon and knapweed plants on the two Battlefield hillslopes; 2) annual surveys since 2012 of 42 permanent 1 m x 2 m intensive study plots to estimate demographic rates in the hillslope and visitor center subpopulations; 3) an annual census since 2011 of established plants in the visitor center subpopulation. The two hillslope study areas have been divided in to 4 experimental blocks for prescribed fire treatments. The first fire treatment was applied within a single block in September 2014. A second block was planned to be burned in 2015 but weather and drought caused that to be deferred. However, the implementation of this replicated treatment design is highly contingent on annual knapweed survey results; if knapweed responds vigorously to fire and/or cannot be controlled, burn plans will be suspended. The first treatment was suspended for two years until it was clear that the increasing trend in knapweed observed during the first 3 years of study could be reversed, an indication of the willingness of Battlefield management to incorporate monitoring information into

adaptive decision-making. This report summarizes the study design and pre-burn trends in penstemon and knapweed populations.

Since 2009, population sizes of established Lemhi penstemon plants have been estimated to range from 1,362 to 3,642. Using a generalized linear mixed model fit to the six-year dataset of extensive plots ($n=1,655$), trend in established penstemon has increased by $\sim 15\%$ per year. According to the model, the number of penstemon plants is estimated to increase by 45% for each standard deviation (SD) increase in slope steepness and to decrease by 21% for each SD increase in plot vegetation biomass, as estimated by a normalized difference vegetation index (NDVI) calculated from 1 m resolution near-infrared aerial photography of the study area. Similar habitat relationships were estimated from a model fit to counts of penstemon basal rosettes (a potential proxy measure of plant vigor and age) and penstemon inflorescences (flowering stems). Reassuringly, there was no apparent difference in mean established plant population sizes and number of rosettes and inflorescences per plant between the first four and last two years of surveys, when intensive herbicide applications began (in 2012 following June surveys). Surprisingly, there were significantly larger numbers of rosettes and inflorescences in the area within burn block 1 when compared with the rest of the hillslope population; this will be accounted for in post-burn analyses.

Similar models were constructed for spotted knapweed. Knapweed increased exponentially during the first 3 years of study, peaking at 17,395 plants (95% confidence interval 13,568 – 21,221) in 2012. The population has since declined to only $\sim 2,300$ plants. Including the same indicator variable for herbicide treatment in 2013-2014 that was used to test for an effect on the Lemhi penstemon population provides very strong evidence in support of the working hypothesis that control efforts have been effective, although this finding needs to be interpreted with caution because of the coarse measure of herbicide application (a simple indicator variable) and potential confounding factors. Interestingly, knapweed counts appear to increase as slope decreases, conversely to the pattern observed for Lemhi penstemon, but decrease with vegetation (i.e., NDVI) as observed for Lemhi penstemon.

Trends in established Lemhi penstemon within the 42 intensive study plots, which began to be monitored more recently in 2012, appear to be relatively stable. Likewise, stable trends are also apparent for seedlings but, as in the extensive plots, appear to have increased for basal rosettes over the 3 years. Established plants and seedlings appear to increase rapidly as bare ground cover increases within plots (e.g., $\sim 28\%$ per SD increase for seedlings, 95% CI 8%-48%). Interestingly, rosettes per plant increase modestly with increasing amounts of vegetation (NDVI) and slope steepness. There was no apparent pre-burn difference between the 9 plots within the first burn block and the other 33 intensive study plots. There has only been one intensive plot found to contain spotted knapweed, and tests for an effect of herbicide application on the intensive plot plant counts have not been conducted. Regression of the number of positive and negative gains in penstemon plants (turnover) within intensive plots during the 2012-2013 and 2013-2014 transitions revealed only weak evidence for a difference between the two transition periods. However, positive gains were greatest on steeper slopes and hotter southwestern aspects.

Since 2011, censuses of the visitor center subpopulation reveal an apparently very steep increase in the number of plants. The subpopulation is centered on a steep barren cut-bank along an irrigation canal that passes through the Battlefield, and the single intensive plot within that subpopulation also contains substantially more seedlings and established plants than has been found on the more vegetated hillslopes.

Acknowledgments

This project is highly collaborative, involving closely-coordinated participation from NPS staff from the UCBN, BIHO, and NEPE, from the Glacier National Park (GLAC) fire management and fire effects monitoring programs, from the North Rocky Mountain Exotic Pest Management Team. The US Forest Service regional botanist has provided assistance in the field.

Introduction

Lemhi penstemon (*Penstemon lemhiensis* (Keck) Keck & Cronq.) is a rare regional endemic forb found only in a single county in Idaho and four counties in Montana, including Beaverhead County where Big Hole National Battlefield (BIHO) is located (Stucki et al. 2013). There are approximately 191 reported occurrences of Lemhi penstemon, with 102 in Idaho and 89 in Montana (Heidel and Shelly 2001). Based on past surveys, the average population size is small, and NatureServe reports global abundance of approximately 3,000 – 10,000 individuals, and has assigned a global ranking for the species of vulnerable (G3; NatureServe 2015). There are three large populations reported to contain over 300 individuals each and half of all other occurrences have populations made up of 30 plants or less (Elzinga 1997, Stucki et al. 2013, NatureServe 2015). The population at BIHO was included among the three core populations noted in the species conservation assessment (Elzinga 1997) and was suspected of containing more individuals than any other population (Elzinga 1997, Heidel and Shelly 2001). However, no formal assessment of the population size in the Battlefield had been attempted prior to National Park Service monitoring initiated in 2009 (Stucki et al. 2013).

Lemhi penstemon is thought to be at risk primarily as a result of habitat loss and altered fire regimes, and competition from the non-native invasive forb spotted knapweed (*Centaurea stoebe* L.; Elzinga 1997, Heidel and Shelly 2001, Stucki et al. 2013). In particular, Lemhi penstemon is believed to require bare-soil microsites for germination, and in the absence of fire, other vegetation may occupy these potential germination sites over time. Competition for resources may be a more general source of stress in the absence of fire and when spotted knapweed infestations are particularly severe. Within BIHO specifically, risks to the species include an increasing population of spotted knapweed and lack of fire (Stucki et al. 2013, Rodhouse and Stucki 2013a,b). Park operations, including weed and vegetation management, also pose a risk. Early results of monitoring (Stucki et al. 2013) indicated that penstemon regeneration in the Battlefield may be low, possibly resulting from lack of fire. The core of the BIHO population is on the Howitzer Hill and Horse Pasture hillslopes (Figure 1) where park activities such as the removal of lodgepole pine (*Pinus contorta*) saplings and the use of prescribed fire has historically occurred. Given that Lemhi penstemon is also thought to be dependent on fire-maintained bare-soil microsites, prescribed fire is being applied in an adaptive, experimental manner to achieve both cultural and natural resource management objectives. However, the extensive infestation of the invasive forb spotted knapweed in some portions of these hillslopes complicates the potential utility of prescribed fire if spotted knapweed also responds vigorously to fire. This complex decision-making environment underscores the importance of the focused, hypothesis-driven monitoring program and the careful documentation of study results. This report provides an evaluation of monitoring results from the first 6 years of study of both the Lemhi penstemon population and the portion of the spotted knapweed population that is spatially coincident with the penstemon population in the Battlefield. It also provides the baseline against which changes induced by experimental prescribed fire treatment, herbicide application, and climate and weather can be assessed.

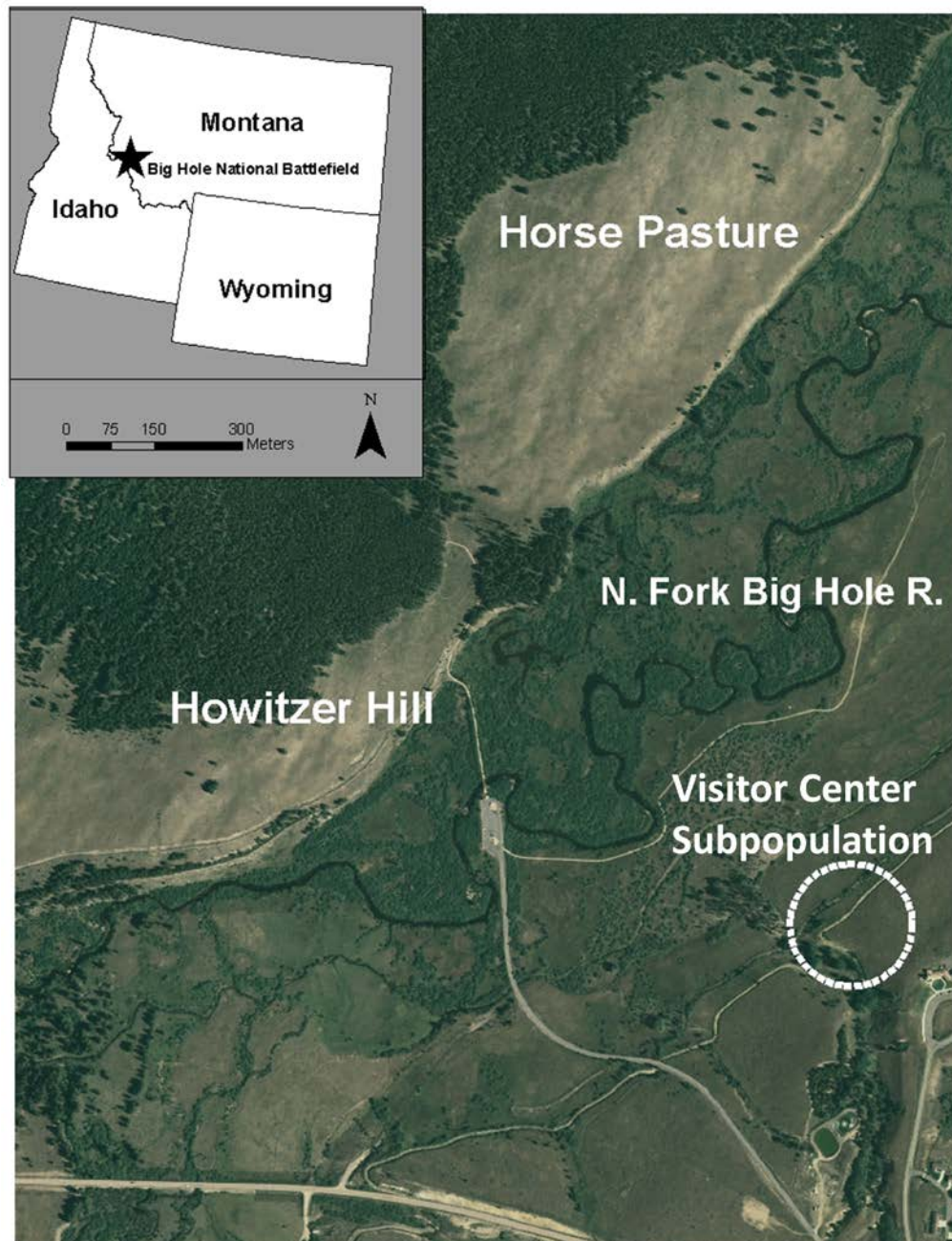


Figure 1. Map of Big Hole National Battlefield, located in southwestern Montana (inset). Monitoring surveys for Lemhi penstemon and spotted knapweed occur on the Horse Pasture and Howitzer Hill slopes, and along the banks of a portion of an irrigation canal below the visitor center (encircled).

Methods

Study Site

Big Hole National Battlefield is located in the upper Big Hole valley of southwestern Montana (Figure 1), along the North Fork Big Hole River. Elevation in the battlefield ranges from 1913 m to 2134 m, and the climate is semi-arid with a thirty-year precipitation average of approximately 30 cm. BIHO is the site of an intense battle that occurred in August 1877 between the U.S. Army and members of the Nez Perce tribe. The Battle at Big Hole was one of several battles between the U.S. Army and the non-treaty Nez Perce during that summer and an estimated 70 to 80 Nez Perce and 31 soldiers and volunteers lost their lives in the 2-day battle. The Battlefield was recognized by Congress in 1883 and was administered by the War Department and later the U.S. Forest Service before becoming a unit of the NPS in 1936.

