ITERATIVE SAMPLING OF NON-NATIVE PLANT SPECIES AT HART MOUNTAIN NATIONAL ANTELOPE REFUGE

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INTRODUCTION

Plant invasions occur when species are transported to, and establish in new and often distant ranges (Elton, 1958; Mack et al., 2000). Many of these species, referred to here as weeds, invasive, exotic, and non-native plant species, are implicated in the listing of at least 42% of all species protected by the Endangered Species Act, and pose the second most important threat to biodiversity (Randall, 1996; Wilcove et al., 1998). Non-native plant species directly compete with native species (Westbrooks, 1998) and preferred forage, alter ecological processes such as hydrologic (Mack et al., 2000) and nutrient cycles (Vitousek et al., 1987), and change fire and other disturbance regimes (D'Antonio & Vitousek, 1992; D'Antonio et al., 1999). In short, the invasion process challenges the Fish and Wildlife Service mission to protect wildlife habitat and native plant species communities on National Wildlife Refuge System lands.

Created in 1936 to maintain remnant herds of pronghorn antelope, Hart Mountain National Antelope Refuge now manages all wildlife species and native ecosystems characteristic of the high desert environment. A 1994 management plan removed cattle and prescribed fire to restore native communities and enhance wildlife habitat after a century of livestock grazing and fire suppression. Plant invasions interact with these management practices and may be disrupting the desired outcome. Ongoing control and monitoring in conjunction with the Oregon department of agriculture has found that Cheatgrass (*Bromus tectorum*), an annual grass from Eurasia, seems to be invading burned areas, other disturbed areas, and riparian corridors.

An understanding that the invasive plant species problem was larger than the eight species frequently controlled at the Refuge (Table 1) highlighted the need for an expanded invasive plant species investigation. Funding secured by the Invasive Species Program of the National Wildlife Refuge System and the National Wildlife Refuge Association will provide training, tools, and volunteers who will map the composition and distribution of non-native plant species in the summer of 2006. Mapping with many volunteers may locate previously undetected or new species that, if needed, could be eradicated before expansive increases in distribution, and will certainly provide a better understanding of the distribution of invasive plant species across the landscape.

Table 1. A list of controlled and monitored non-native plant species.

Common Name	Scientific Name
Canada thistle	*Cirsium arvense*
cheatgrass	*Bromus tectorum*
Dyer's woad	*Isatis tinctoria*
hoary cress / whitetop	*Cardaria draba*
Mediterranean sage	*Salvia aethiopis*
perennial pepperweed	*Lepidium latifolium*
Russian knapweed	*Acroptilon repens*
Scotch thistle	*Onopordum acanthium*

Few sampling efforts, even when augmented by the inexpensive labor of volunteers, can afford to sample an entire landscape. This holds for the nearly half-million acres of Hart Mountain National Antelope Refuge and highlighted the need for prioritization to maximize the volunteer effort. The Iterative Sampling Design (Fig. 1)

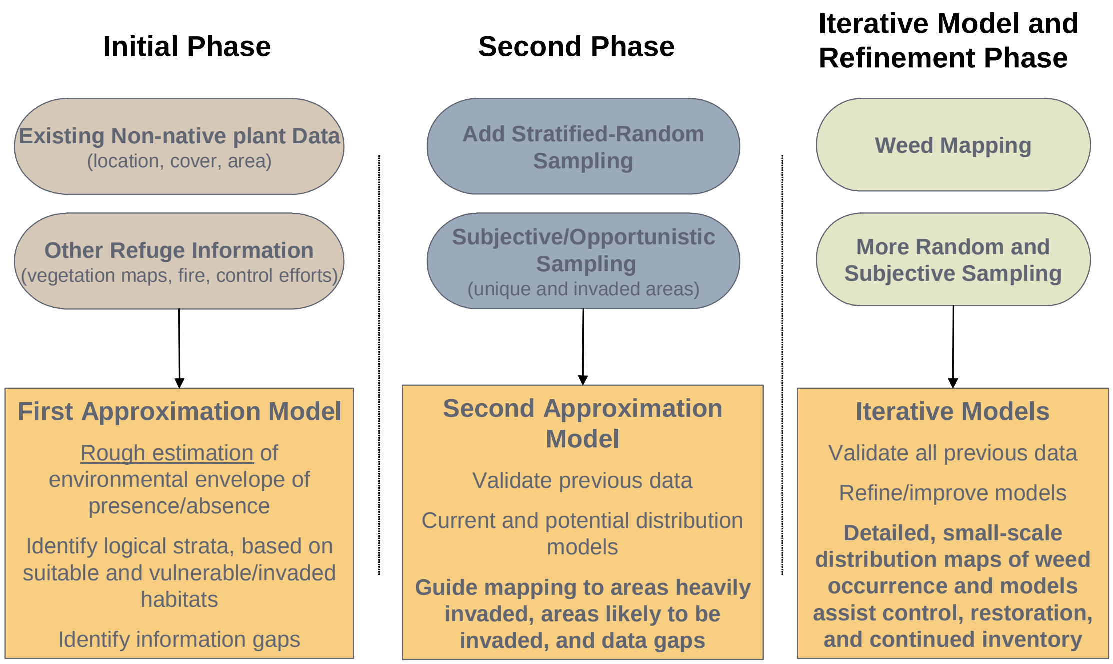


Figure 1. The Iterative Sampling Design.

suggests that successive inventories, each building on previous results, more efficiently provides an understanding or picture of invasion across the landscape. In the Initial Phase we gathered and assessed some of the existing non-native plant species information at the Refuge. This report describes the Second Phase: A stratified-random plot sampling and mapping effort designed to assess vulnerable habitats and model the cover and distribution of invasive plant species. The inventory attempted to answer two questions: 1) what/where are the non-native plant species; and 2) what is their relationship to fire. The results and models (Second Approximation Model, Fig. 1) of this investigation can direct mapping to refine species lists, fine-scale distributions, and improve models and the understanding of the invasion picture at Hart Mountain National Antelope Refuge.

METHODS

In July 2004, we located non-native plant species with mapping techniques, and sampled native and non-native plant species with a plot-based design at Hart Mountain National Antelope Refuge. A north-south fault-block causes an 1,219-m uplift on the western edge of the Refuge. The north-south ridge at the top of this escarpment gives way to the bulk of the refuge which slopes gently to the east encompassing a gradation of mountain big sage (*Artemisia tridentata* ssp. *vaseyana*), low sage (*Artemisia bigelovii*), and Wyoming big sage (*Artemisia tridentata* ssp. *wyomingensis*). Riparian corridors, aspen (*Populus tremuloides*), ponderosa pine (*Pinus ponderosa*), meadows, and several other vegetation types occupy smaller portions of the 116,549-ha landscape.

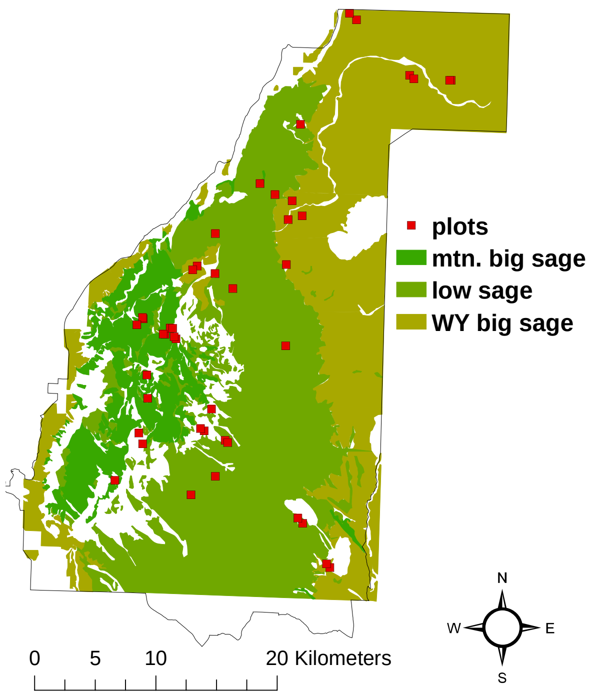


Figure 2. Plot sampling locations.

