

Vegetation Monitoring to Detect and Predict Vegetation Change: Connecting Historical and Future Shrub/Steppe Data in Yellowstone National Park

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Abstract

A 2002 National Research Council (NRC) evaluation of ungulate management practices in Yellowstone specifically concluded that previous (1957 to present) vegetation monitoring efforts were insufficient to determine whether climate or ungulates were more influential on shrub/steppe dynamics on the northern ungulate winter range. The NRC further recommended that the National Park Service employ more contemporary and acceptable “range” monitoring efforts in the future that allow for deterministic analyses of vegetation change. In response to these recommendations, we have begun to develop and test new, more robust methods for sampling vegetation on Yellowstone National Park’s northern range, while maintaining a connection to over 50 years of historical data. In 2009 we sampled transects associated with existing vegetation exclosures using historical (transects) and new (multi-scale circular plots) methods simultaneously. In 2010 we expanded our methods comparison and collaborated with the National Ecological Observatory Network planning and design phase to map the occurrence of several non-native species of interest to the park. The overall objectives of the project are to provide: 1) a comparison of sampling methods, particularly their ability to detect changes in native and non-native species presence/absence and cover; 2) an expanded monitoring design that samples “missing” vegetation types and considers the landscape scale and the National Ecological Observatory Network northern range site; and 3) example forecasts of the presence of native and non-native species of interest under climate change scenarios. Here we provide an overview of the project to date.

Introduction

The northern range of Yellowstone National Park, comprised of the Lamar and Yellowstone River drainages, is important winter habitat for many of the ungulates that reside in higher-elevation areas of the park during summer. These wintering grounds extend beyond the northern edge of the park into Montana and are commonly thought to be essential to the fitness of the ungulate populations that utilize them. The ecology of the northern range has long been, and continues to be, at the center of debates over the Park Service’s management of these populations (Huff and Varley 1999).

The composition and integrity of vegetative communities on these grazing lands has been the subject of extensive research (Yellowstone National Park 1997),

and this landscape has changed considerably over the past century. It remains unclear, however, which factors are responsible for driving these changes and how the driving factors will alter this ecosystem in the future. A 2002 National Research Council (NRC) evaluation of ungulate management practices specifically concluded that previous (1957 to present) vegetation monitoring efforts were insufficient to determine whether climate change or ungulates were more influential on shrub/steppe dynamics on the northern ungulate winter range. The NRC further recommended that the National Park Service employ more contemporary and acceptable “range” monitoring efforts in the future that allow for deterministic analyses of vegetation change.

In response to these recommendations, we have begun to test new, more robust methods of sampling vegetation and groundcover on Yellowstone's northern range, while maintaining a connection to over 50 years of historical data. In 2009 (Chong et al. 2010) and 2010 we sampled transects associated with existing vegetation exclosures across the northern range using historical (transects) and new (multi-scale circular plots) methods simultaneously. Here we present preliminary results from two sets of data from these exclosures, Gardiner and Blacktail, that were obtained using a contemporary, multi-scale circular plot sampling technique (Barnett et al. 2007). We also mapped distributions of several non-native species of interest, which were incorporated into models of spatial distribution variability. The spatial distribution models are being developed in order to forecast the presence of native and non-native species of interest under climate change scenarios and to help locate additional vegetation sampling locations.

Our research aims to integrate three influences that can profoundly impact this important landscape: land use, climate change, and invasive species. Many researchers have studied these interrelated topics from a variety of angles and more will continue to do so. We present one option for how vegetation data might be collected and analyzed to provide managers, scientists, and the public with possible answers to the question: "what plants might grow on Yellowstone's northern range in a future with a different climate and with varied resource management actions?"

Methods

Multi-Scale Circular Plot Vegetation Sampling. In July and August 2009 we sampled 36, 168-m² circular, multi-scale vegetation plots modified from the National Forest Service Inventory and Analysis (FIA) Program (Fraye and Furnival 1999; Barnett et al 2007; Figure 1). Species composition, foliar cover and height, and cover of abiotic variables (e.g., rock, litter, bare soil) were recorded in three 1-m² subplots nested within the 168-m² plot. (Species codes and species nativity follow the PLANTS Database [USDA NRCS 2011].) Species composition was also recorded for the entire 168-m² plot. The circular plots were placed in and adjacent to four grazing exclosures that were constructed in 1957 and 1962. These 2-hectare exclosures are located on the Blacktail Plateau (two exclosures, nine plots) and on the Gardiner Bench west of the Roosevelt