The NPS currently manages a 265-hectare area that includes two very steep southeast-facing slopes, the Horse Pasture and Howitzer Hill (Figure 1). They overlook the river and are composed of lodgepole pine (*Pinus contorta*) forest on the upper portions and open sagebrush steppe on the lower portions dominated by mountain big sagebrush (*Artemisia tridentata vaseyana*), perennial bunchgrasses including bluebunch wheatgrass (*Pseudoroegneria spicata*) and Idaho fescue (*Festuca idahoensis*), and perennial forbs including arrowleaf balsamroot (*Balsamorhiza sagittata*), sulphur buckwheat (*Eriogonum umbellatum*), and Lemhi penstemon. The low-lying areas of the battlefield are made up of a willow (*Salix* spp.) dominated floodplain along the river and includes wet meadows dominated by rushes (*Juncus* spp.), sedges (*Carex* spp.), and camas (*Camassia quamash*). These extant vegetation patterns, including the open and historically fire-maintained slopes where the core of the Lemhi penstemon population occurs, have remarkable resemblance to the period of historic significance and are crucial to the interpretation of the site and the quality of visitor experience (NPS 2008). An artists' sketch from 1878 (Figure 2a) and a modern day photo of the Horse Pasture in 2011 (Figure 2b) illustrate that the historic setting and rare plant habitat have not dramatically changed in over one hundred years and helps underscore the importance of maintaining the cultural landscape.

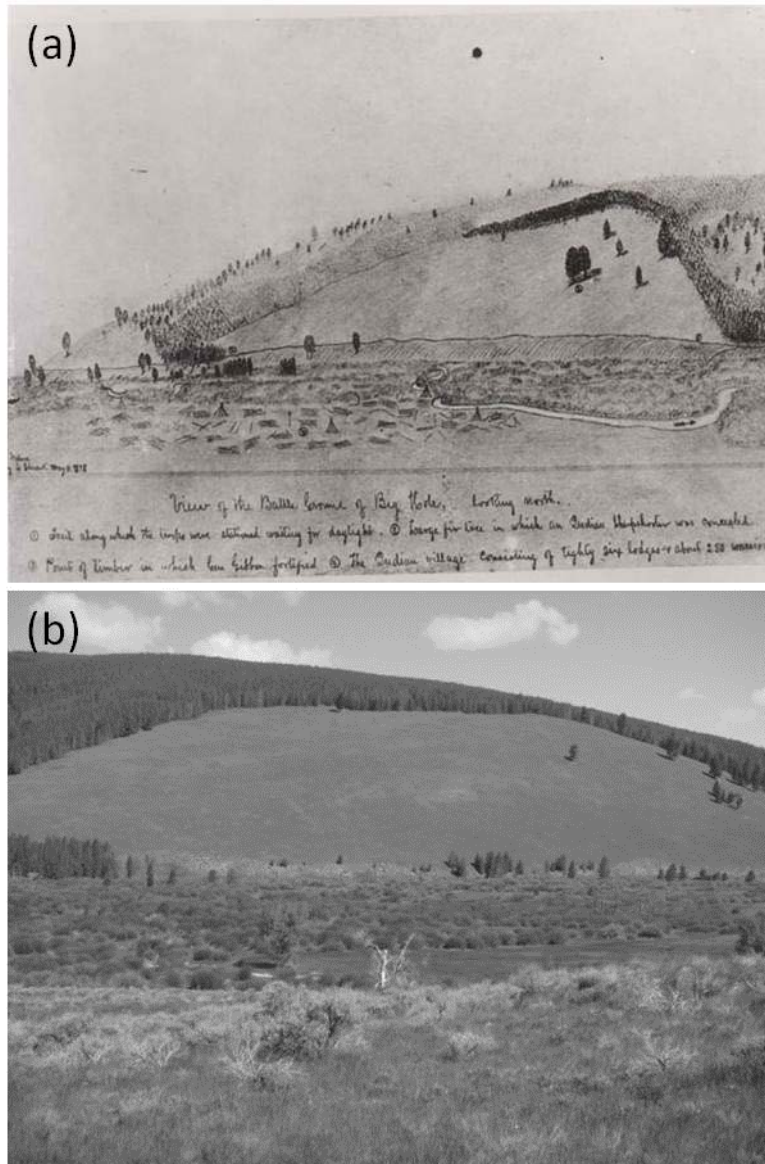


Figure 2. (a) A pioneer sketch of the Horse pasture drawn by Granville Stewart in 1878 (courtesy of the Montana Historical Society Collection, X1968.43.17), and (b) NPS photo of the Horse pasture in 2011.

Climate During the Study Period

The climate in the Upper Big Hole Valley is semi-arid with a thirty-year precipitation average of approximately 30 cm (weather station 249067, Western Regional Climate Center, <http://www.wrcc.dri.edu/>). Winter temperatures are often below zero for long stretches of time (e.g., Figure 3) and snow cover is persistent throughout most winters. Precipitation was above average during most of the study period, especially in spring (Figure 4), and was more so during the first half of the study period (Figure 5). Temperatures were colder than average during the first half of the study period and have been somewhat warmer than average during the second half of the study period (Figure 5).

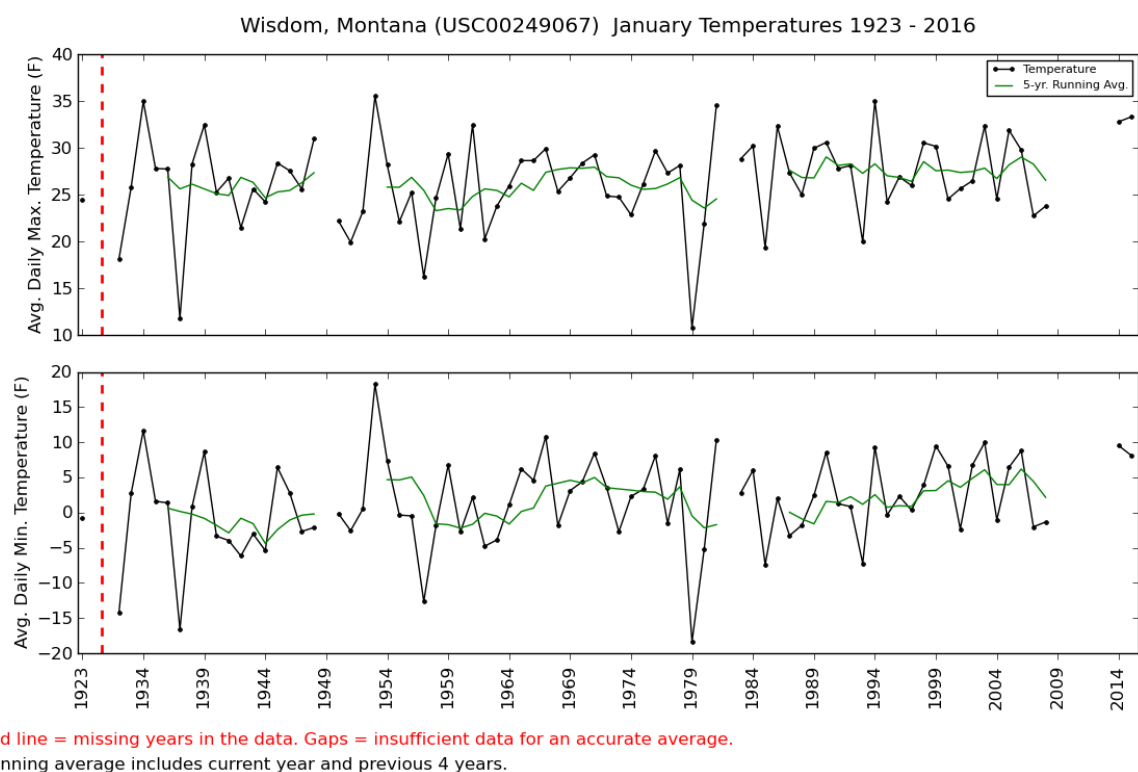
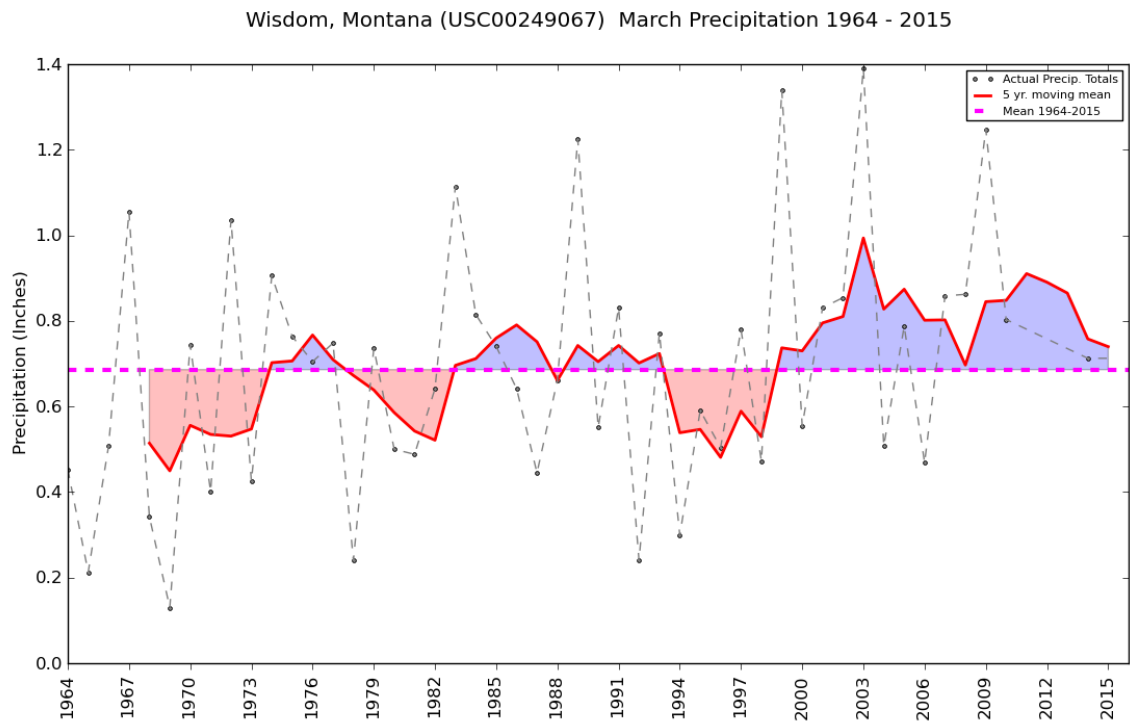


Figure 3. Long-term records of average January temperature in the town of Wisdom, 10 miles east of the Battlefield, indicates that long stretches of subfreezing temperatures are typical in the upper Big Hole Valley.



The running mean is based on a time series with 7.7% (4 out of 52) missing values.
Mean Precip. is calculated over period of graph: 1964-2015
Running average (solid red line) includes current year and previous 4 years. Missing years are linearly interpolated (dashed gray lines)

Figure 4. Precipitation during the study period was generally above average, particularly during later winter and spring, as illustrated here for March totals.

Wisdom, Montana (USC00249067) 2009-2014: Departure from 1981 - 2010 Avgs.

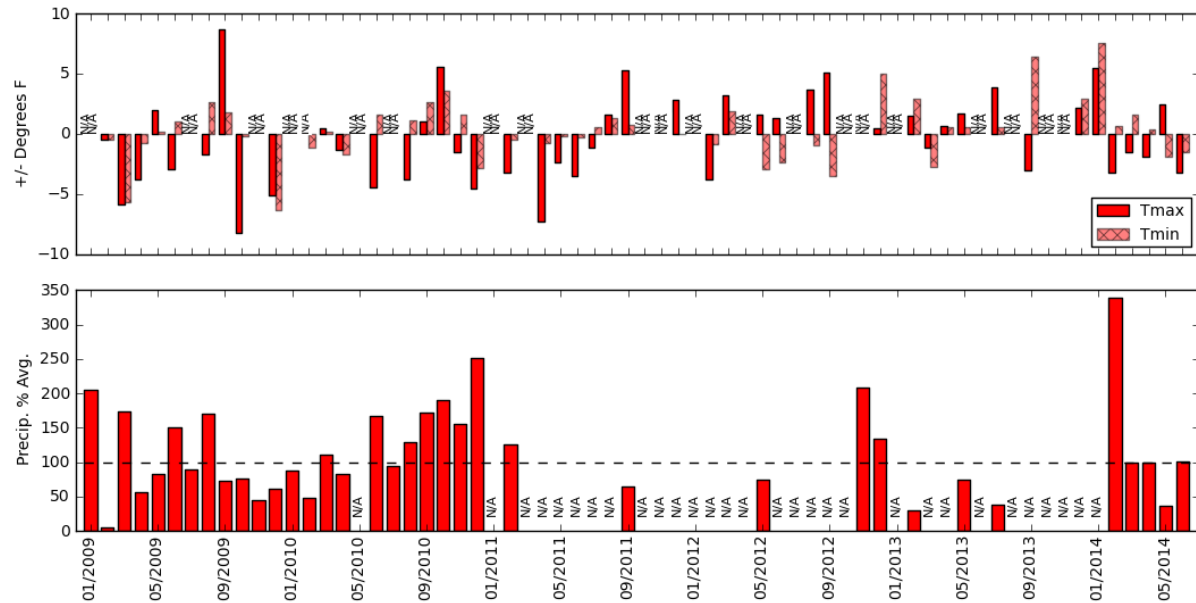


Figure 5. A pattern of above average precipitation and below average temperatures during the first several years of study, followed by a period of above average precipitation (although with missing data) and above average temperatures in the later period of study, was recorded in Wisdom.