Plot sampling

The Hart Mountain National Antelope Refuge vegetation map provided the basis for a stratified-random sampling design. Forty-four plots (Fig. 2) were placed in fifteen of the vegetation types included in the Refuge vegetation map. Some of the plots were placed according to locations specified by a stratified-random design, while a supplementary purposive sampling design directed the location of other plots. We intended to describe the landscape and pattern of invasion in an unbiased way with the stratified design, and capture additional patches of invasion and extremes in environmental gradients with the purposive sampling.

We sampled with a modification of the multi-scale Modified-Whittaker plot (Stohlgren et al. 1995, 1997a,b,c, Fig. 3, Appendix I). Species composition, cover, the average height of each species, and cover of abiotic variables (lichen, litter, moss, poop, rock, soil, standing duff, water, and wood) were recorded to the nearest 1% in each 1-m^2 subplot. The multi-story overlap of species accounts for the total percent periodically totaling more than 100. We also collected species composition in a 10-m^2 subplot and the entire 100-m^2 plot. The nature of the multi-scale, nested plot design qualified presence of a species in any of the smaller sub-plots as part of the composition list for the entire plot.

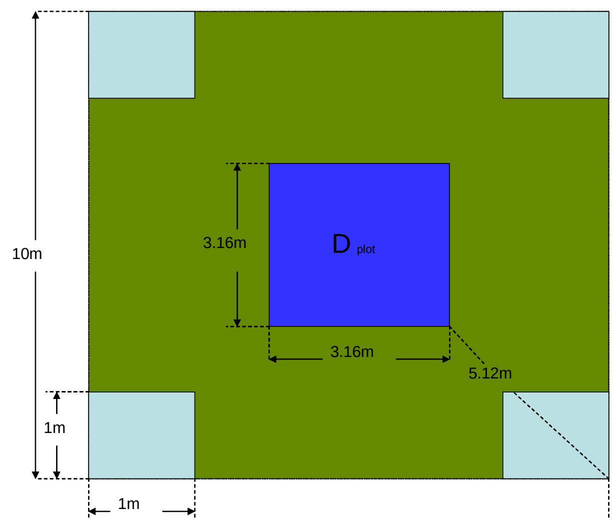
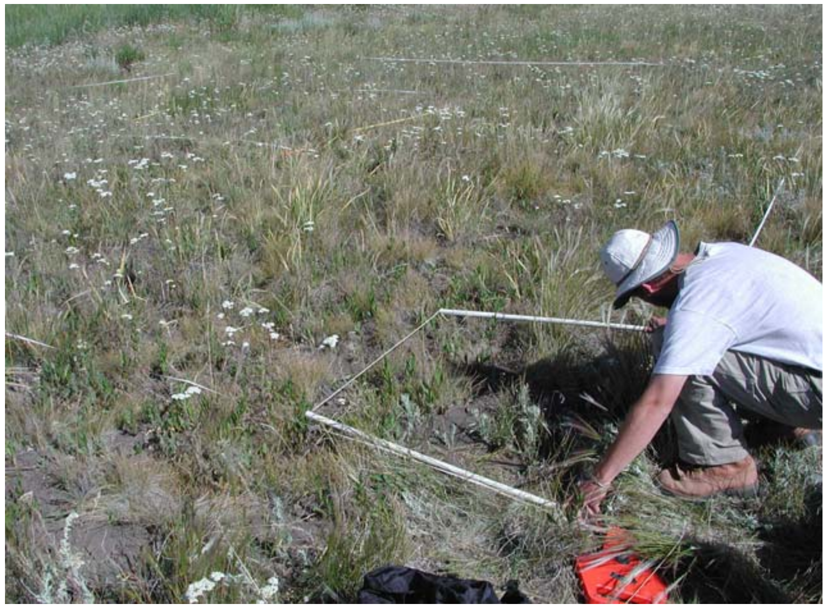


Figure 3. A diagram of the multi-scale plot used to sample native and non-native vegetation

Soil samples were collected at each plot. Soils were collected in the center of the plot and at the inside corner of each 1-m^2 subplot and analyzed for texture and carbon and nitrogen content (texture - % sand, silt, and clay; inorganic C, organic C, total C, and total N). Ancillary data including slope degree and slope aspect were



Jenny Ericson photo

recorded at the location. Other variables including the distance to road, distance to water, LANDSAT remote sensing information, and the slope, aspect, and elevation from a Digital Elevation Model (DEM) were attributed to each plot during analysis.

The sampling locations were recorded but not permanently marked on the ground. This decision reflected concerns for wildlife and the goal of providing distribution information for further inventory. Each plot can be roughly geo-referenced with associated UTM coordinates to place repeat measurements generally 2 to 5-m from the original plot. Repeat sampling should include a search of the area surrounding each plot to account for extant species of concern that the plot may have missed.

Unknown species were collected and/or photographed and subsequently identified by expert botanists in the University of Wyoming Herbarium. Data was consolidated in a Microsoft Access database, analyzed with in a Geographic Information System (ESRI, ArcGIS 9.2) and the S Plus and Systat statistical packages.

Non-native plant species mapping

Non-native plant species were mapped using hand-held computers connected to

Weed mapping in Post Meadows, Jenny Ericson photo

global positioning system (GPS) receivers according to the North American Weed Mapping Association (NAWMA; www.nawma.org, Appendix II, III) standards. We collected species identity, cover, and location in the field, while other required variables were added later. Smaller patches or single individuals were recorded as a single point, and 'gross area' (general area occupied but not entirely covered by the species), 'infested area' (subset of gross area that is occupied by a non-native plant species), and 'cover' (of species in the infested area) were recorded. We recorded larger patches as a polygon by mapping the perimeter of the patch and estimating 'infested area' and 'cover'.

STATISTICAL ANALYSIS

Non-native plant species modeling

Managers must consider entire landscapes, not point locations. Spatial models attempt to describe a variable of interest across an entire landscape based on information gleaned from point-specific sampling. Some models included only plot-based data (variables such as non-native species richness could only be estimated in plots), some incorporated the plot and mapping data. None of the dependent variables demonstrated spatial autocorrelation, so true spatial statistics were not used. The same independent variables (slope, elevation, absolute aspect (0-180 degrees transformation to make the variable linear and approximate degrees from the driest South slopes), distance to road, distance to water, relative vegetation type moisture (Table 2), and LANDSAT bands 1, 4, 6) were used for each model and log transformed to approximate assumptions of normality when appropriate. Independent variables were assessed for collinearity, and limited by availability to continuous variables.

Table 2. Sampled vegetation types ranked according to

Vegetation Type	Moisture Gradient
riparian	1
meadow	2
aspen	3
hot spring	4
mountain big sage	5
ponderosa	6
mountain mahogany	7
bitterbrush	8
low sage	9
juniper	10
wheat grass	11
lake bed	12
Wyoming big sage	13
basin big sage	14
desert shrub	15

Few modeling techniques estimate variability across unsampled regions without true absence data. We developed new tools to compare mapped locations to environmental variables to estimate a surface of “Envelope of Occurrence.’ This approach may be useful for mapping-only assessments that do not record true absence data or when faced with a small sample size of species limited in distribution. When absence data could be used with plot data, models were developed for multi-species metrics (non-native plant species richness and cover), and probability models were created for a selection of single non-native plant species. A description of each modeling process follows.

•Envelope of Occurrence. Comparing species-specific presence data from mapping techniques to a geospatial layer allowed us to identify a range, or environmental window, of the layer with conditions suitable to invasion by that species (e.g. if whitetop (*Cardaria draba*) was mapped <20-m from water, all areas <20-m from water were identified as suitable for invasion). We combined repeated comparisons of bull thistle (*Cirsium vulgare*) to the independent variables to create a surface. Each pixel of the surface quantified the number of these variables that were outside the range of the presence of bull thistle at that location.