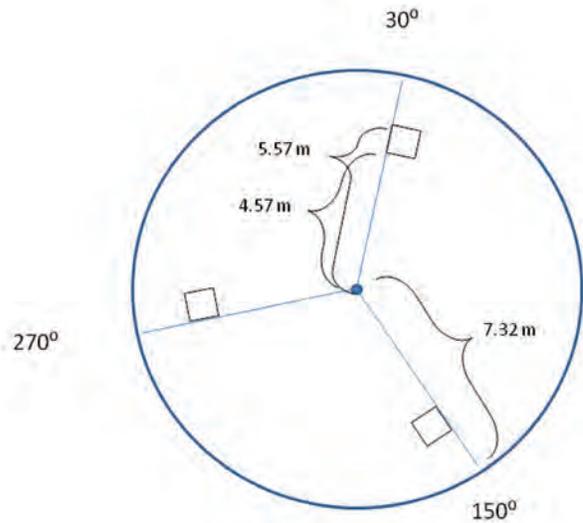


Figure 1. Multi-scale circular plot. Square subplots are 1 m x 1 m.

Arch (two exclosures, 19 plots). These plots were centered on the midpoint of historical 100-foot transects. Eight additional plots were sampled in and around the Blacktail Plateau exclosures in July 2010.

Non-native Plant Species Mapping. In July and August 2010, we used global positioning system (GPS) receivers to locate and record the presence of non-native species of concern (pale madwort, *Alyssum alyssoides*; desert madwort, *Alyssum desertorum*; annual wheatgrass, *Agropyron triteceum*; and cheatgrass, *Bromus tectorum*). Our mapping efforts were largely limited to easily accessible areas along roads or trails, but, when possible, we surveyed away from these areas until the limit of occurrence was reached. We also acquired mapping data for these species of interest collected on the northern range that were compiled and distributed by the Greater Yellowstone Coordinating Committee's Invasive Species Working Group (Greater Yellowstone Coordinating Committee 2006).

Vegetation Modeling. By integrating field data with descriptions of the landscape and climate, models provide an opportunity to understand the processes (causation) associated with observed patterns (description) of vegetation (Kerr et al. 2007; McMahon et al. 2009). Habitat suitability models describe the environmental conditions that most overlap a species' distribution and project that relationship across a defined space. The accuracy of habitat suitability models depends on the number and distribution of observed presence locations, the completeness of the species surveys, and the resolution

and relatedness of predictor layers in the models (e.g., climate, geology and soils, vegetation, and remote sensing layers). Once a habitat suitability map is generated, it can be validated by withholding some of the occurrence data for testing, or through new survey data.

We used a Maxent (Elith et al. 2006; Phillips et al. 2006) species-habitat matching model to estimate the distributions of the non-native species of interest under current climate and land use. Maxent employs a machine learning method based on the principal of maximum entropy to probabilistically describe locations (grid map cells) with conditions conducive to species occurrence based on individual environmental variables. Environmental variables we used included: topographic characterizations, remotely sensed Landsat 7 data, and 19 bioclimatic variables (Hijmans et al. 2005) derived from monthly total pre-

cipitation and monthly mean, minimum, and maximum temperature as compiled by WorldClim (www.worldclim.org). Climate data reflect averages from 1960–1990. Cross-correlated environmental variables were removed ($r > 0.8$), and we report the Maxent test area under the curve (AUC) values generated from 25 model iterations with 15 percent of the location data withheld to test the accuracy of the model.

Results

We identified the same number (63) of total plant species in our 168-m² circular plots at the Gardiner and Blacktail grazing exclusion sites. The Jaccard's coefficient of similarity between sites was 0.24, which means 24 percent of the species found occurred at both sites ($J = 1.0$ is complete similarity). The Jaccard's coefficient comparing species