Study Species

Lemhi penstemon

Lemhi penstemon [*Penstemon lemhiensis* (D.D. Keck) D.D. Keck & Cronquist] is a robust and showy blue-flowering perennial penstemon (family Plantaginaceae) that can grow to a height of 70 cm (Figure 6; Hitchcock and Cronquist 1973; Elzinga 1997). Plants consist of one or many basal rosettes of leaves growing from a branching underground caudex (Hitchcock et al. 1959). Inflorescences are produced on stems that arise from the center of the rosettes, allowing for a single plant with multiple rosettes to also have multiple flowering stems. Lemhi penstemon reproduces only through seed and is a near-obligate outcrosser which requires cross-pollination to reproduce (Ramstetter 1983, Heidel and Shelly 2001). The primary pollinator for the species is the pollen wasp (*Pseudomasaris vespoides*; Figure 7; Ramstetter 1983). Lemhi penstemon does not have any specialized morphological adaptations or known animal hosts for seed dispersal and the seeds fall to the ground within 1 m of the base of the parent plant after the seed capsules dehisce and open in late summer (Heidel and Shelly 2001). Such a low dispersal capacity may partially explain its restricted distribution, and likely contributes to its overall rarity. Seeds of the species are reportedly viable for at least 8 years and considerable year-to-year variability in germination associated with variable winter and spring precipitation patterns has also been reported (Heidel and Shelly 2001).

Lemhi penstemon occurs in early- to mid-succession habitats and is usually found in association with big sagebrush (*Artemisia tridentata*) on steep, sparsely vegetated slopes (Heidel and Shelly 2001) but is also found in other habitat types including edges and open spaces within coniferous forest

(Ramstetter 1983, Elzinga 1997). Recently disturbed areas such as road cuts also provide habitat for small populations, probably because of the species' need for bare soil microsites for germination (Elzinga 1997). Competition from other vegetation due to natural succession, including grasses, shrubs, and invasive plants appear to have negative consequences on Lemhi penstemon populations (Ramstetter 1983, Elzinga 1997, Heidel and Shelly 2001). Heidel and Shelly (2001) provided evidence from a small experiment that the species might respond favorably to prescribed fire, presumably because of reduced litter accumulation and competition from other plants.



Figure 6. Lemhi penstemon in flower at Big Hole National Battlefield. Photo courtesy of Michael Durham, reproduced with permission.



Figure 7. A pollen wasp (*Pseudomasaris vespoides*) feeding on a Lemhi penstemon corolla in Big Hole National Battlefield. Photo courtesy of Michael Durham, reproduced with permission.

Spotted knapweed

Spotted knapweed (*Centaurea stoebe* L.) is a perennial species of the Asteraceae family, introduced to North America from Eurasia. It is widespread across much of the continent and is an aggressive invader of disturbed ground in much of the intermountain West and Northern Rocky Mountains. When well established, it can out-compete native vegetation. Flowering branches of the plant often reach ≥ 30 cm in height, growing from a stout taproot and producing one to many basal rosettes. Leaves are deeply lobed and typically have a silvery-gray cast from the fine hairs that cover the leaves. The dark tips of the involucre bracts are a distinguishing characteristic that gives the plant its name (Figure 8). The plant is easily recognized in BIHO, although young, small rosettes may be inconspicuous.



Figure 8. Spotted knapweed with its characteristic dark (spotted) involucre bracts.

Management Hypotheses and Objectives

The landscape of the Big Hole Valley at the time of the 1877 battle was devoid of human development, including roads, buildings, and other structures (NPS 2008). What defined the landscape were the natural components, including the vegetation, topography, hydrology, and sweeping vistas of the valley and surrounding mountains (NPS 2008). These features not only set the scene and defined the character of the battle that was to occur; they played a significant role in the events and outcome of the battle itself (NPS 2008). It is only through preservation and maintenance of these natural features, and the ecological processes that allow for their continued existence, that the significance of the site can be fully understood and appreciated.

As with any living landscape, the natural systems of BIHO are in constant flux, evolving, growing, declining, and dying over time. With a few exceptions, the composition of the vegetation that exists today cannot be definitively identified as having been present at the time of the battle. However, the integrity of the Battlefield landscape depends not on individual features, nor on freezing the landscape in an unchanging historic state, but rather on maintaining the overall natural patterns, general composition, and processes that produced the organization of the landscape that comprised the historic scene (NPS 2008).

Today, those elements of the landscape that are essential to convey the site's significance are relatively intact, combining to set a scene very similar to the one that greeted the battle participants on the morning of August 9, 1877. Preservation and maintenance of these natural features and systems is of primary importance to park managers. Both the Howitzer Hill and Horse Pasture were integral to the historic events in 1877 and are likewise central to the contemporary Battlefield landscape and visitor experience. As they were in 1877, the hillslopes today are covered in native steppe vegetation bordered by dense lodgepole pine forest on the upper edges. Descriptions of the

site from battle participants, as well as photographs, drawings, and maps produced in the years following the battle give a relatively clear picture of the extent and character of the forested areas in 1877 (Figure 2; NPS 2008:48). It is believed that at the time of battle the forest covered the majority of the mountain slopes, with the noted exceptions of the southeastern facing Horse Pasture and Howitzer Hill, much as it does in the present era.

Battlefield managers hypothesize that these open slopes were maintained through natural fire cycles aided by the topographic aspects of the site. Supported with historic documentation, park management has periodically utilized prescribed fire and mechanical thinning to remove encroaching overstory trees and shrubs in attempts to replicate natural processes and maintain the open slopes. These efforts began in the late 1960's with the last treatment occurring in 1997.

More recently, as knowledge regarding the importance of the Battlefield landscape to the conservation of Lemhi penstemon has grown, park management has participated in efforts to better understand the local, site-level ecological processes necessary for long-term preservation of the penstemon population. Park managers feel that the BIHO site has a unique opportunity to integrate rare plant conservation into long-term historic landscape preservation objectives (Stucki et al. 2013). To achieve this end, a fire effects study has been incorporated in to long-term population monitoring. Burn objectives focus on benefiting the Lemhi penstemon population, while simultaneously reducing tree and shrub cover to effectively maintain the open hillsides and thereby preserve the historic scene. The approach is highly adaptive, with plans to sequentially burn each of the 4 halves of the two hillslope study areas over time contingent on demonstrated capacity (through monitoring results) to control the spotted knapweed infestation.

Monitoring Hypotheses and Objectives

The monitoring results reported here and in future years will support the Battlefield's assessment of Lemhi penstemon and spotted knapweed population trends in the context of climate- and management-induced hillslope vegetation change. The primary focus is on the subpopulations on the Howitzer Hill and Horse Pasture hillslopes. However, a small Lemhi penstemon subpopulation along the irrigation canal below the BIHO visitor center (Figure 1) is also being monitored, providing a useful out-group for testing hypotheses.

The fundamental working hypothesis for monitoring is that persistence of the relatively closed (i.e., very low rate of seed dispersal and colonization from outside the Battlefield) Lemhi penstemon population in the Battlefield is dependent upon recruitment of germinants (fecundity, generally) and increased survival and reproductive vigor of established plants in bare-soil microsites where sunlight, water, and soil nutrients are available in adequate supply. The corollary is that encroachment of lodgepole pine, densification of native steppe vegetation, and spread of spotted knapweed will reduce the number and size of these microsites and cause a decline in the penstemon population through resource competition. When natural processes and Battlefield management activities (e.g., fire and downslope soil movement [i.e., solifluction], herbicide application) create microsites and suppress competitive vegetation, the Lemhi penstemon population is expected to respond within 3-5 years with increased reproduction and survival resulting in an overall increase in population size. It is

likely that 2-3 years are required before a seedling is recruited into the established population, exhibited by ≥ 1 well-developed basal rosettes (Elzinga 1997, Heidel and Shelly 2001).

Figure 9 is a simple conceptual model of Lemhi penstemon population change over time as a function of survival and fecundity rates and the external ecological influences on those rates including both biotic and abiotic forces.

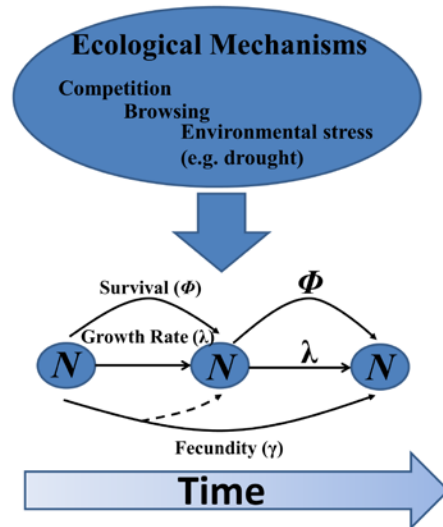


Figure 9. A conceptual model of Lemhi penstemon population change, or growth rate, represented by λ . Abundance, the state variable at each annual time step, is represented by N . Population change is governed by the vital rates survival (ϕ) and successful reproduction, or fecundity (γ). Vital rates are hypothesized to be influenced by external ecological mechanisms, particularly from competition from native steppe vegetation and from the invasive spotted knapweed, from ungulate browsing, and from climate and weather patterns in the Big Hole Valley. Fire is expected to be a major mechanism driving penstemon and knapweed population dynamics directly by causing plant mortality and indirectly by influencing competition and soil resource availability.

Objectives

The objectives of Lemhi penstemon monitoring in Big Hole National Battlefield are to:

1. Provide status (N) and trend (λ) estimates of the total number of established (excluding seedlings) Lemhi penstemon plants in Big Hole National Battlefield from surveys of spatially-extensive temporary plots in the Horse Pasture and Howitzer Hill and from an annual census of penstemon plants in the Visitor Center subpopulation.
2. Provide status and trend estimates of the total number of spotted knapweed plants within the Horse Pasture and Howitzer Hill monitoring areas from the spatially-extensive plot surveys.
3. Provide status and trend estimates of the density (plants/m²) of all Lemhi penstemon plants, including seedlings, and the attributes of age and reproductive vigor (number of rosettes and inflorescences) of each penstemon plant within permanent intensive plots in Big Hole National Battlefield.
4. Provide status and trend estimates of bare ground and vegetation cover within intensive plots in Big Hole National Battlefield.
5. Provide status and trend estimates of the density of spotted knapweed plants within permanent intensive plots in Big Hole National Battlefield.
6. Provide comparative status and trend estimates of established Lemhi penstemon and spotted knapweed plant densities; penstemon seedling, rosette, and inflorescence densities; and estimates of bare ground and vegetation cover in burned and unburned intensive study plots.

Study Design

The History of monitoring Lemhi penstemon and spotted knapweed in the battlefield

A brief study of Lemhi penstemon pollination was conducted by Ramstetter (1984), who discovered the visitor center subpopulation (although this knowledge was lost until her thesis was made known to NPS staff in 2011). Monitoring of Lemhi penstemon in the Battlefield began in 2007 with an incomplete walking census performed partly by student volunteers that identified two subpopulations on the Howitzer Hill and Horse Pasture hillslopes. This information was used to guide implementation of a spatially-extensive sampling design beginning in 2009 to monitor both the Lemhi penstemon population and the invasive spotted knapweed population that is spatially coincident with the Lemhi penstemon population (Stucki and Rodhouse 2009, Stucki et al. 2013, Rodhouse and Stucki 2013a,b). A third smaller subpopulation was discovered in 2011 near the Battlefield Visitor Center and has been censused every year; contributing additional plants into the estimates from the hillslopes. Early survey results established that the Battlefield population is the largest known population and is globally significant from the perspective of Lemhi penstemon conservation. An intensive survey methodology initiated in 2012 involving forty-two 1 m x 2 m permanent plots was implemented to augment spatially-extensive survey efforts and to provide the Battlefield staff with better information about the relationship between prescribed fire, bare soil microsite habitat, and regeneration.