•Trend Surface Models. Working with plot-based data increased our ability to model the variability of non-native plant species. We used multiple regression analysis (OLS; Reich & Davis, 1998) to evaluate coarse-scale variability with a stepwise procedure to select the independent variables to include in the regression models. We then modeled the error (i.e., residuals) from the regression model with a binary regression tree (De'ath & Fabricius, 2000), and avoided over-fitting the model with a 10-fold cross-validation procedure to identify the tree size that minimized the total deviance associated with the tree. We generated grids using model parameter estimates from the regression model. Passing the appropriate independent variables through the regression tree created another grid representing the error in the regression model. A sum of the two grids amounted to the final surface (Reich et al., 2004).

·Probability Models. We combined data from the plot and mapping methods to create probability models of single-species occurrences. Logistic regression is a type of general linear model (GLM) appropriate for data with a binary distribution such as species presence or absence (McCullagh & Nelder, 1989). Logistic regression used a logit link function that assumed a binomial distribution (Statistical Sciences, 2005). Variables were selected using a stepwise procedure for GLM in S-plus. The probability surface was generated using the predictor variable raster layers with the statistical output from S-plus. The resulting cell values were in the logit scale and were therefore back-transformed to the original scale of the probability surface using:

$$p = \frac{e^{(LP)}}{1 + e^{(LP)}}$$

where *p* is the probability and LP is the linear predictor. Percent deviance (D^2, similar to an R^2 value) was used to evaluate the model percent deviance explained and measurediscrimination were calculated. Percent deviance explained was calculated as

$$Percentdeviance = \frac{NullDev - \operatorname{Re} sDev}{NullDev} X100$$

where NullDev is the null deviance of the evaluation data and ResDev is the residual deviance of the evaluation data in relation to probabilities predicted by the model. This measurement is of overall goodness of fit of the model to the known observations.

RESULTS

Plot sampling

In the plot-based survey, we identified a total of 292 species in the forty-four 100-m^2 plots. The NRCS PLANTS Database (USDA, 2005) listed forty-one (Table 3) of these as non-native plant species. While the sampling effort was not equitable across each vegetation type (Table 4), we found more cumulative and non-native species per plot in riparian meadows, aspen, and around hot springs (Table 4). A riparian meadow plot contained the most non-native species (11 species), while twelve sage-dominated plots had not been invaded by any non-native species.

Cheatgrass (*Bromus tectorum*) occurred with the highest frequency (19 plots). Other species occurring with high rates of frequency include common yarrow (*Achillea millefolium*, 10 plots) yellow salsify (*Tragopogon dubius*, 9 plots), and bull thistle (*Cirsium vulgare*, 6 plots). Twenty non-native species occurred on only one plot (Table 3).

Table 3. The non-native plant species, frequency (Freq.) and average cover by plot and mapping techniques. Standard errors appear in parenthesis where appropriate.

Species	Map Freq.	Map Cover	Plot Freq.	Plot Cover, avg. of 1-m^2 subplots	Plot Dominance (freq. x cover)
Achillea lanulosa			9	0.88	7.92
Achillea millefolium			10	0.33	3.3
Agropyron cristatum	2	100 (0)			
Alyssum desertorum	3	100 (0)			
Alyssum minus var. micranthum			1	0.5	0.5
Alyssum parviflorum			2	3.3	6.6
Alopecurus pratensis			1		
Arabis hirsuta			2		
Bromus inermis	6	53.33 (10.9)	1	17.8	17.8

Bromus japonicus	17	79.88 (7.86)	5	3.3	16.5
Bromus tectorum	53	44.75 (2.67)	19	4.2 (1.3)	79.8
Cardaria draba	40	67.65 (5.2)	1		
Camelina microcarpa			4	2.8	11.2
Carduus nutans	25	80.92 (7.8)	1		
Ceratocephala testiculata			1	0.25	0.25
Cirsium arvense	6	73.33 (11.5)	1		
Cirsium vulgare	18	93.33 (5.38)	6	0.5	3
	3	20.33 (15.1)			
Descurainia sophia	21	62.52 (6.95)	2	2.3	4.6
Elaeagnus angustifolia	4	85 (0)			
Erodium cicutarium	17	29.71 (3.8)	1		
Erysimum repandum	8	54.38 (9.8)	3		
Hordeum jubatum	8	37 (10.54)	2	1	2
Kochia scoparia	7	85 (0)			
Lactuca serriola	9	47.22 (5.47)	2	0.5	1
Lepidium latifolium	1	85 (0)			
Lepidium perfoliatum	55	61.64 (4.42)	5	2.95	14.8
Llinum usitatissimum			1		
Marrubium vulgare	6	85 (0)			
Melilotus officinalis	3	100 (0)			
Onopordum acanthium	3	28.33 (1.67)			
Phleum pratense	1	40 (0)	5		
Poa annua			1		
Polygonum arenastrum			1	0.13	0.13
Polygonum aviculare	1	85 (0)	2	0.56	1.1
Poa bulbosa	13	74.23 (7)	1	21.8	21.8
Poa compressa			1		
Poa pratensis	1	20 (0)	3		
Ranunculus testiculatus			4	0.18	0.7
Rumex crispus	8	43.5 (8.66)	1		
Salvia aethiopis	1	15 (0)			
Salsola tragus	6	85 (15)			
Sisymbrium			2	1.75	3.5

altissimum					
Silene noctiflora			1		
Sonchus asper			1		
Taraxacum officinale	1	15 (0)			
Thlaspi arvense	3	45 (16.07)	1		0
Trifolium campestre			1		0
Tragopogon dubius	15	84 (6.16)	9	0.13	1.17
Ulmus pumila	1	100 (0)			
Urtica dioica			1		0
Veronica serpyllifolia			1		0
Verbascum thapsus			1	0.25	0.25

Table 4. Sampled vegetation types, and the cumulative and average number of native and non-native species found in forty-four plots. Standard errors appear in parenthesis where appropriate.

Vegetation Type	Number of Plots	Native Cumulative Species	Native Means Species/Plot	Non-Native Cumulative Species	Non-Native Mean Species/Plot
Aspen	1	36	36	4	4
Basin big sage	1	13	13	1	1
Bitterbrush	3	50	17 (3.28)	12	4 (2.3)
Desert shrub	1	7	7	1	1
Hot spring	2	33	17 (0.5)	7	4 (0.5)
Juniper	2	49	25 (3.5)	2	1 (0)
Lake bed	3	17	6 (2.03)	4	2 (0.33)
Low sage	8	129	16 (1.82)	18	3 (0.86)
Meadow	5	105	21 (3.56)	26	5.2 (0.73)
Mountain big sage	5	105	21 (3.39)	4	1 (0.37)
Mountain mahogany	1	29	29	2	2
Ponderosa	1	23	23	1	1
Riparian	3	66	22 (4.16)	25	9 (1.86)
Wheatgrass	1	3	3	2	2
Wyoming big sage	7	97	14 (2.49)	7	1 (0.49)

Nineteen non-native species only occurred on the large plot (Fig. 3) and do not have cover values. Of the twenty-one non-native species occurring in subplots, bulbous bluegrass (*Poa bulbosa*) in a bitterbrush vegetation-type plot had the highest average cover of a particular non-native species on a single plot (21.8 %). Several other species had values in double digits, but most average cover values were < 3% (Table 3).

Non-native plant species mapping

We mapped non-native plant species at 367 locations and recorded 34 non-native plant species. Mapped 'gross area' of all patches totaled 733.2-ha with an average patch size of 2.0-ha (SE = 0.3). Of that area, the 'infested area' (area actually infested by plant species) amounted to 239.3-ha (μ = 0.6, SE = 0.1) with an average cover of 63.4 % (SE = 1.7). Clasping pepperweed (*Lepidium perfoliatum*) was the most frequently mapped species (55 locations) and cheatgrass had the largest infested area (112.1-ha, 53 locations). Many of the species were found only once, and infestations were often limited to a single individual.