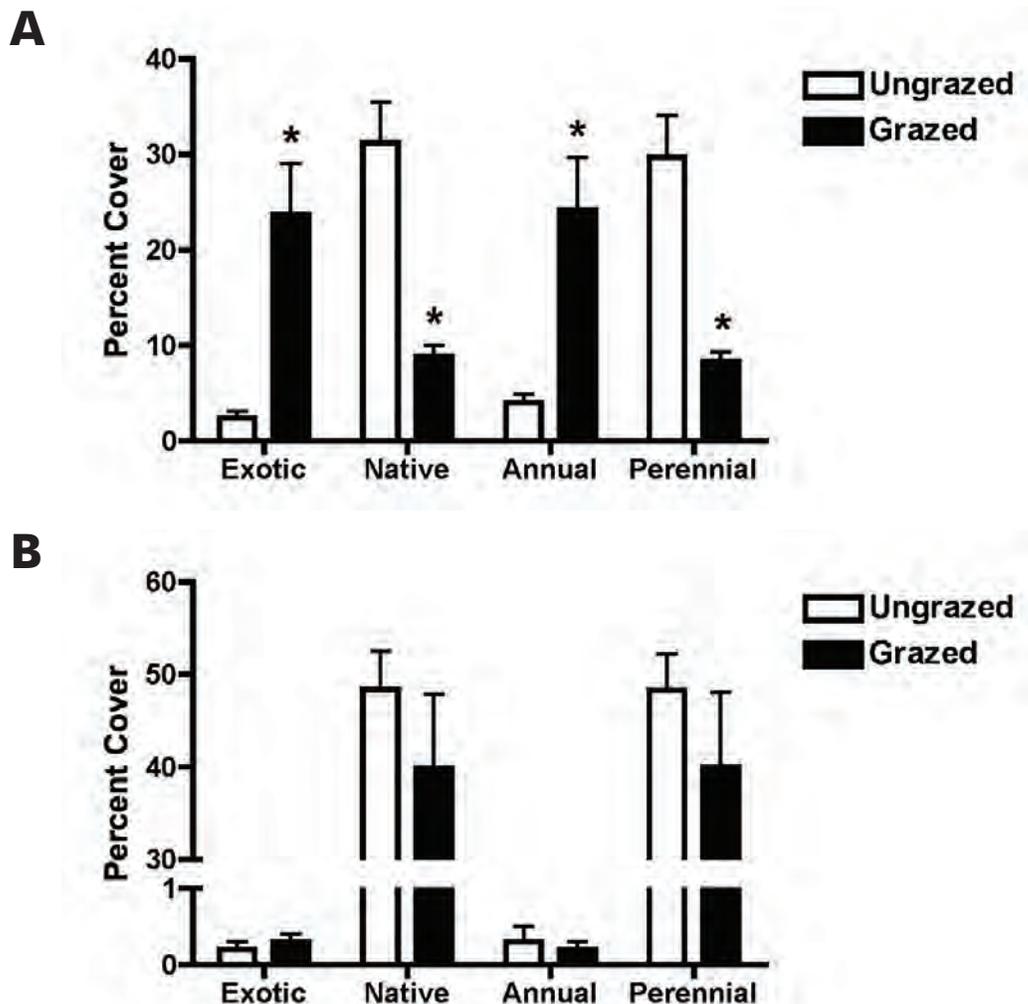


Figure 2. Percentage cover data from A) Gardiner and B) Blacktail exclusions in Yellowstone National Park. Asterisk indicates significant difference between grazed and ungrazed ($p < 0.001$, two-tailed t-test).

Table 1. The mean \pm standard error of the mean (SEM) number of plant species sampled in circular plots in and around exclosures in Yellowstone National Park. The number of plots sampled for each treatment are listed in parentheses.

	Species per plot (mean \pm S.E.M)			
	Gardiner		Blacktail	
	Ungrazed (11)	Grazed (8)	Ungrazed (10)	Grazed (7)
Total	21.5 \pm 1.9	23.1 \pm 1.7	18.6 \pm 1.5	22.1 \pm 1.8
Native	18 \pm 1.6	16.5 \pm 1.0	18.0 \pm 1.5	21.1 \pm 1.6
Non-native	3.5 \pm 0.5	6.6 \pm 0.8	0.7 \pm 0.2	1.2 \pm 0.2

Table 2. Percentage cover data from exclosures in Yellowstone National Park. Asterisk indicates significant difference between grazed and ungrazed ($p < 0.001$, two-tailed t-test).