A monitoring protocol was developed in 2014 that will support long-term monitoring using the spatially extensive methods that provide for net trends in population size, the intensive methods that provide information on habitat characteristics and plant density, regeneration, and mortality at fine spatial scales, and the annual censusing of the small visitor center subpopulation (Rodhouse et al. *in revision*).

Planning for an experimental study of fire effects on Lemhi penstemon and spotted knapweed on the hillslopes began in 2011 (Harris 2013, Stucki et al. 2013). The replicated before-after-control-impact study design (i.e., “beyond BACI”, Overton 1994) was superimposed on the existing monitoring design so that both near-term study objectives and long-term monitoring objectives could be pursued in an integrated manner. The first of 4 anticipated fire treatments was completed in September 2014.

Target Populations and Sampling Frames

There are three spatially-disjunct subpopulations of Lemhi penstemon in the Battlefield, shown in Figure 1 and in Figure 10. Each of these subpopulations is targeted for monitoring. The two hillslope subpopulations are large enough that statistical sampling is required. However, the visitor center subpopulation is small and discrete enough for effective censusing. Sampling frames were established in the Howitzer Hill and Horse Pasture in 2009 by drawing convex polygons around each subpopulation (Figure 10). The Howitzer Hill frame contains 6 hectares (ha; 14 acres) and the Horse Pasture contains 26 ha (64 acres) of steppe habitat on steep hillslopes. The core of each subpopulation is concentrated along the center axes of the frames where slopes are steepest, and, in the case of the Howitzer Hill, along the roadcut near the lower boundary of the frame.

The spotted knapweed population in the Battlefield appears to be widespread across the Battlefield in many discrete patches. It is not feasible to establish a Battlefield-wide sampling frame for spotted knapweed monitoring. Therefore, only the portions of the spotted knapweed population that occur within the hillslope sampling frames and within the additional (42nd) permanent intensive plot in the visitor center subpopulation are targeted for monitoring and captured within the sampling design. Scope of inference of penstemon and knapweed population estimates is restricted to within the hillslope sampling frames. The census of penstemon below the visitor center is not included within this scope of inference, but the plant counts are added to hillslope estimates.

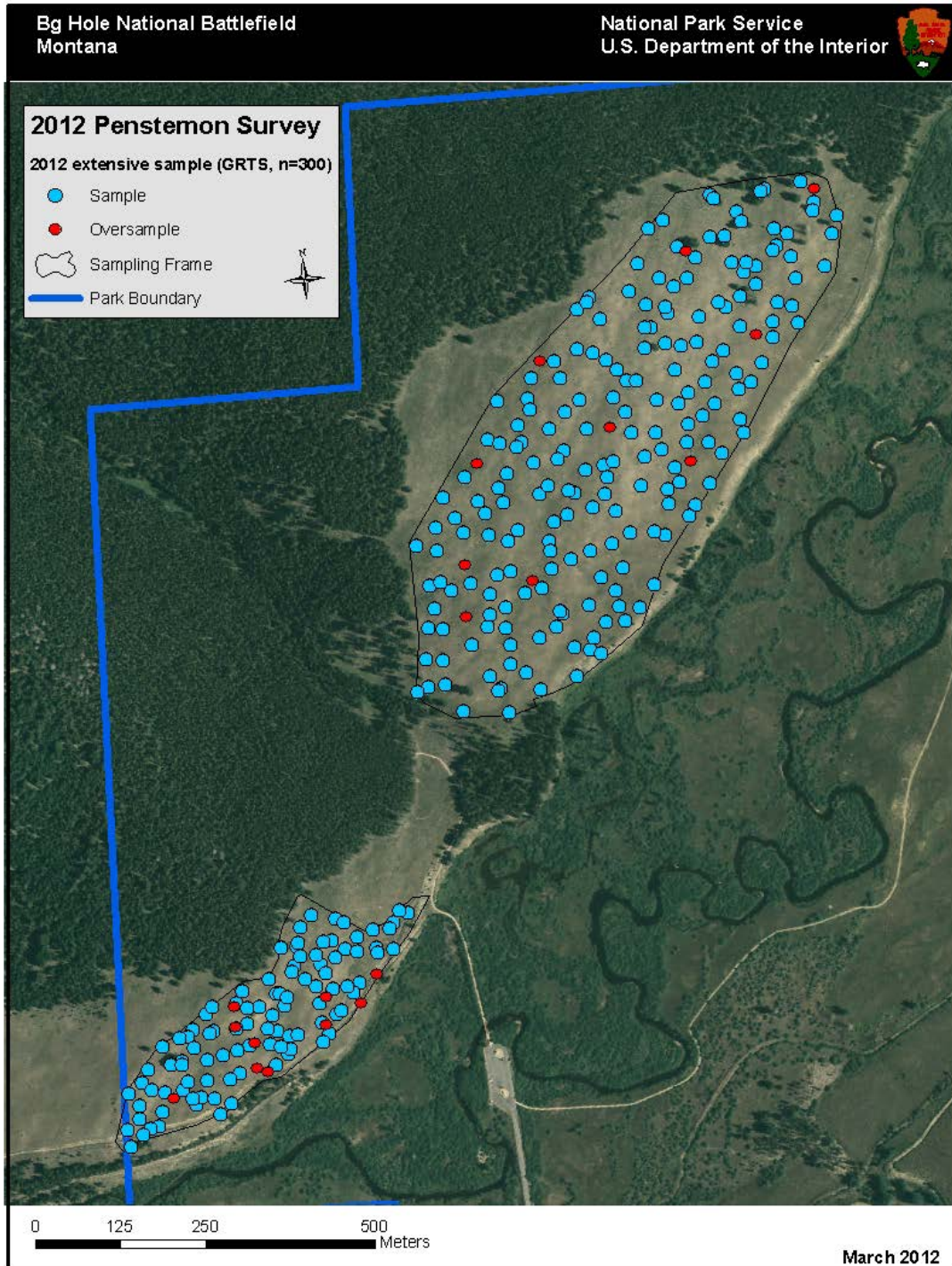


Figure 10. Hillslope sampling frame strata and a spatially-balanced random sample of belt transect origin locations from 2012. New samples of locations for placing temporary belt transects have been used each survey year since 2009, a 1- n (never revisit) design (following notation from McDonald 2003).

Response Design

Extensive Plot Surveys

Temporary plots, called extensive plots because of their spatially-extensive distribution, are used to develop population estimates for established Lemhi penstemon and spotted knapweed across both of the hillslope subpopulations (Figure 10). Plot locations are generated using the Generalized Random Tessellation-Stratified (GRTS) algorithm to ensure random, spatially-balanced plot placement (Stevens and Olsen 2004). The GRTS algorithm has also been shown to be statistically efficient for spatial surveys of environmental resources, generally, and a statistically-efficient “local” variance estimator has been developed for estimating state variables (e.g., N) from GRTS surveys that yields much more precise estimates than if standard Horvitz-Thompson population estimators are used (Stevens and Olsen 2003, Rodhouse et al. 2011). Target sample sizes are 100 plots in the Howitzer Hill sampling frame and 200 plots in the Horse Pasture sampling frame, with sample sizes reflecting the difference in area between the two sampling frames. The area sampled ($300 \times 100 \text{ m}^2$) represents ~9% of the total frame area, including both hillslopes. New GRTS samples are drawn each year, resulting in a “never revisit” design (a [1- n] design, following notation of McDonald 2003).

Extensive plots are 100 m^2 belt transects $50 \text{ m long} \times 2 \text{ m wide}$, modified from an approach described by Lesica (1987). Plots originate at the randomly selected GRTS point locations and are oriented perpendicular to the slope in a northeasterly direction. This allows for observers to traverse the steep slopes safely. Plots are searched for mature Lemhi penstemon plants and spotted knapweed plants by walking down the center of the belt transect, using a 2 m long PVC pole to determine plot boundaries. Lemhi penstemon plants are considered mature when one or more fully developed basal rosette(s) of leaves are present. Lemhi penstemon seedlings are difficult to detect and are excluded from spatially-extensive surveys in order to reduce observer bias due to imperfect detection. All established Lemhi penstemon and spotted knapweed plants are counted in extensive plots, as well as the number of penstemon rosettes and inflorescences. The slope and aspect (in degrees) and normalized difference vegetation index (NDVI) of each plot is averaged across the 50 m azimuth from a 10-m digital elevation model and from aerial imagery.

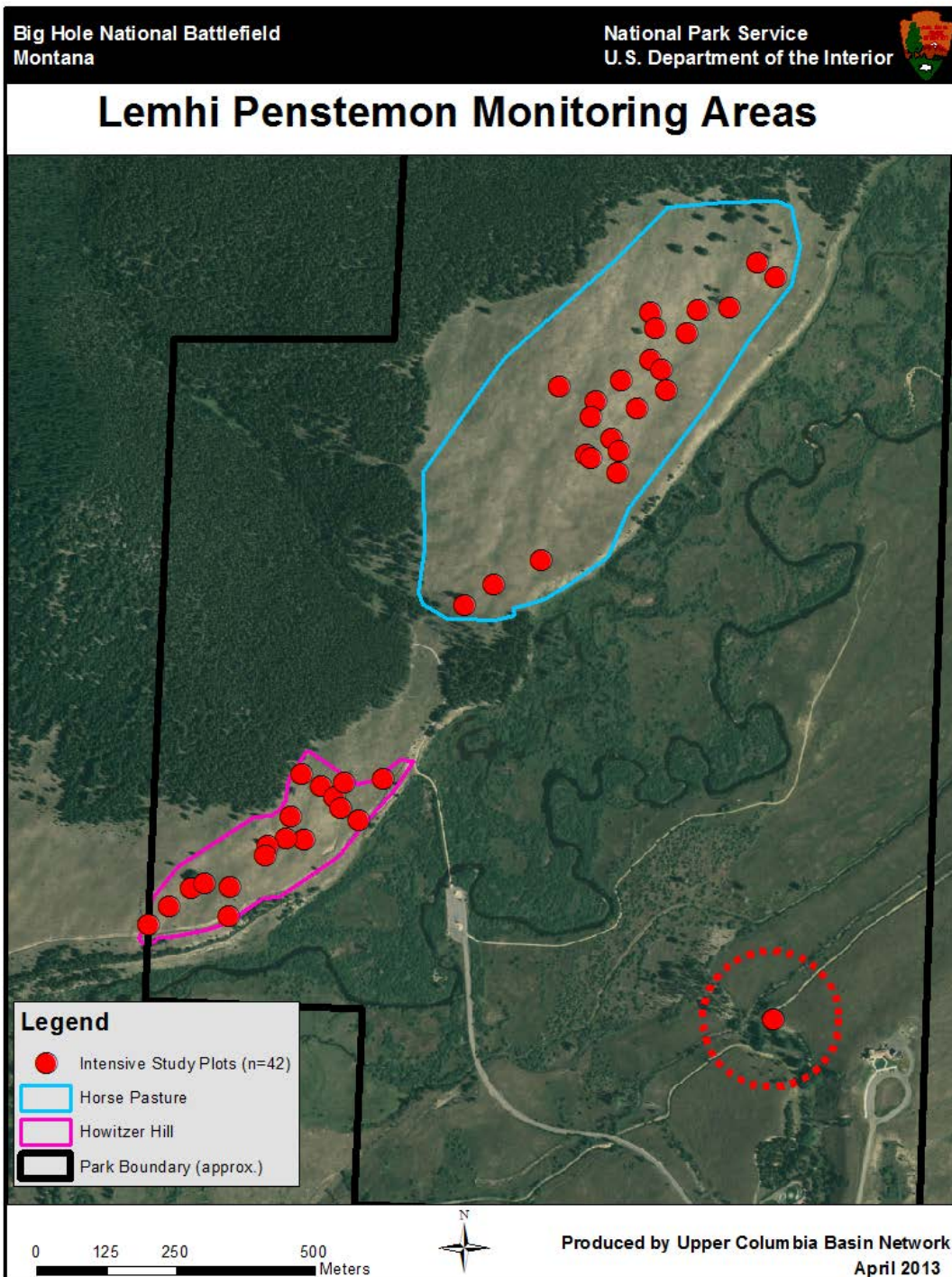


Figure 11. Map of permanent intensive study plots.