Modeling distributions of non-native plant species

The modeling resulted in single and multi-species models, and an 'Envelope of Occurrence' surface (Figures 4-11, Table 5). The modeled surfaces are easily interpreted, and we described the *C. vulgare* Envelope of Occurrence surface to provide an example of possible interpretation. Evaluation of the presence of *C. vulgare* against each of the independent variables resulted in a surface where pixels were defined by the number of layers that pixel was outside the observed sampled range (Fig. 10). Thus, a pixel with a score of zero would have a higher probability of containing *C. vulgare* than a pixel with a value greater than zero.

Table 5. The relationship of significant independent variables and the amount of variability explained in models of species distributions.

Modeled Variable	Model	R^2 contribution	Total Variability Explained	Fig.
Non-native plant species richness - plot data	trend surface = 18.0700 - 0.0105 * absasp - 0.0018 * eleft - 0.5271 * moisture fine-scale = regression tree	0.57 0.2	R^2 = 0.77	4a,b
Non-native plant species cover - plot data	trend surface = 14.3137 - 0.0021 * waterdist - 0.8402 * moist fine-scale = regression tree	0.25 0.4	R^2 = 0.65	5a,b
Probability of whitetop - plot and mapping data	probability = 8.361867 - 0.0009562974 * distrd + 0.0006383515 * distwater + 0.01047774 * absasp - 0.001758195 * ele - 0.06629415 * ls1 + 0.05927537 * ls4	N/A	D^2 = 0.30	6
Probability of cheatgrass - plot data	probability = 43.80837 1.749981 * ldistrd + 2.859737 * lslope - 0.02184244 * absasp - 0.007361927 * ele - 0.3767792 * moist - 0.2721269 * ls1 + 0.06889456 * ls4 + 0.1698399 * ls6	N/A	D^2 = 0.46	7
Probability of cheatgrass - plot and mapping data	probability = 13.02116 + 1.030424 * ldistwater + 1.142584 * lslope - 0.002947469 * ele + 0.02503204 * ls5	N/A	D^2 = 0.32	8
Cover of cheatgrass - plot data	trend surface = 15.9221 + 1.6763 * ldistrd + 4.8918 * lslope - 0.0029 * ele - 0.5688 * moisture	0.32 0.19	R^2 = 0.51	9a,b
Envelope of Occurrence, musk thistle – plot and mapping data	Envelope of Occurrence model	N/A	N/A	10
Probability of Canada thistle - plot and mapping data	probability = 15.29829 - 0.004110045 * ele - 0.2273241 * moist + 0.06854622 * ls4	N/A		11

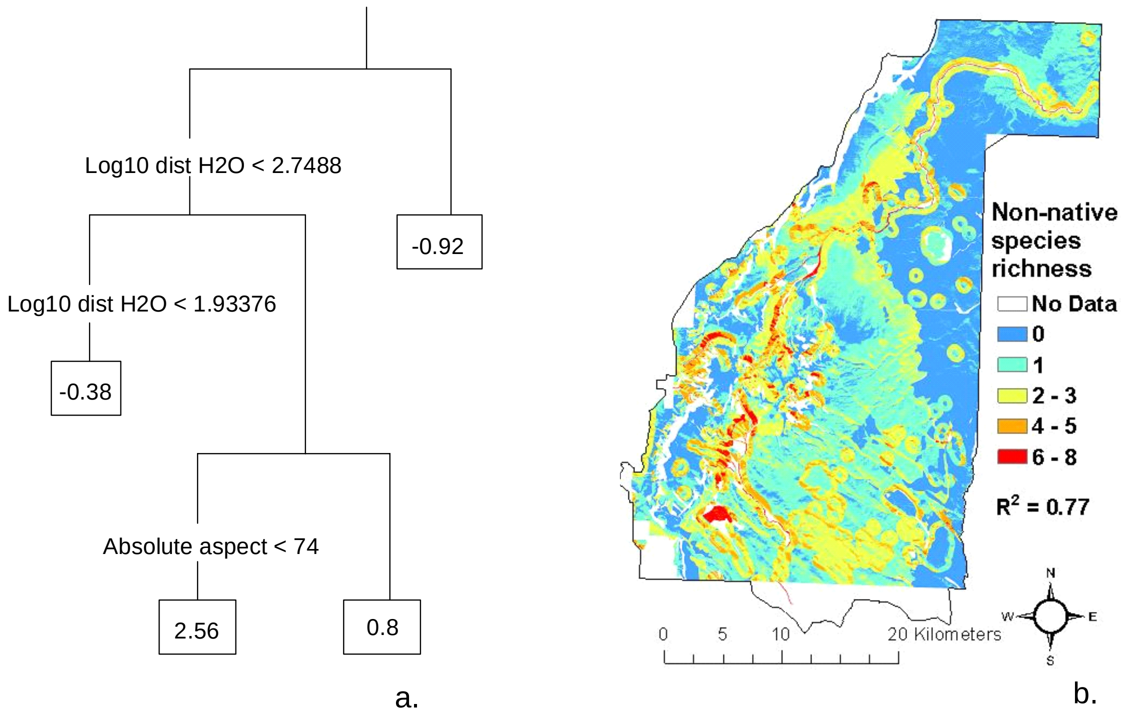


Figure 4. The regression tree that explained the fine-scale variability (a) and the modeled surface of non-native plant species richness (b).

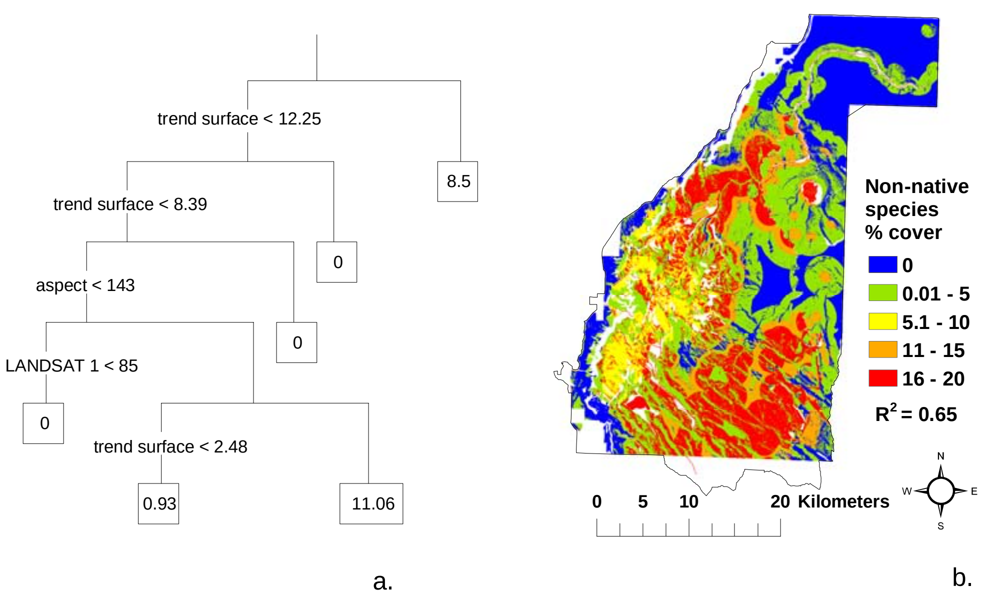


Figure 5. The regression tree that explained the fine-scale variability (a) and the modeled surface of non-native plant species cover (b).