	Percentage cover (mean \pm S.E.M)			
	Gardiner		Blacktail	
	Ungrazed	Grazed	Ungrazed	Grazed
Vegetation	33.6 \pm 4.6	32.6 \pm 5.7	48.6 \pm 4.1	40.2 \pm 8.0
Veg: Native	31.2 \pm 4.3	8.9 \pm 1.1*	48.4 \pm 4.1	39.9 \pm 8.0
Veg: Non-native	2.4 \pm 0.7	23.7 \pm 5.3*	0.2 \pm 0.1	0.3 \pm 0.1
Veg: Annual	4.0 \pm 0.9	24.2 \pm 5.4*	0.3 \pm 0.2	0.2 \pm 0.1
Veg: Perennial	29.7 \pm 4.3	8.4 \pm 0.9*	48.3 \pm 3.9	40.0 \pm 8.0
Abiotic	69.3 \pm 5.5	66.0 \pm 9.7	57.9 \pm 5.1	59.1 \pm 8.8
Abio: Litter	11.8 \pm 4.7	11.5 \pm 6.3	11.9 \pm 2.7	6.6 \pm 2.3
Abio: Rock	34.3 \pm 4.2	21.9 \pm 4.5	27.4 \pm 3.9	34.5 \pm 7.2
Abio: Soil	19.8 \pm 3.5	29.0 \pm 6.5	16.4 \pm 2.7	16.0 \pm 2.2

Table 3. Top species by percentage occurrence. Species codes (USDA, NRCS 2011): *Agropyron spicatum*, Agsp; *Agropyron triteceum*, Agtr5; *Alyssum desertorum*, Alde; *Allium textile*, Alte; *Antennaria microphylla*, Anmi3; *Artemesia frigida*, Arfr4; *Artemesia tridentata*, Artr2; *Atriplex gardneri*, Atga; *Camelina microcarpa*, Cami2; *Elymus elymoides*, Elel5; *Festuca idahoensis*, Feid; *Koeleria cristata*, Kocr; *Poa secunda*, Pose.

	Percentage Occurrence							
	Gardiner				Blacktail			
	Ungrazed		Grazed		Ungrazed		Grazed	
Alde	77.3	Agtr5	100.0	Feid	95	Kocr	89.3	
Agsp	68.2	Alde	93.8	Kocr	85	Feid	78.6	
Artr2	65.9	Elel5	71.9	Artr2	82.5	Agsp	75.0	
Pose	65.9	Atga	59.4	Agsp	77.5	Arfr4	71.4	
Alte	61.4	Cami2	53.1	Anmi3	67.5	Pose	64.3	
				Pose	67.5			

Table 4. Top five species by average cover. Species codes (USDA, NRCS 2011): *Agropyron spicatum*, Agsp; *Agropyron triteceum*, Agr5; *Alyssum desertorum*, Alde; *Antennaria microphylla*, Anmi3; *Artemesia frigida*, Arfr4; *Artemesia tridentata*, Artr2; *Atriplex gardneri*, Atga; *Festuca idahoensis*, Feid; *Koeleria cristata*, Kocr; *Opuntia polyantha*, Oppo; *Poa secunda*, Pose; *Sarcobatus vermiculatus*, Save4.

Average Cover							
Gardiner				Blacktail			
Ungrazed		Grazed		Ungrazed		Grazed	
Artr2	12.9	Agr5	10.9	Artr2	20.9	Feid	13.5
Pose	2.9	Alde	10.5	Feid	8.4	Agsp	5.8
Agsp	2.8	Atga	1.5	Anmi3	4.4	Artr2	5.3
Atga	2.4	Pose	1.5	Agsp	2.8	Kocr	2.4
Oppo	2.0	Save4	1.0	Kocr	2.0	Arfr4	2.3

Table 5. Average cover of non-native species of interest. Species codes (USDA, NRCS 2011): *Agropyron triteceum*, Agr5; *Alyssum desertorum*, Alde; *Bromus japonicus*, Brja; *Bromus tectorum*, Brte.

Average Cover				
	Gardiner		Blacktail	
	Ungrazed	Grazed	Ungrazed	Grazed
Agr5	0.06 (0.06)	10.9 (2.6)*	0.0	0.0
Alde	1.4 (0.4)	10.5 (3.0)*	0.0	0.0
Brja	0.71 (0.35)	0.85 (0.69)	0.0	0.0
Brte	ND	0.79 (0.74)	0.0	0.0

similarity in and around the grazing exclosures was 0.54 and 0.60 for the Gardiner and Blacktail areas, respectively. We sampled similar numbers (approximately 50) of total species inside and adjacent to the exclosures at each of the sites. The mean values of plant species found per plot were similar across treatment areas (approximately 20, Table 1). In general, though not statistically significant, more non-native species were encountered at the Gardiner site, and, about twice as many non-natives were found in the grazed plots than the ungrazed plots at this site (Table 1).