Intensive Plot Surveys

Permanent plots, known as “intensive” plots, were established in 2012 and will allow for long-term study of individual Lemhi penstemon plants and seedlings, as well as ground cover, offering a fine-scale view of regeneration (fecundity), survival, and habitat characteristics. The first 41 plots were

selected in consecutive order from the 2011 spatially-balanced ordered list of GRTS locations where Lemhi penstemon plants were found during the 2011 survey. This resulted in 18 plots located in the Howitzer Hill sampling frame and 23 plots in the Horse Pasture sampling frame (Figure 11). A 42nd intensive plot was non-randomly placed within the center of the subpopulation below the Visitor Center on a steep southwest facing bank of the irrigation canal. The permanent plots within the Horse Pasture and Howitzer Hill sampling frames are not located in the original position of the spatially-extensive plot origins but were instead placed along the 50 m transect so that at least one mature Lemhi penstemon plant was located within the intensive plot. The intensive plots are 2 m² in size with dimensions of 1 m × 2 m and are oriented with the long axis (2 m) oriented perpendicular to the slope (see Figure 12). Each intensive plot is divided into two 1 m² subplots, a left (L) subplot and a right (R) subplot. Within intensive plots, all mature Lemhi penstemon are counted, along with the number of basal rosettes and inflorescences on each plant. Lemhi penstemon seedlings are also counted, as well as spotted knapweeds plants. Inflorescences that have been browsed are also noted. Percent ground cover is estimated using the point interception technique (Elzinga et al. 2001) at 98 positions within the 2 m² plot (Figure 13). Values for each of the physiognomic ground cover categories [which include bare ground, soil crust, forb (not including Lemhi penstemon), graminoid, litter, Lemhi penstemon, rock > 5 mm in diameter, shrub, tree, and wood] are totaled and converted to a percentage for each plot quadrant. These permanent intensive study plots are re-surveyed annually, resulting in an “always revisit” design (a [1-0] design, McDonald 2003).

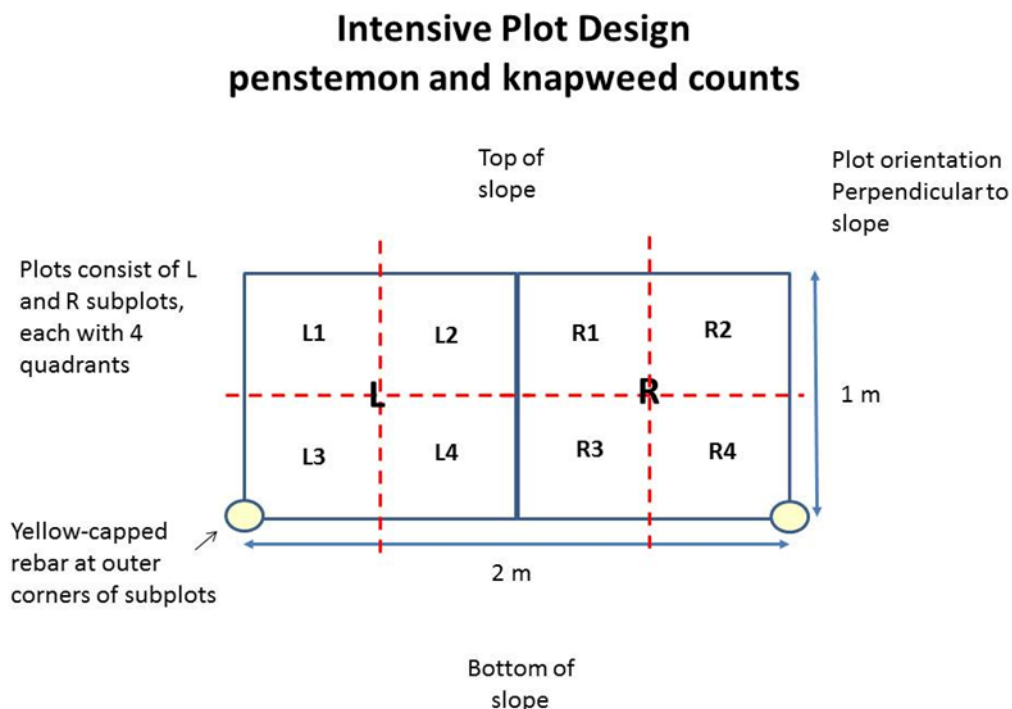


Figure 12. Diagram for counting Lemhi penstemon and spotted knapweed plants in the 42 permanent intensive study plots.

Intensive Plot Design

Point-intercept Cover Estimation

Plots consist of L and R subplots, each with 49 intercepts and a total of 98 intercepts

Grid of pvc pipe for point-intercept cover estimation

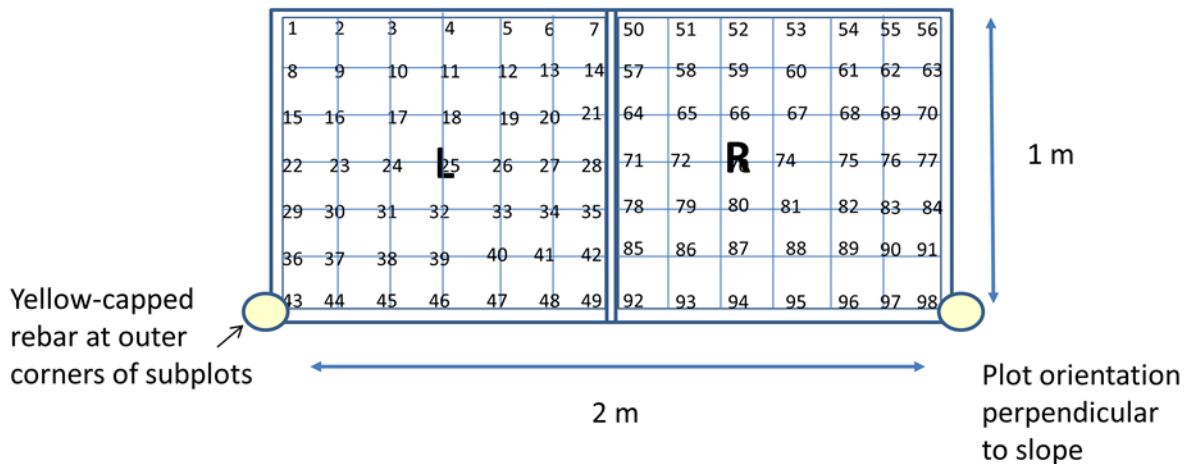


Figure 13. The diagram for estimating ground cover in intensive study plots with a point-intercept frame.

Visitor Center Subpopulation Census

The visitor center subpopulation (Figure 1) is concentrated along the banks of an irrigation canal that bisects the middle of the west-facing slope below the visitor center on an old alluvial fan that was reportedly influenced by mining activity prior to the establishment of the Battlefield. Extensive searches each year beginning in 2010 through 2014 have confirmed that the subpopulation is small and does not extend away more than ~ 10 m away from the portion of the canal that bends sharply to the northeast. Each year beginning in 2011 we have utilized all available staff and volunteers to spend the final afternoon of the week-long field effort locating every established plant. Plants are temporarily marked with pin flags before the final tally. Plant rosettes and inflorescences are also counted. The 42nd intensive plot, which is located on the east bank (visitor center side) of the canal, is also surveyed at this time.

Prescribed Fire Experimental Design

A prescribed fire plan was developed for the Battlefield and is integrated into the long-term monitoring program (Harris 2013). The plan which was written by the Glacier National Park fire management team with substantial input from park and Network I&M staff outlines 4 consecutive fire treatments to be applied to each half of the two hillslopes during consecutive years (Figure 14). The first treatment was applied to the southeast half of the Howitzer Hill (burn block 1) in September 2014 (Figure 14 and Figure 15). This was delayed two years until it was evident that spotted knapweed infestations could be controlled (Harris 2013; see Results). The experimental design is a

replicated asymmetrical before-after-control-impact (“beyond BACI” design; Green 1979, Overton 1994). This design supports strong causal inference to fire effects on Lemhi penstemon and spotted knapweed because of the highly-replicated structure in which each block is subjected to experimental treatment sequentially and treated and control plots are well replicated within each block. Importantly, the sequential asymmetry will enable climate and weather effects to be accounted for.

BIHO Pasture Rx Plan BURN BLOCK MAP

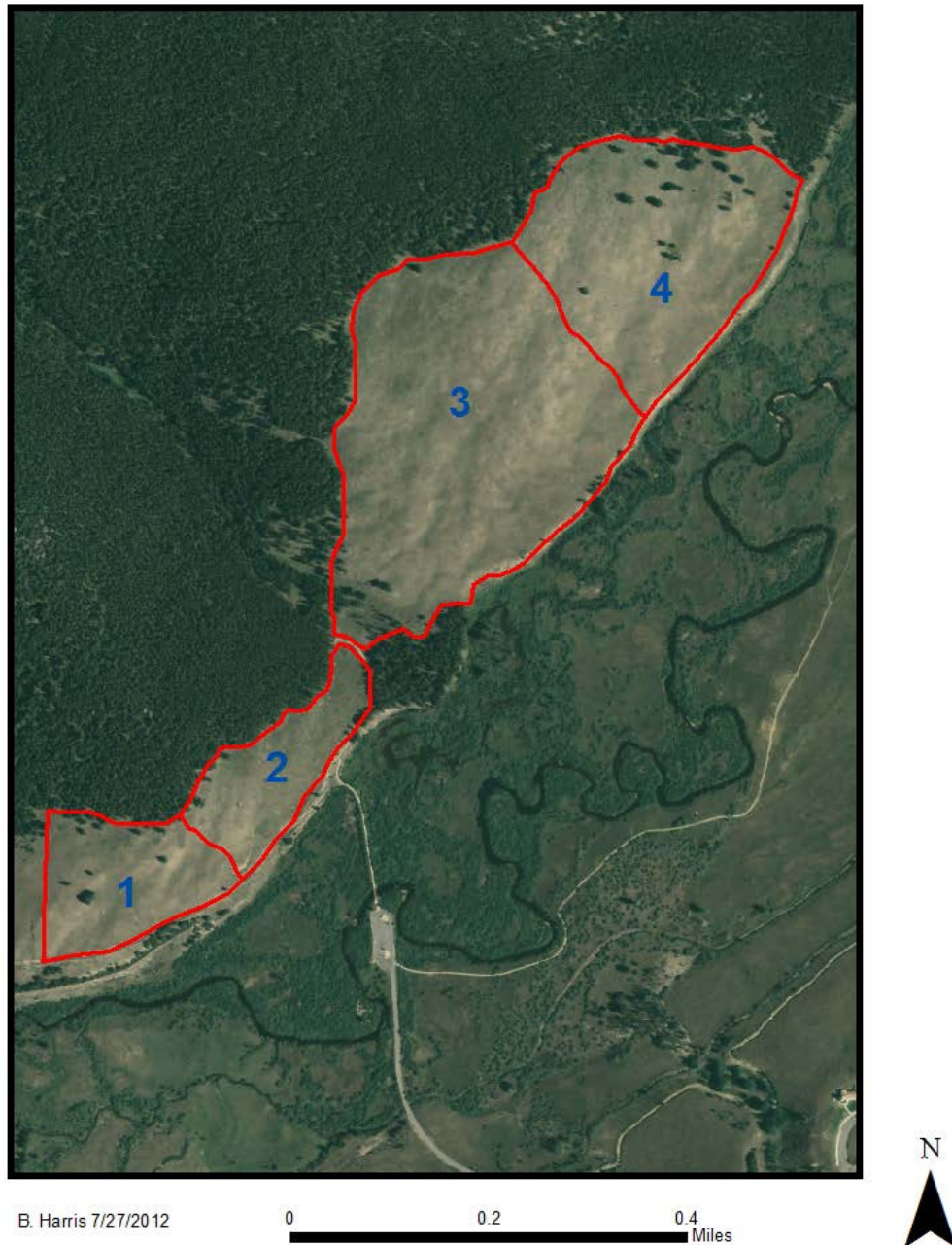


Figure 14. The 4 proposed experimental burn blocks superimposed on to the Howitzer Hill and Horse Pasture long-term Lemhi penstemon and spotted knapweed monitoring study areas.