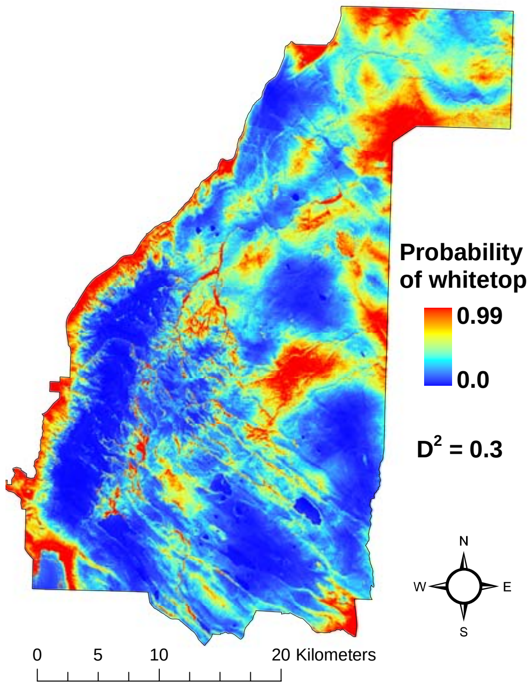


Figure 6. The probability of occurrence of whitetop on Hart Mountain National Antelope Refuge. The surface was generated using a combination of the plot and mapping data and can be evaluated by the percent deviance (D^2, similar to R^2), which is a measure of the goodness of fit of the model to the observations.

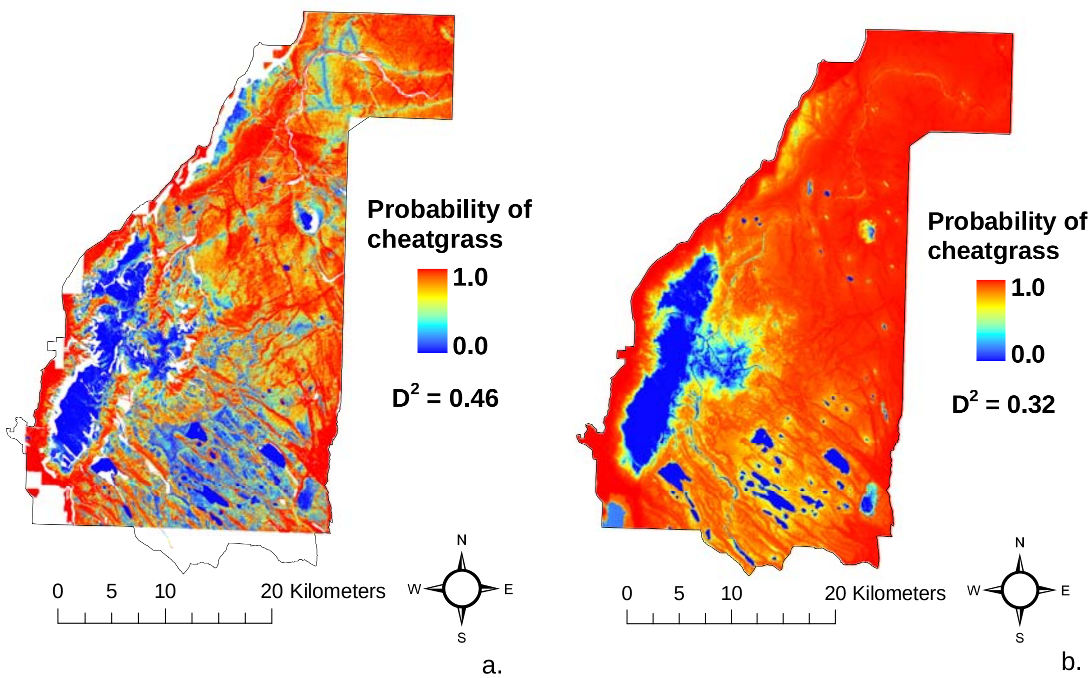


Figure 7. Probability models of cheatgrass. One surface is based on the information available from the plot data (a), and the other (b) uses plot and mapping data.

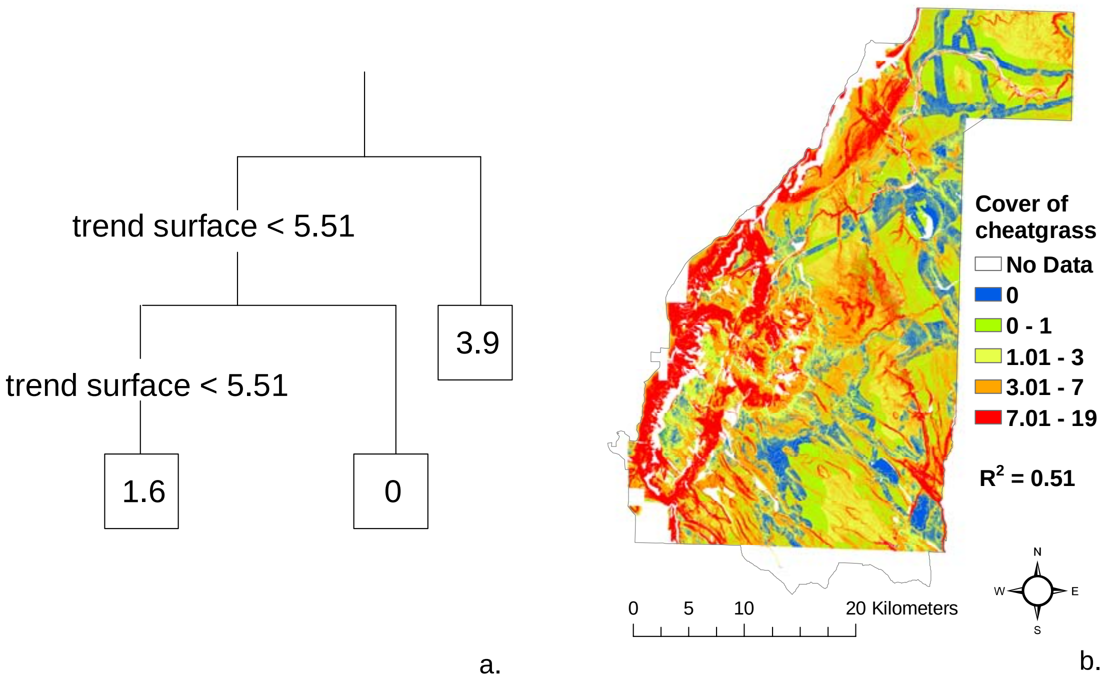


Figure 8. Regression tree of the fine-scale variability of cheatgrass (a), and the estimated cover of cheatgrass (b) based on plot data.

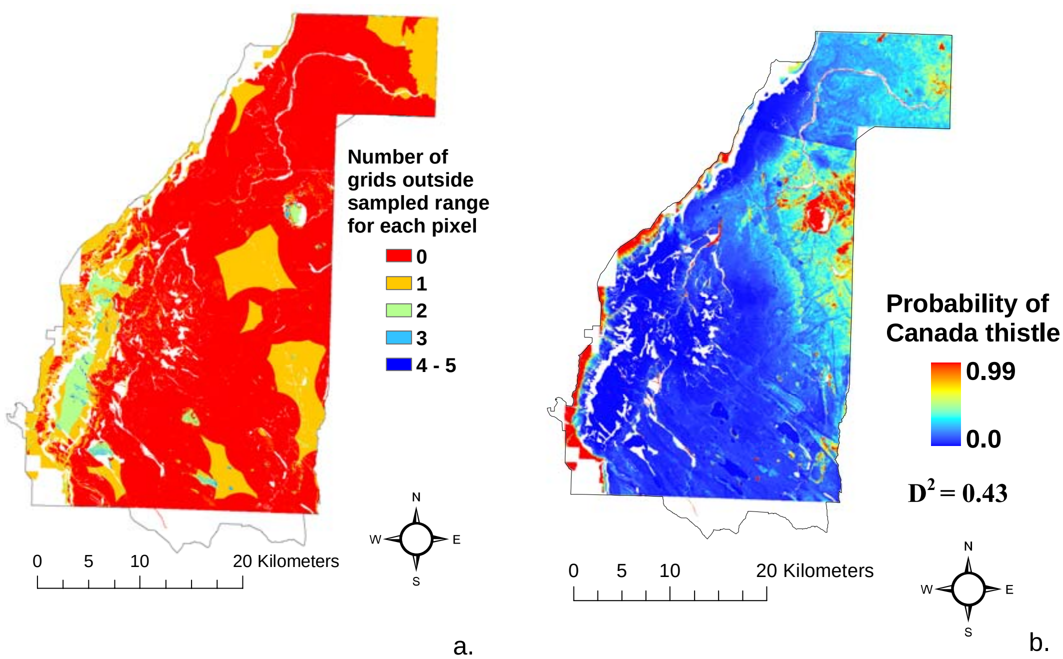


Figure 9. Envelope of Occurrence describing by layer those areas within the range of variability that nodding plumeless thistle was detected (a) and the probability of occurrence of Canada thistle (b).