Cover data from the 1-m² subplots from the Gardiner exclosures illustrate significant differences between the cover of native or non-native species in grazed and ungrazed areas (Figure 2A). The Gardiner exclosure had significantly more non-native vegetation cover, more annual cover, and less perennial cover (Table 2). In contrast, similar differences were not found in and around the Blacktail exclosures (Figure 2B). No statistically significant differences were found in the cover of total vegetation or various abiotic cover types between grazed and ungrazed areas at either site (Table 2). The differences in vegetation between the grazed and ungrazed areas of the Gardiner site

are further highlighted by examining the top species by occurrence (Table 3) and cover (Table 4). In grazed areas at the Gardiner site, three out of the top five species by occurrence were non-native, with *Agropyron triteceum* and *Alyssum desertorum* occurring in 100 percent and 94 percent of the measured areas, respectively. Additionally, these two non-native plants averaged 10 percent cover (Tables 4 and 5). In contrast, in ungrazed Gardiner plots *Alyssum desertorum* occurred with less frequency and was the only non-native species listed in the top five species by occurrence (Table 3). Furthermore, the top five species by cover inside the Gardiner exclosures (ungrazed) were all native species. We also found that *Artemesia tridentata* (big sagebrush) occurred with greater frequency (Table 3) and had greater cover (Table 4) in ungrazed areas at both sites. It is notable that non-native species are absent from the top five species lists for occurrence and cover at the Blacktail site (Tables 3 and 4).

The Maxent analysis of the contribution of independent variables to describing cheatgrass (*Bromus tectorum*) distribution shows elevation was the most influential in the cheatgrass model (Figure 3). The logistic

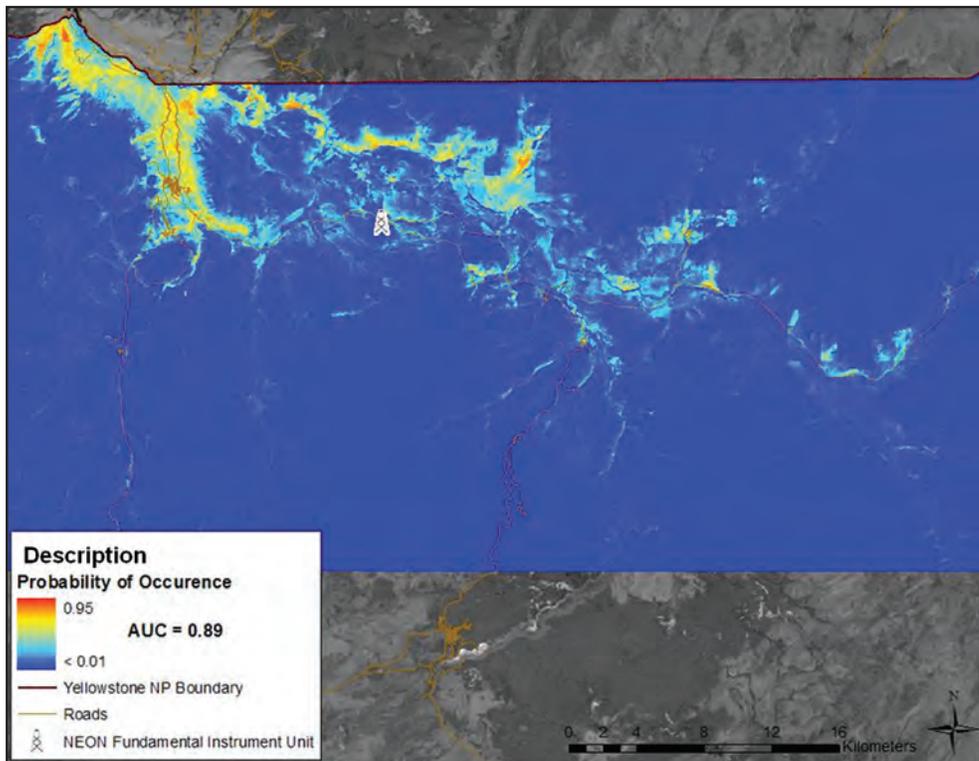


Figure 3. The probability of occurrence of cheatgrass as described by maximum entropy modeling with a variety of climate, topographic, and biotic descriptors of the landscape as influential independent variables. The National Ecological Observatory Network (NEON) Fundamental Instrument Unit indicates a potential area of location, not an actual location. The area under the curve (AUC) is an indicator of the amount of variation explained by the model.

response curve for elevation (describing logistic response as each elevation is varied, keeping all other independent variables at average sample value) reached a maximum at 1,700 m (Figure 4), which indicates that cheatgrass is currently most often observed around 1,700 m elevation. Other influential variables in the model included tassel cap soil brightness (a moisture index), vegetation type, precipitation of the wettest annual quarter, landform, and the annual range in temperature (Figure 3).