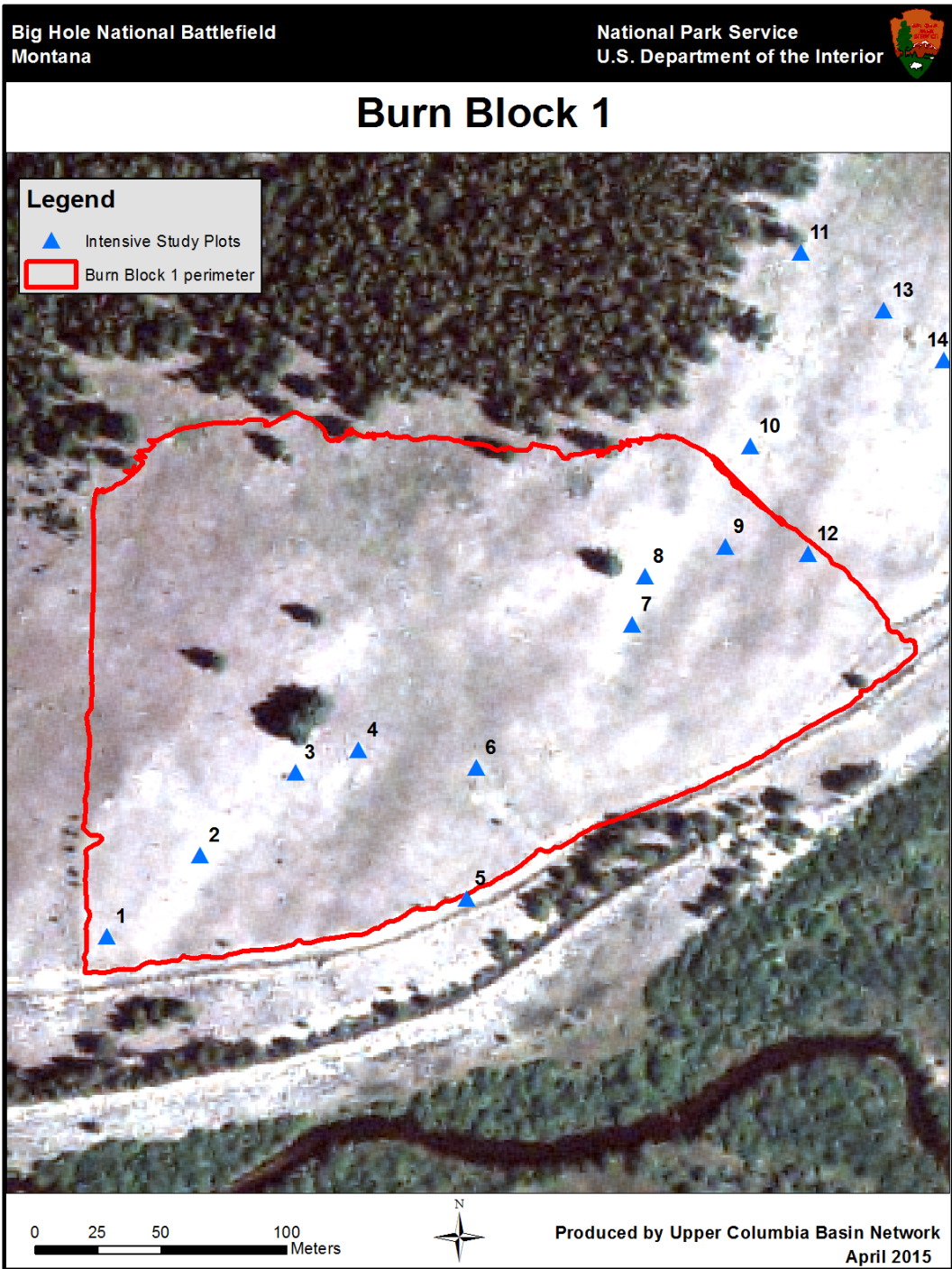


Figure 15. The perimeter of the first experimental burn in block 1, completed in September 2014. Nine intensive study plots were included in the perimeter.

Data Analysis

Population status estimation

The population sizes (N) of established Lemhi penstemon and spotted knapweed populations within the hillslope study areas were estimated with a design-based approach, drawing on the extensive plot

survey design. Because of the spatially-balanced GRTS design, I used the modified Horvitz-Thompson “local” variance estimator developed for GRTS surveys (Stevens and Olsen 2003) which is more efficient than the standard Horvitz-Thompson estimator. Calculations were performed with the *spsurvey* library (Kincaid and Olsen 2013) in the R statistical environment (R core team 2014).

Model-based trend estimation and hypothesis testing

I used a model-based analysis of covariance (ANCOVA) approach to estimate trends over time in established plant populations (the “growth rate” λ), in rosettes and inflorescences, and in seedling counts (fecundity, γ). Differences among plots in slope steepness, vegetation biomass (as measured by proxy with a normalized difference vegetation index [NDVI]) and, for intensive plots, cover of bare ground, were accounted for. I included an indicator variable to test the hypothesis that plots within the block 1 burn perimeter (Figure 14 and 15) differed significantly prior to treatment (treatment occurred after field surveys). I also used an indicator variable to test the hypothesis that herbicide treatments beginning in summer of 2012 (affecting plant counts in 2013 and 2014) decreased the spotted knapweed population. Models of counts were constructed as generalized linear mixed models using the negative binomial distribution in order to account for overdispersion in counts (e.g., zero inflation and skew).

Following the parameterization recommended by Hilbe (2011) for negative binomial regression, I define the (vector of) counts of plants as $Y_i \sim \text{Negative-binomial}(\mu, \alpha)$, with mean $\mu = e^{X'\beta}$ and variance $\mu + \alpha\mu^2$, for which α is the overdispersion parameter. Note that the Poisson distribution can be considered a special case of the Negative Binomial distribution as overdispersion approaches 0 and the variance reduces to μ . The regression predictors $X'\beta$ (e.g., year and slope) are linearly related to the mean on the log scale via the negative binomial link function such that exponentiated regression coefficients are interpreted in terms of a multiplicative change in the population growth rate, λ , for each unit change in a given predictor (holding all other predictors included in the model constant). This modeling strategy provides a natural connection to the monitoring and sampling hypotheses and objectives. It provides flexibility for addressing questions about the influence of prescribed fire, and environmental factors such as slope because they also can be included as regression predictors. Model 1 describes the model for counts from extensive plot data:

$$\log(\mu) = \beta_0 + \beta_1 * \text{HorsePasture} + \beta_2 * \text{aspect} + \beta_3 * \text{slope} + \beta_4 * \text{slope}^2 + \beta_5 * \text{NDVI} + \beta_6 * \text{NDVI}^2 + \beta_4 * \text{year} + \beta_5 * \text{RxFire} + \beta_6 * \text{herbicide}, \quad [1]$$

where HorsePasture, RxFire, and herbicide represent indicator variables that provide additional parameters so that different means (intercepts) between counts in the Howitzer Hill and Horse Pasture and between treated and untreated plots can be estimated. This is analogous to the analysis of covariance (ANCOVA) strategy. Temporal trend is modeled as a deterministic linear fixed effect.

A similar approach was used to model change in the seedling rate (γ) from seedling counts and in other measures obtained from intensive plots. However, these plots are permanent, creating a repeated-measures scenario in which counts from plots are highly correlated, much more so than any among-plot correlation. This necessitates the construction of a mixed-effects or hierarchical model (Gelman and Hill 2007) in which counts are grouped within plots, as described by Model 2:

$$y_{j[i]} \sim \text{Negative-Binomial}(\mu_{j[i]}, \alpha), \quad [2]$$

$$\log(\mu_{j[i]}) = \beta_{0j} + \beta_1 * \text{Slope} + \beta_2 * \text{bare ground cover} + \beta_3 * \text{NDVI} + \beta_4 * \text{RxFire} + \beta_5 * \text{Year},$$

$$\beta_j \sim N(\mu_\beta, \sigma_\beta^2),$$

where $y_{j[i]}$ is the observed i th count, from $1, \dots, n$, $n = \text{years} \times \#$ of permanent intensive plots, nested within j plots from $1, \dots, 42$. This is a random-intercept type of hierarchical regression model (Gelman and Hill 2007). The count-generating process has a characteristic mean, $\mu_{j[i]}$, for each count, that is modeled on the log scale as a linear combination of the intercept plot-level β_{0j} after accounting for fundamental differences in slope, vegetation biomass (NDVI and % bare ground cover), prescribed fire treatment (fixed effects) and year (as a 3-level factor). The intercept varies among plots according to a normal distribution each with mean, μ_β , and variance, σ_β^2 . Note that μ_β provides overall estimates of the mean count for the entire population, whereas β_{0j} provides mean estimates for each of the 42 permanent plots. This parameterization accounts for the correlation of within-plot counts. This model describes a plausible ecological scenario of annual count-generating processes for each permanent intensive plot, drawn from a common population-level mean and variance. Note that this model can be augmented with a random slope for year (nesting repeated counts within plots and years), as described in the protocol (Rodhouse et al., *in revision*) when more than 3 (preferably ≥ 5 ; Gelman and Hill [2007]) years of counts are available. I used the *glmmADMB* library in R (Fournier et al. 2012, Skaug et al. 2014) to fit models.

Model Covariates

Slope steepness was estimated from a 10-m digital elevation model (DEM, US Geological Survey National Elevation Dataset, <http://ned.usgs.gov/>). The NDVI proxy for biomass was estimated from 2013 near-infrared 1-m resolution aerial photography obtained from the National Agricultural Imagery Program (NAIP, USDA Farm Service Agency, http://www.fsa.usda.gov/Internet/FSA_File/naip_info_sheet_2013.pdf). Percent bare ground cover was estimated using the point-interception technique in intensive plots (Figure 13). To construct indicator variables for treatments, plots within the block 1 burn perimeter were coded as 1, else 0; extensive plots in 2013 and 2014 were coded as 1 to indicate herbicide treatment, which began in summer 2012 (after 2012 surveys). Additional ground cover data collected in plots (litter, forb, graminoid, etc...) were used to evaluate change in cover for the severity rankings of the 9 intensive plots burned in 2014.

Results

Spatially Extensive Plots and Visitor Center Census

The estimated total number (N) of mature Lemhi penstemon plants across both the Howitzer Hill and Horse Pasture sampling frames based on the most-recent survey in 2014 was 3,642 ($n=300$; 95% confidence interval 2,872 – 4,412). This was up substantially from previous years but with overlapping margins of error (Figure 16), and provides evidence for increasing trend since 2009. There has also been a steady increase in the number of plants found in the visitor center subpopulation since counts began in 2011 (Table 1). Accompanying the increasing trends in established Lemhi penstemon on the hillslopes has been the positive trend in spotted knapweed, marked by the 2012 spike (Figure 16). Spotted knapweed was not encountered in Horse Pasture plots until 2012, when large patches were found on the southwest half. This pattern of exponential trend was abruptly reversed in 2013, followed by a slight increase in 2014. The population was estimated in 2014 to be 2,266 (95% confidence interval 1,066 – 3,466).

Model based trend estimates of both the Lemhi penstemon and spotted knapweed populations on the hillslopes also show clear positive population growth, even after adjusting and accounting for important design, management, and environmental factors (Figure 17). The inclusion of the stratum factor, which provides for a separate mean for the Horse Pasture, was clearly important, illustrating how that portion of the study area has much lower densities of penstemon and knapweed. There was modest evidence for a positive effect of aspect on counts, increasing towards the southwest. Slope steepness was clearly important for both species, most notably for Lemhi penstemon plants, rosettes, and flowering stalks, which tend to be most abundant on steeper slopes in the study area. The negative relationship between slope and knapweed was striking (Figure 17d). Adding a quadratic term for slope did not appear to contribute meaningfully for penstemon, although it did suggest that knapweed counts decrease at an increasing rate (a downward curve) as slope increases (Figure 17d). Both penstemon and knapweed populations appear to decrease with increasing NDVI (vegetation biomass), although this pattern did not hold for penstemon rosettes and inflorescence rates. As with slope, the quadratic form of NDVI suggested that decreasing knapweed counts accelerate as NDVI increases. There was no evidence that herbicide applications made during the last 3 years (affecting counts in 2013 and 2014) affected Lemhi penstemon. However, adding this indicator variable to the knapweed model had a very strong influence, reflecting the sharp inflection in knapweed counts from 2012 to 2013 (Figure 16). Finally, average counts for both species were apparently lower in burn block 1 than in the rest of the howitzer hill (the model intercept, estimates not shown), although higher than in the Horse Pasture (Figure 17). These differences were most pronounced in established plant counts (Figure 17a and 17d).