DISSICUSSION

There are numerous ways that this inventory will contribute to the fine-scale distribution mapping of non-native plant species at Hart Mountain National Antelope Refuge. A simple risk analysis can be used to evaluate the vulnerability of habitats to invasion and prioritize the current invaders according to threat to Hart Mountain National Antelope Refuge. Spatial models can be used to estimate the actual and potential distribution of non-native species richness, cover, and the probability of occurrence. And, in addition to directing volunteers and staff to locations vulnerable to invasion across the Refuge, these models provide an indication of how environmental variables contribute to these distributions, and can also be useful for directing control and assessing impact to natural resource assets and management objectives.

Non-spatial Assessment

Vegetation types with larger non-native plant species accumulations and higher numbers of non-native species per plot provide an indication of vegetation types that are more vulnerable to invasion (Table 4). The number of plots per vegetation type was determined by representation across the landscape and an attempt to get at least two plots in each of the relatively rare vegetation types. After an initial inventory, additional plots were added to vegetation types with steep invasive species accumulation curves. These curves evaluate the number of new species detected, on average, with the addition of each plot. Based on this analysis, we added more plots to the meadow and riparian areas (unfortunately, two plots in the aspen vegetation type were destroyed with field equipment). To map the most non-native plant species for time invested, volunteers should focus on mapping in vegetation types with higher numbers of non-native plant species (Table 4). It should also be noted that, while the results were not statistically significant ($p = 0.07$) the habitat types with the highest numbers of non-native plant species seemed to support higher native species richness. While mapping non-native plants can be a useful inventory tool, effective monitoring should include native species to allow an evaluation of the impacts of non-natives and control in these diverse areas.

A habitat analysis can be useful for determining vulnerability, but species identity matters in invasion biology. Some species wreak havoc on natural systems while others seem to be additive, existing at low levels that do not disrupt native species. Most of the detrimental-invasive-plant species undergo a lag phase, existing at low, background numbers and densities for some time before spreading across the landscape. The difficulty of differentiating between relatively harmless invasive species and the next big invader drives our rational for including all non-native plant species in the analysis.

A species-specific approach not only provides a list of the invasive plant species volunteers might expect to find, but the frequency of occurrence and cover of these species can provide an estimate of how prevalent these species are on the landscape (Table 3). Dominance (cover x frequency) combines these two metrics to provide another way to assess the relative importance of species across the landscape. The relatively high dominance score of cheatgrass (*Bromus tectorum*) reflects it's pervasiveness (Table 3). Cheatgrass may not be worth mapping except in specific areas of interest, or to track response to manipulations like prescribed burning. Many species had low dominance scores, and some of these despite moderately high frequencies (e.g. *Achillea* sp.). These species may not threaten native plant species as they are not taking up a lot of space or resources. Bulbous bluegrass and smooth brome (*Bromus inermis*) had relatively high dominance scores despite occurring in only one plot. These species should be mapped by volunteers given their ability to dominate specific locations. Other species with moderate dominance scores that should be of concern given history on other landscapes include Japanese brome (*Bromus japonicus*), clasping pepperweed (*Lepidium perfoliatum*), littlepod false flax (*Camelina microcarpa*), and bull thistle (*Cirsium vulgare*).

The frequency and cover data collected by mapping is not directly comparable to the plot information. Cover measured and averaged across four 1-m^2 subplots can not be compared to cover estimated across a large patch of invasive species or a single individual invasive species; the units are not comparable. Frequency is also difficult to compare. A particular species might be rare on the landscape but have a high mapping frequency as a result of several individuals or patches in a small area being mapped separately (Fig. 13). The actual distribution must be visibly evaluated, but can add to the invasion story. Mapping described fine-scale distributions, and located otherwise undetected species. For example, whitetop (*Cardaria draba*; mapping frequency = 40) seems to be more common on the landscape

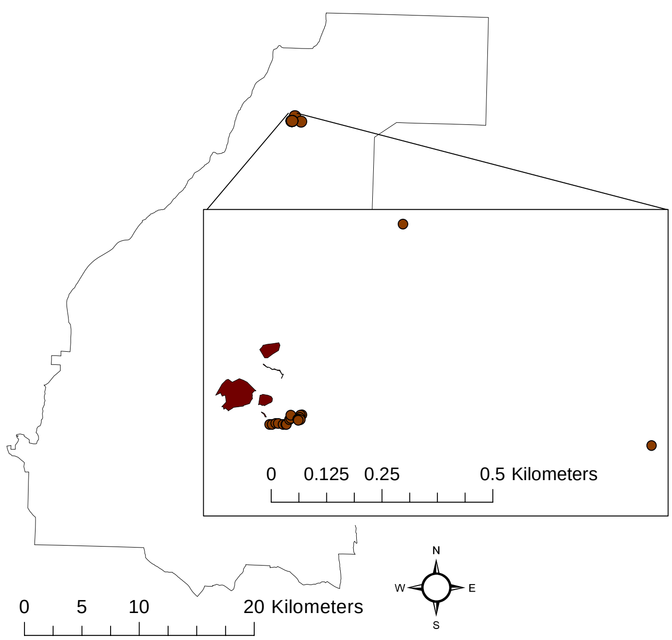


Figure 13. The clumped distribution of nodding plumeless thistle (*Carduus nutans*).

than might be expected given the plot sampling information (plot frequency = 1, Table 3), and suggests that combining plot and mapping data may be an effective and informative tool.

Combining Plot and Mapping Data

A combination of mapping and plot data might be the best way to efficiently understand the composition, distribution, abundance, and impact of invading non-native plant species on a landscape (Parker et al., 1999). Mapping techniques only tell half the story. While they effectively describe the general distribution of non-native plant species, and, with strategic searching, function as a valuable contribution to the early detection of new and rare invaders on the landscape (Stohlgren & Schnase, 2005), the metrics may not be repeatable and they ignore native species and important ancillary data for predictive spatial models. Plot sampling may miss rare species and fail to capture the fine scale distribution of invasive plant species, but it can describe conditions with accurate and repeatable methods, and record native species information and ancillary data. The two techniques compliment each other.

Sampling forty-four plots in fifteen different vegetation types, we detected forty-one non-native plant species. Mapping at 367 locations detected thirty-seven non-native plant species. The total number of species detected by each method is similar, but the methods did not capture the same species. Twenty-three of the non-native plant species found in plots were not detected with mapping techniques, and eighteen of the thirty-seven mapped non-native species were not captured with plot sampling. A total of fifty-nine non-native species were captured with the combination of the two methods. Like rare plant surveys, searching with mapping techniques located rare non-native species on the landscape. Of the eighteen species unique to mapping, nine of these were mapped three or fewer times. However, stratified-random plot sampling reached locations and detected rare non-native species that may have otherwise gone unsampled. Of the twenty-three non-native species unique to plots, ten occurred in only one plot (Table 3).