Discussion

To best detect and forecast change in response to climate variability and management actions, vegetation monitoring designs should consider needs for field data collection, management, and multi-scale analyses. The National Ecological Observatory Network (NEON) Northern Rocky Mountain domain includes Yellowstone National Park's northern range and provides an opportunity to collaborate with NEON's investigations into scaling models of plant species distributions from plots, to landscapes, to regions, and forecasting changes in species distributions related to climate change.

Spatial analyses of species distributions, such as the example we presented here of the current distribution of the non-native, annual cheatgrass, will provide information on where additional sampling sites should be established. The Maxent model to describe current cheatgrass distribution, for example, could be used with climate change scenario data (e.g., changes in precipitation and temperature) to describe potential future distribution and thus direct management action. Models of other species' current distributions could be used to test the strength of existing data and thus guide the placement of new monitoring sites.

Because long-term exclosures reflect inherent site differences and effects caused by grazing and the exclusion of grazing, our data are descriptive and not explanatory. Although extensive sampling techniques are not necessary for the trained eye to perceive differences in grazing effects between the current, predominant vegetation in the Gardiner and Blacktail areas, differences must be quantified to allow comparisons through time and space to detect and respond to change. Our initial analyses confirm that there are significant vegetative differences between the Gardiner and Blacktail exclosure sites. That the cover of native and

non-native species was found to be significantly different between grazed and ungrazed plots for the Gardiner exclosures, but not the Blacktail exclosures suggests that these differences are not solely attributable to ungulate grazing effects. Rather, they likely reflect a variety of factors including, but not limited to, climate, soil chemistry, human influence, and grazing. However, *Artemisia tridentata* occurred with greater frequency (Table 3) and had greater cover (Table 4) in ungrazed areas at both sites, suggesting that grazing may be a driving factor for this species.

Mapping efforts to determine the extent of four non-native annuals, including two mustards, *Alyssum desertorum* and *A. alyssoides*, and two grasses, *Agropyron triteceum* and *Bromus tectorum* (data compiled by the Greater Yellowstone Coordinating Committee), laid a foundation for modelling efforts to predict where these species may spread under various climate change scenarios. We were concerned about these species dominating and expanding because they degrade rangeland. Issues with range degradation include reduced palatability (e.g., phytoliths), nu-

trition, productivity (carbon sequestration), soil fertility and water holding capacity, increased fire frequency, and, related to climate change, phenology or timing of resource availability (e.g., early green-up and early senescence result in reduced forage availability in the winter). The current probable distribution of cheatgrass (Figure 3) is of concern because of its potential to spread in the northern range at the expense of native vegetation that provides more valuable forage and other ecosystem services.

The Gardiner Bench area, which is the hottest and driest part of the park, has become dominated by a few annual, non-native plant species (e.g., *Alyssum alyssoides*, *A. desertorum*, *Agropyron triteceum*, and *Bromus tectorum*). Our mapping efforts suggest that while *Bromus tectorum* is relatively widespread throughout the northern range, the range of *Agropyron triteceum* does not currently extend up the Gardiner River drainage beyond the Boiling River. Similarly, while both species of *Alyssum* occur sporadically throughout the northern range from Gardiner to the Lamar Valley, *A. desertorum* dominates vast expanses at the