Table 1. Results from 2009-2014 surveys for Lemhi penstemon in the spatially-extensive 100 m² monitoring plots for the Howitzer Hill and Horse Pasture. Standard deviations are provided in parentheses. The Visitor Center census count results are included as well.

Subpopulation	Year	Plots	Plants	Frequency	$\bar{x}_{\text{Plants per m}^2}$	$\bar{x}_{\text{Rosettes}}$	$\bar{x}_{\text{Inflorescences}}$
Howitzer Hill	2009	75	61	0.25	0.0081(0.024)	3.7(3.1)	1.0(1.3)
	2010	149	76	0.19	0.0051(0.015)	4.2(2.6)	0.5(0.8)
	2011	60	97	0.30	0.0162(0.077)	2.7(2.7)	1.0(1.5)
	2012	99	120	0.24	0.0121(0.037)	4.7(4.8)	0.3(0.9)
	2013	100	111	0.35	0.0111(0.026)	7.5(7.2)	0.9(1.5)
	2014	100	184	0.36	0.0184(0.051)	9.9(7.8)	1.9(2.1)
Horse Pasture	2009	73	24	0.12	0.0033(0.012)	3.4(2.0)	0.6(0.6)
	2010	150	65	0.18	0.0043(0.014)	3.5(2.7)	0.4(0.6)
	2011	250	184	0.20	0.0074(0.025)	2.7(2.1)	1.2(1.5)
	2012	200	125	0.23	0.0063(0.015)	4.6(4.3)	0.4(1.2)
	2013	199	149	0.27	0.0075(0.018)	5.8(5.8)	0.5(0.9)
	2014	200	187	0.33	0.0094(0.022)	5.5(3.3)	1.1(0.9)
Visitor Center	2011	-	33	-	-	4.7(5.4)	1.9(3.8)
	2012	-	42	-	-	5.0(5.3)	0.2(0.7)
	2013	-	63	-	-	4.0(5.9)	0.2(0.7)
	2014	-	75	-	-	4.8(6.8)	1.1(3.1)

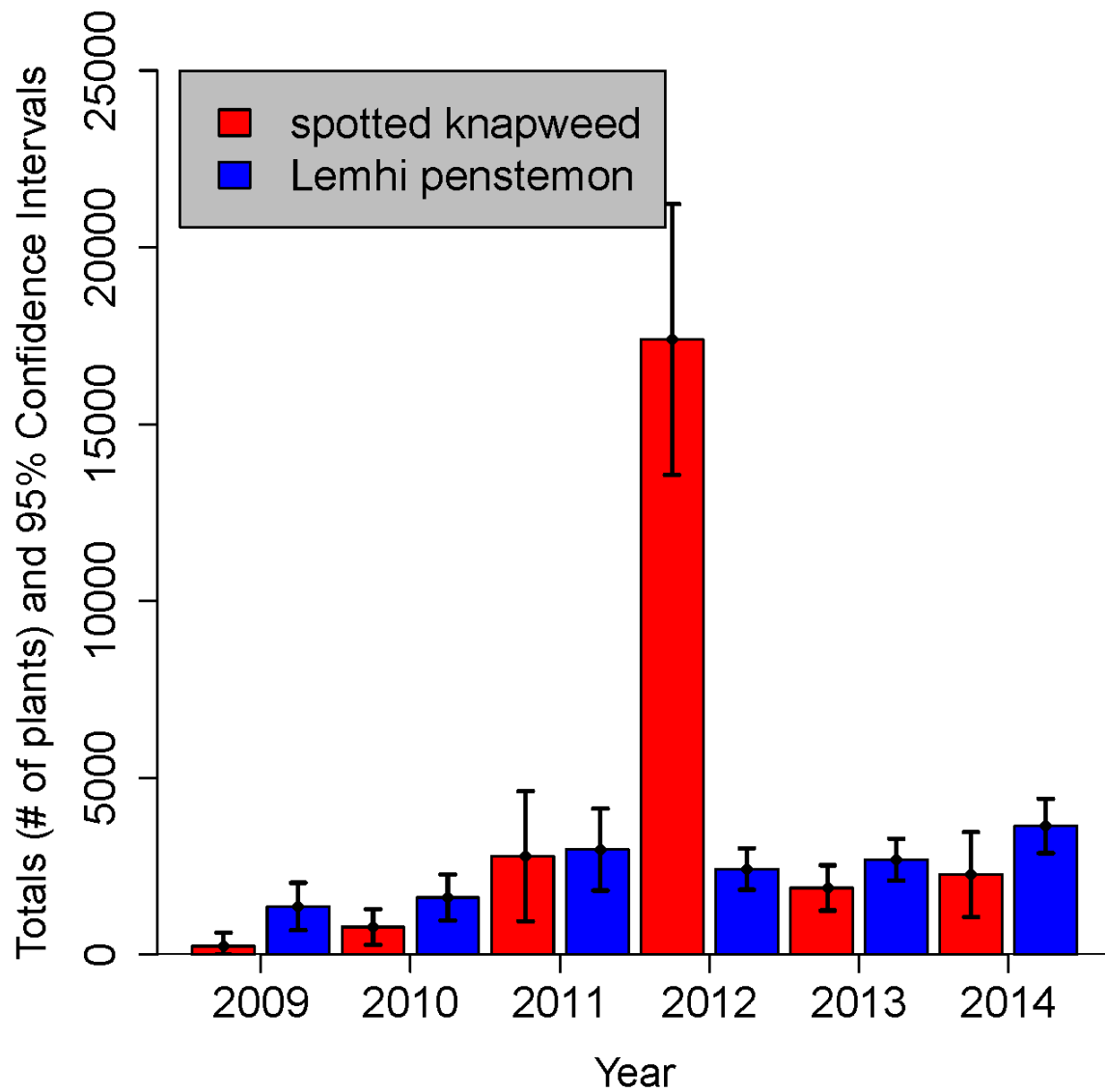


Figure 16. Population estimates (N) for spotted knapweed and established Lemhi penstemon plants in the Howitzer Hill and Horse Pasture hillslope study area of BIHO, 2009-2014.

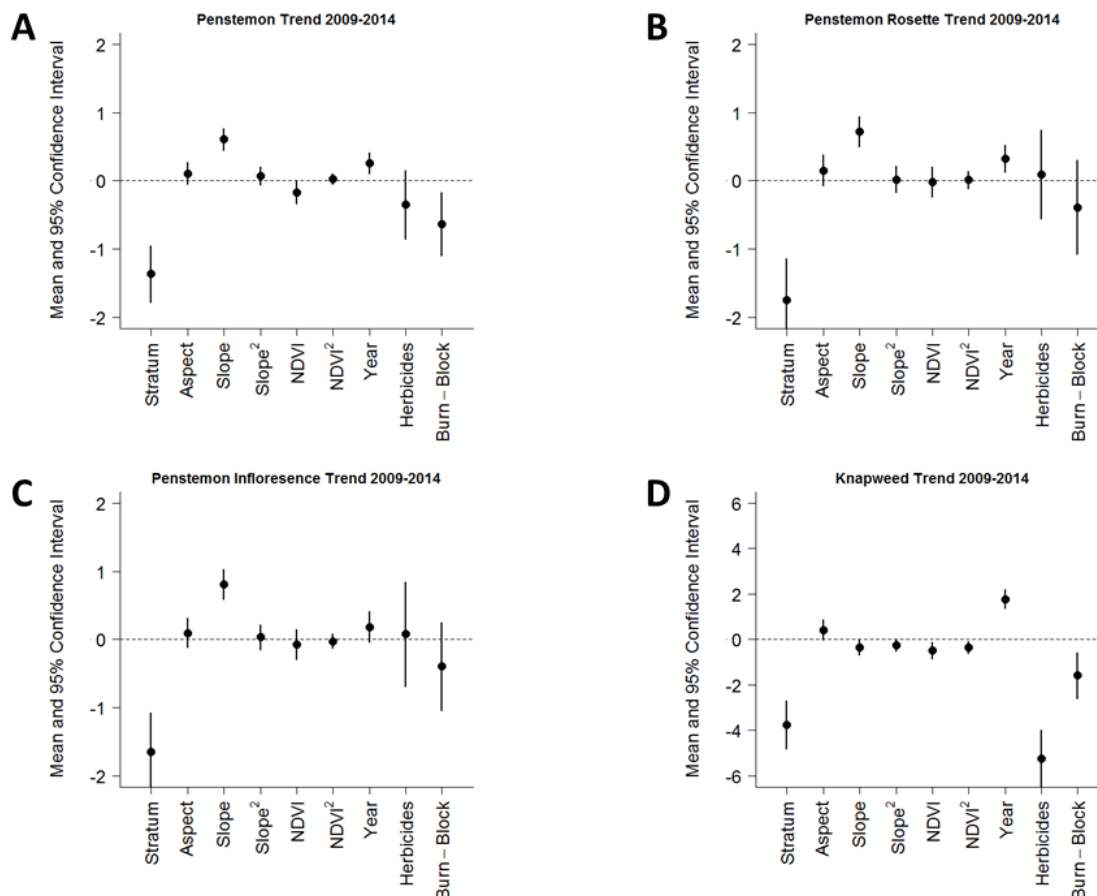


Figure 17. Regression coefficient estimates for population trend models of A) established Lemhi penstemon plants, B) Lemhi penstemon basal rosettes, C) Lemhi penstemon inflorescences, and D) spotted knapweed populations from extensive plot surveys conducted in the Howitzer Hill and Horse Pasture hillslope study area of BIHO, 2009-2014.

Intensive Plots

There was no evidence for short-term trend in number of penstemon plants based on the regression models fit to three years of intensive plot data (Figure 18a). However, there was evidence for an increase in the number of rosettes and inflorescences over the 3 years (Figure 18). Interestingly, seedling counts declined slightly in 2014, although confidence intervals were very wide for regression coefficients from the seedling model. Bare ground, slope, and NDVI were all positively associated with increases in plants, rosettes, inflorescences, and seedling counts, although the relative strength of influence of these factors varied among the 4 count responses (Figure 18). For example, bare ground was most influential for seedling counts, whereas slope appeared to be most influential for rosette counts (Figure 18). Turnover in penstemon plants within plots varied significantly along the slope and aspect gradient, but less significantly between the two transition periods (Figure 19).