Inventory in Post Meadows with a combination of both plot and mapping techniques demonstrates the compatibility of both methods. Only three of the non-native species were mapped in the area; white top (*Cardaria draba*), Japanese brome (*Bromus japonicus*), and field pennycress (*Thlaspi arvense*; Fig. 14). Both *C. draba* and *B. japonicus* occurred in small patches. *T. arvense,* being widely distributed with many dense and often connected patches, was mapped as one large 0.1-km^2 patch, but approximately one-half of that area was infested with an average cover of 30% across those patches. While these estimations are rough and difficult to ascertain, the patch boundary provided an accurate baseline of the local distribution of field pennycress. Cover and frequency of *T. arvense* is better quantified by a plot that recorded *T. arvense* in one (average cover = 18%) of four subplots and in the largest plot. *C. draba* (2 subplots, average cover = 11%) and *B. japonicus* (present in 100-m^2 only) were also recorded in the plot. The plot captured an additional seven non-native plant species (USDA, 2005), and 28 native plant

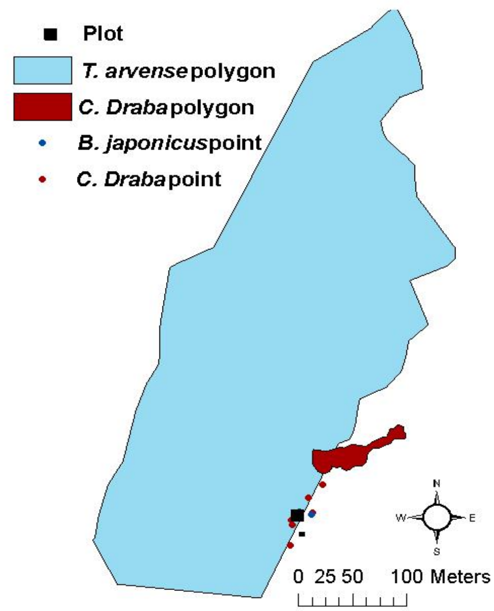


Figure 14. The combination of plot and mapping data in Post Meadows.

species. Of the non-native species, only *Achillea millefolium* was common (present in all 4, 1-m^2 subplots with an average cover of 13%, and present in the 100-m^2 plot). Six species appeared in at least one subplot, and three non-native species were found in either the 10 or 100-m^2 plots. The information contributed by the plot includes cover, which is a better metric for the long-term comparison of cover and frequency of the species, and trends on native species in the face of increased distribution of non-native species as described by the mapping techniques.

Spatial Assessments

Spatial models describe species distributions that can be used to direct volunteers in mapping fine-scale species distributions. The models reflect statistically derived relationships that approximate extant distributions or potential distributions based on the field sampling effort. Assessing the accuracy of spatial models that describe spreading organisms is difficult; this effort simply relied on the percent of variability explained (R^2 or D^2). The statistical accuracy and representation of actual distributions will be improved with the addition of more data as volunteers map species and further the Iterative Sampling process. Volunteers interested in mapping specific species should start in areas with a high probability of occurrence or low 'envelope' values (Figs. 4-12). A more generalized approach directs volunteers to areas with high non-native plant species richness and cover. Areas with high cover describe areas where non-native plant species may be edging out native plant species. Areas with high non-native plant species counts seem to be vulnerable to invasion. Volunteers mapping in these areas are likely to find more species for the effort and perhaps most likely to find species new to the system that could be eradicated before spreading across the landscape.

The variables useful in the models (statistically significant) provide some insight to the factors controlling invasive species distributions at Hart Mountain National Antelope Refuge. Moisture is a factor. Wetter vegetation types (Fig. 4b, 5b, 7a, 9b, Table 5) and areas closer to water (Fig. 5b, Table 5) were conducive to invasion, mirroring the finding of the habitat assessment. Many of the single species had higher probability of occurrence at lower elevations (Figs. 6, 7a, 7b, 8b, 9b). Few of the plots at the highest elevations contained many invasive species, suggesting that elevation is a barrier to invasion for many species, or that the species simply have not had the opportunity to spread to these elevations given the reduced levels of disturbance and less frequent travel. The lowest elevation plots also tended to not support high levels of invasive plant species richness or cover. The middle elevations with greater habitat heterogeneity (small pockets of riparian meadows, aspen forests) may support the highest levels of richness and cover. Aside from the distance to road and fire, disturbance was not well quantified in the spatial models. The cheatgrass models demonstrated higher probability and cover closer to road systems, and indeed it does seems to line many of the roads of the Refuge. Fire, added as a categorical variable to many of the models, did not seem to have an influence on invasive species distribution. The fire-cheatgrass interaction was explored further.

Fire and Cheatgrass

Visual assessment suggested that disturbance associated with the fire prescription in the management plan may be providing an opportunity for invasion. While this study was not designed to evaluate the impact of fire on the landscape, we attempted to evaluate the propensity of cheatgrass to establish in burned areas. There was no significant relationship between year since fire and the cover of cheatgrass, and fire was not a significant variable in any models of cheatgrass cover or probability (Table 5). A regression tree of the cover of cheatgrass did include fire as a significant predictor of cheatgrass distribution. In wetter vegetation types, the presence of fire was conducive to higher cheatgrass cover (Fig. 15).

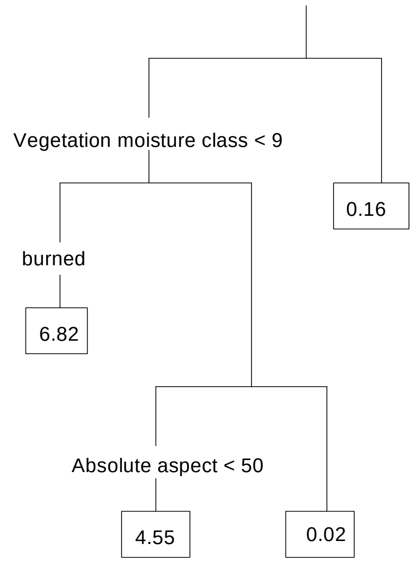


Figure 15. Regression tree describing the cover of cheatgrass.

Realizing the study design may not have been useful for statistical comparison we did sample several paired plots on and off burns. Neither of the higher elevation paired plots contained any cheatgrass. The lower elevation pair was located on the east-facing hillside above the hot spring on and near the Degarmo 1999 fire. The cover of cheatgrass in the two plots quantified what could be seen while standing in the plot and from a distance: there is more cheatgrass in the burned area (Fig. 16). In an effort to quantify this result, a t-test demonstrated a significant difference in the mean cover of cheatgrass in

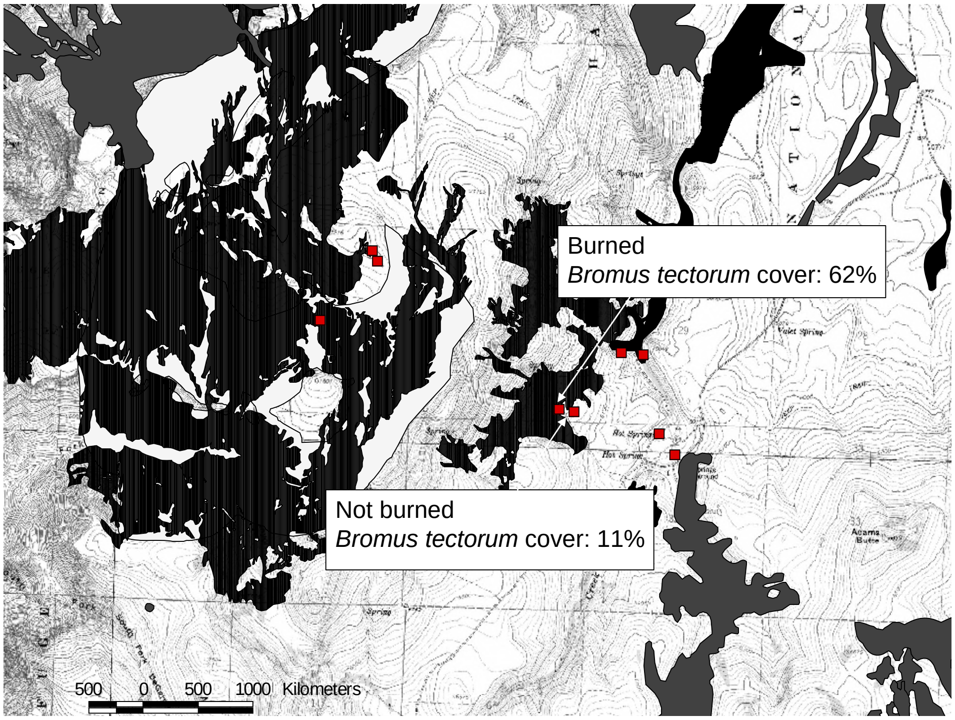


Figure 16. A burned and unburned plot demonstrating the potential impact of fire on the establishment of cheatgrass.

burned and unburned plots across the entire refuge ($p = 0.02$). The mean of cheatgrass (averaged across all four subplots) was 4.6% on burned plots and 0.85 on unburned plots. These results, combined with visual observations strongly suggest that the fire is contributing to the establishment of cheatgrass at Hart Mountain National Antelope Refuge.