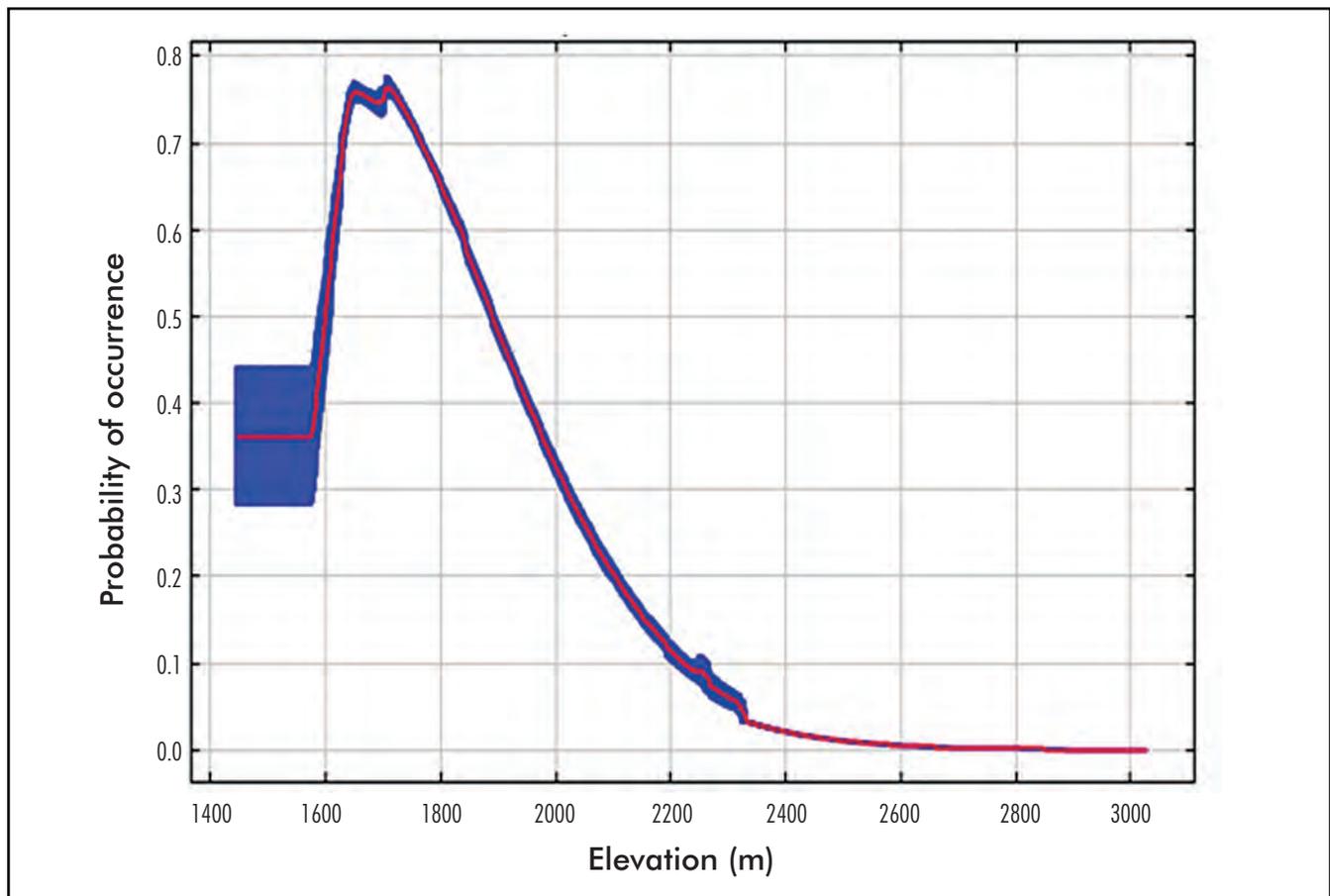


Figure 4. The probability of cheatgrass occurrence as described by elevation. The curves show the mean response of the 25 replicate Maxent runs (red) and the mean +/- one standard deviation (blue).

lower elevations of the Gardiner area. Under certain climate change scenarios these species may expand into other portions of the northern range, with potentially negative consequences for critical winter habitat.

In summary, ecosystems change in response to climate, land use, and invasive species. Species distribution modeling is a tool that integrates knowledge of how vegetation has already changed and predictions of how it may change in the future to manage risks to critical habitat. For example, managers could use spatial distribution models to develop non-native species control and native species restoration plans. The connections between field-based data and modelling are critical to provide natural resource managers with methods of sampling vegetation that detect change and with hypotheses of the drivers of change, and thus ways to model future vegetation distributions. Here we have presented one possible use of plot and ground-based vegetation data in non-spatial analyses and spatial models. We hope that advancing correlations between past and present sampling techniques and using modelling techniques to explore how plants may be distributed under changes in climate will allow natural resource managers to make decisions that allow for adaptation to change and/or risk management.

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