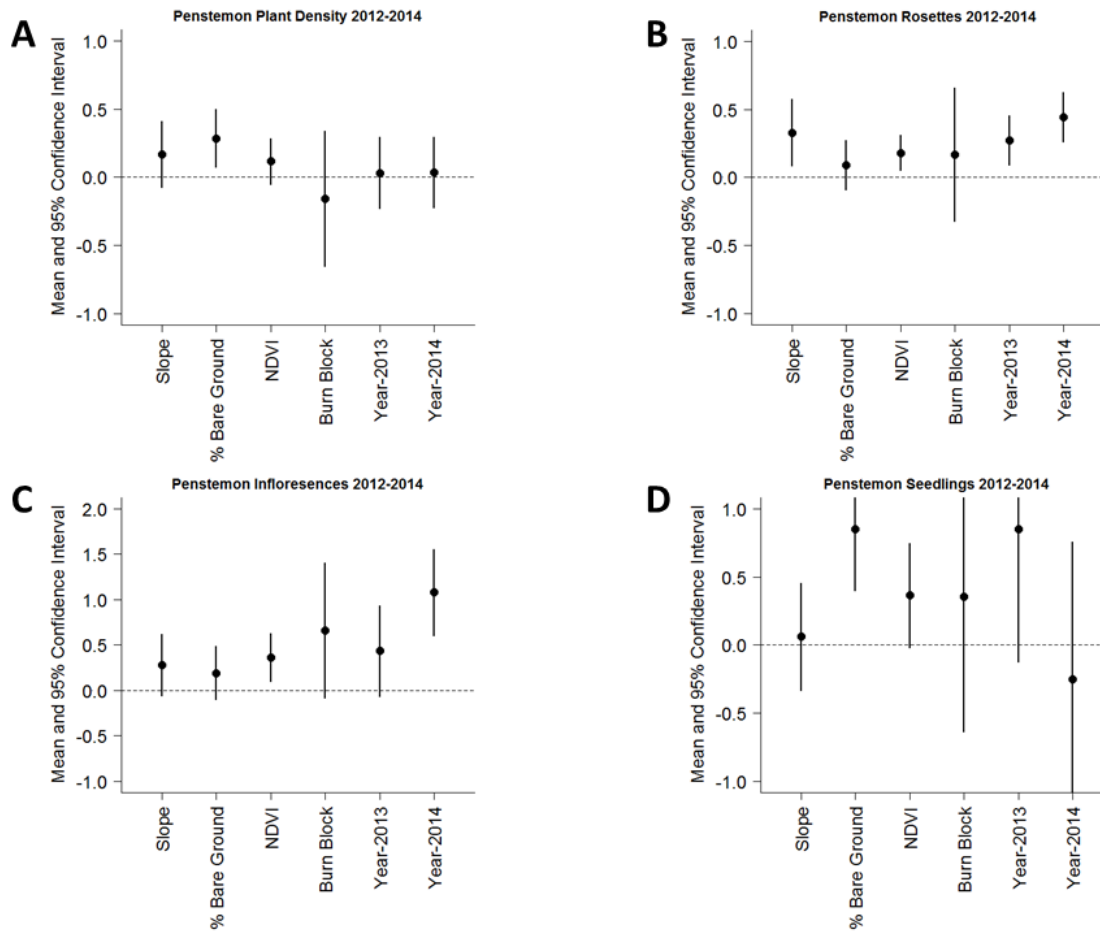


Figure 18. Regression coefficient estimates for Lemhi penstemon established plants, rosettes, flowers, and seedlings for intensive plots.

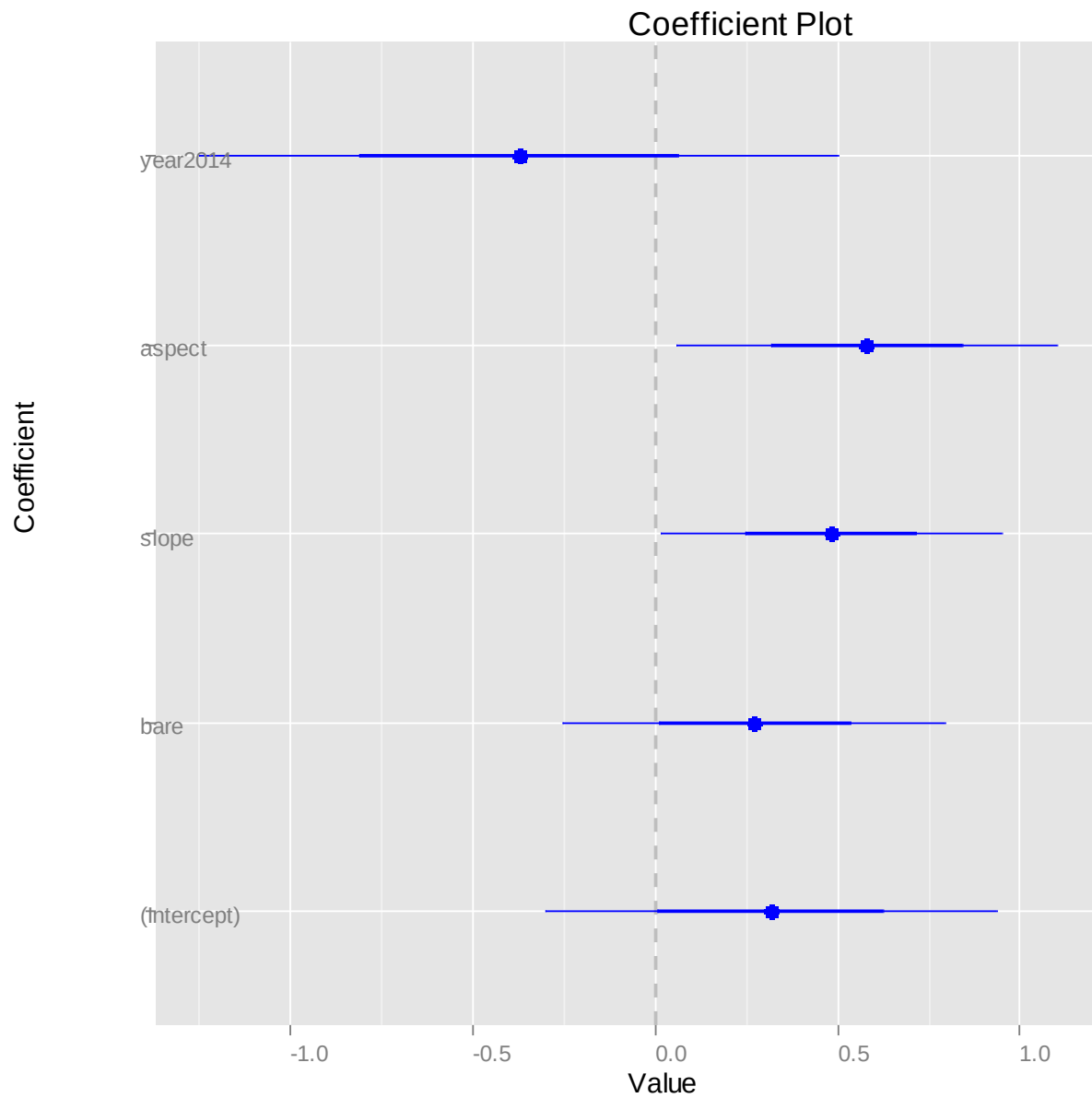


Figure 19. Regression coefficient plot for Lemhi penstemon established plant turnover between 2012-2013 and 2013-2014. Note weak evidence for fewer plants (higher losses, negative turnover) during the transition between 2013-2014 but a much stronger overall pattern of gains (higher positive turnover, empty plot quadrants becoming occupied) on steeper slopes and hotter aspects.

Discussion

This report presents results from the first 6 years of monitoring Lemhi penstemon and spotted knapweed in Big Hole National Battlefield (BIHO), including a 4-year census of a relocated historic subpopulation below the visitor center and 3-year preliminary insights from the study of plant demographic rates in a small number of intensive plots. There is unequivocal evidence that BIHO is home to the largest known population of Lemhi penstemon within its endemic range. There is strong evidence that the population has increased during the study period. An alarming spike in spotted knapweed appears to have been checked following a redoubling of effort by park management to control the infestation with herbicides. Evidence from this study suggests that penstemon and knapweed both may have benefitted from the above-average precipitation patterns during the study period. Interestingly, both penstemon and knapweed appear to favor bare soil conditions, presumably due to reduced competition from other perennial vegetation. However penstemon appears to favor steeper slopes, whereas knapweed was associated with flatter portions of the study area. These insights suggest that there is indeed a risk associated with using prescribed fire – during wet years knapweed may be able to aggressively respond to the increased bare ground microsites created by fire. The difference in affinity for slope between the two species may mediate the competition between the two species. Preliminary insights from the regression of counts of penstemon plant turnover (plant losses and gains) in intensive plots revealed no clear differences between years (2012-2013 and 2013-2014) but meaningful variation along the slope and aspect gradients. This is interesting because it suggests that habitat quality may indeed mediate demographic rates. For example, survival may be higher in better sites or when competition from other vegetation is lower. This presents an exciting opportunity for further study as monitoring continues in the coming years.

Literature Cited

- Elzinga, C. 1997. Habitat conservation assessment and conservation strategy for *Penstemon lemhiensis* (Lemhi Penstemon). Unpublished report to the U. S. Forest Service and Bureau of Management. Missoula, MT. Available on-line: <https://irma.nps.gov/App/Reference/Profile/2181243>.
- Fournier, D.A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimizing Methods Software* 27:233-249.
- Gelman, A., and J. Hill. 2007. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press, New York.
- Harris, B. 2013. Prescribed Fire Plan: Pasture Rx. Big Hole National Battlefield. Plan. Available on-line: <https://irma.nps.gov/App/Reference/Profile/2215791>.
- Heidel, B. and J. S. Shelly. 2001. The effects of fire on Lemhi penstemon (*Penstemon lemhiensis*) – final monitoring report, 1995-2000. Report to the Beaverhead-Deerlodge National Forest and the Dillon Field Office – Bureau of Land Management. Montana Natural Heritage Program, Helena, MT. Available on-line: <https://irma.nps.gov/App/Reference/Profile/2194307>.
- Hilbe, J. M. 2011. Negative binomial regression. 2nd edition. Cambridge University Press, UK.
- Hitchcock, C. L., A. Cronquist, M. Ownbey, and J. W. Thompson. 1959. Vascular Plants of the Pacific Northwest, Pt. 4. University of Washington Press, Seattle.
- Hitchcock, C. L., and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle.
- Kincaid, T. M. and Olsen, A. R. 2013. spsurvey: Spatial Survey Design and Analysis. R package version 2.6. Available on-line: <http://www.epa.gov/nheerl/arm/>.
- Lesica, P. 1987. A technique for monitoring nonrhizomatous perennial plant species in permanent belt transects. *Natural Areas Journal* 7:65-68.
- McDonald, T. L. 2003. Review of environmental monitoring methods: survey designs. *Environmental Monitoring and Assessment* 85:277-292.
- National Park Service (NPS). 2008. National Park Service cultural landscape inventory: Big Hole National Battlefield Site. Unpublished Report. National Park Service Pacific West Regional Office, Seattle, WA.
- NatureServe. 2014. *Penstemon lemhiensis*: Lemhi beardtongue. NatureServe explorer: an online encyclopedia of life. Version 7.1. Available on-line: http://explorer.natureserve.org/servlet/NatureServe?sourceTemplate=tabular_report.wmt&loadTe

[mplate=species_RptComprehensive.wmt&selectedReport=RptComprehensive.wmt&summaryView=tabular_report.wmt&elKey=149938&paging=home&save=true&startIndex=1&nextStartIndex=1&reset=false&offPageSelectedElKey=149938&offPageSelectedElType=species&offPageYesNo=true&post_processes=&radiobutton=radiobutton&selectedIndexes=149938.](#)

- R Development Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (<http://www.R-project.org>).
- Ramstetter, J. 1983. An ecological study of the regional endemic *Penstemon lemhiensis* (Keck) Keck and Cronq. (Scrophulariaceae). M.S. Thesis, University of Montana, Missoula.
- Rodhouse, T. J., and D. S. Stucki. 2013a. Lemhi penstemon monitoring in Big Hole National Battlefield: 2012 annual report. Natural Resource Technical Report NPS/UCBN/NRTR—2013/733. National Park Service, Fort Collins, Colorado.
- Rodhouse, T. J., and D. S. Stucki. 2013b. Lemhi penstemon monitoring in Big Hole National Battlefield: 2013 annual report. Natural Resource Technical Report NPS/UCBN/NRTR—2013/805. National Park Service, Fort Collins, Colorado.
- Rodhouse, T. J., D. S. Stucki, J. W. Lyon, M. Lonneker, and G. H. Dicus. *In revision*. Population monitoring protocol for Lemhi penstemon (*Penstemon lemhiensis*) and spotted knapweed (*Centaurea stoebe*) in Big Hole National Battlefield: Narrative version 1.0. Natural Resource Report NPS/UCBN/NRR—2015/XXX. National Park Service, Fort Collins, Colorado.
- Skaug H., D. Fournier, B. Bolker, A. Magnusson, and A. Nielsen. 2014. Generalized Linear Mixed Models using AD Model Builder. R package version 0.8.0.
- Stevens, D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. *Environmetrics*. 14:593-610.
- Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* **99**:262-278.
- Stucki D. S., and T. J. Rodhouse. 2009. Distribution and abundance of Lemhi penstemon (*Penstemon lemhiensis*) at Big Hole National Battlefield: 2009 inventory report. Natural Resource Technical Report NPS/UCBN/NRTR—2009/239. National Park Service, Fort Collins, Colorado.
- Stucki, D. S., T. J. Rodhouse, J. W. Lyon, and L. K. Garrett. 2013. Natural resource conservation in a cultural park: evaluating the importance of Big Hole National Battlefield to the endemic Lemhi penstemon (*Penstemon lemhiensis*). *Natural Areas Journal* 33:50-58.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 341/131807, March 2016

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA TM