RECCOMENDATIONS

A crew dedicated to the purpose of finding invasive plant species on a landscape is an invaluable tool. Understanding the distribution of both rare and more common invasive plant species will be valuable for monitoring changes in distribution over time and to direct control efforts. In addition to describing the fine-scale distribution of species, the volunteers will be an excellent early detection tool. The eradication of a few non-native individuals is possible, but by definition new invaders are rare and can be hard to find. Even extremely well funded efforts can not afford to sample the entirety of a large landscape, so we hope the findings and recommendations of this inventory will be an asset to the upcoming mapping project.

•Volunteers should initially focus on those areas that seem to be most vulnerable to invasion to a multitude of species. They will likely find the highest number of non-native species to map, and the distribution and composition of invasive plant species in these areas is important to understand given the higher levels of native plant species diversity in these vegetation types.

•Volunteers should also focus on mapping areas that, according to the spatial models created in this report, tend to support higher non-native plant species richness, cover, and probability of occurrence. Model layers can be viewed in a GIS environment to obtain spatial coordinates of these areas.

•While mapping is useful, incorporating at least some kind of plot data provides valuable information. Plots describe the status and composition of the native species that coexist with the invasive species. This information allows for prioritization of control and facilitates an assessment of the impact of invasion and control when the plots are monitored over time. The drawback of plot information is the time, expense, and the need for a highly-trained botanist. If plots can not be measured in conjunction with the mapping effort, another option would be to measure a plot and simply make a record of the invasive plant species in the plot. This would provide an indication of non-native species richness and the absence of non-native plant species at specific locations. Both of these metrics will be valuable information for the Iterative Sampling process.

•Since volunteers likely will not be trained botanists, they should carry and be familiar with species included in "A field guide to Lake County's Noxious Weeds," and other non-native plant species of interest.

•To keep mapping data consistent and comparable (like frequency, e.g. Fig. 13), volunteers should adhere to a set of rules that dictate when a patch is mapped as a point or a polygon, and be sure to have a clear definition of how cover is being estimated. The 'Beyond NAMWMA' methods present one option (www.NAWMA.org). Volunteers should also keep track of areas that have been mapped to avoid confusion during the study and to allow differentiation between new occurrences and unmapped areas in future mapping efforts.

•Cheatgrass is too widespread to map. It could be mapped, if encountered, in relatively uninvaded areas (e.g. higher elevations) and in areas of special management concern (prescribed fire, etc.) to monitor change over time.

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Appendix I: Methods for Assessing Cover and Richness of Non-native Species

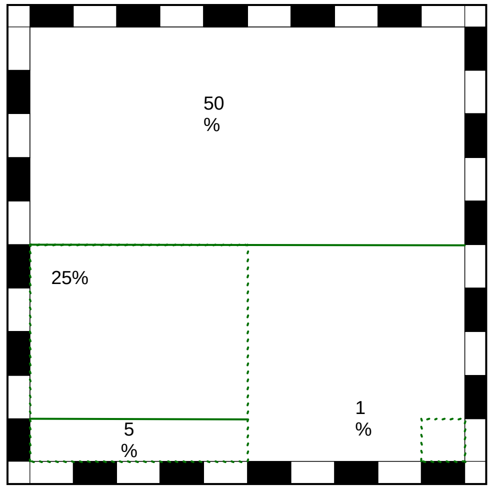
At the predetermined location, a center pin is inserted and flagged. Transect lines (T1, T2, T3) are located on the 30°, 150°, and 270° azimuths from subplot center, radiating out 24 ft (7.32m). Transects are flagged at the 24ft (7.32m) mark to delineate the perimeter of the subplot. Vegetation quadrats are located at 15ft and 18.3ft (4.57m and 5.57m) along transects. Flag all four corners of each quadrat to prevent trampling. Note: all distances are horizontal distance, therefore transect lines are corrected for slope.

Vegetation diversity and cover measurements are taken with a small 1-m^2 quadrat. On each quadrat, the following types of data are recorded: species identification and dominant microhabitat codes, and cover estimated to the nearest 1% for each plant species and microhabitat variable present. The botanist identifies each plant species in the quadrat and enters its corresponding standardized NRCS (Natural Resource Conservation Service) PLANTS database code (USDA, NRCS. 2001. The PLANTS Database, Version 3.1 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA). Percent cover to the nearest 1% is estimated for each species. Cover is then estimated to the nearest 1% for each ground variable listed in the Microhabitat Variables Table.

Microhabitat Variables

Code	Definition
1	Dead wood; log and slash (>10cm diameter), stump, branches and limbs
2	Dung
3	Fungus
4	Lichen
5	Litter / Duff; accumulation of organic matter over forest mineral soil.
6	Live root / bole; living roots at the base of trees or exposed at the surface of the forest floor or soil and cross-sectioned area of live tree boles at the ground line.
7	Mineral soil / Sediment; physically weathered soil parent material that may or may not also be chemically and biologically altered.
8	Moss
9	Road
10	Rock; a large rock or boulder or accumulations of pebbles or cobbles.
11	Standing water / flooded; ponding or flowing water that is not contained within banks.
12	Stream; body of flowing water contained within banks.
13	Trash / junk

Each 1-m^2 quadrat frame is calibrated (painted in 10 cm sections) to make cover estimates easier. Only estimate cover on plants or portion of plant that falls inside the quadrat frame. Visually group species together into a percent cover. Fine tune that estimate by subtracting out any spaces or gaps. Familiarize yourself with what certain cover estimates (e.g., 1%, 10%, 15%, etc.) look like and use them as reference sizes. For example, if you know that 1% cover is about the same size as your fist, use your fist as a reference. There will often be overlap of plant species. Therefore, your total cover for a quadrat may exceed 100%.



After completing the three quadrats, the botanist does a walking search of the entire subplot looking for and recording any new species that were not previously found on any of the quadrats, adding species to the total species list.

Appendix II: NAWMA Standards

It is not the object of this document to discuss or describe the existing standards in detail. The complete standards can be obtained from NAWMA (www.NAWMA.org).

Field Name	Required	Content
Collection Date	yes	yyyymmdd
Examiner	no	Name of observer
Plant Name	yes	Genus, species, common, code
Gross area and unit of measure	no	Area of general infestation
Infested area and unit of measure	yes	Area of land containing one species
Canopy cover	yes	Percent of ground covered by foliage
Ownership	yes	Ownership of infestation location
Data source	yes	Manager of data
Country	yes	Country where infestation is located
State or Province	yes	State or Province of infestation
County or Municipality	yes	County or Municipality of infestation
Hydrologic unit code (HUC)	yes	HUC for aquatic infestation only
Location	yes	Lat-Longs or UTM at center of infestation
Quad Number	no	Quad code from index map
Quad Name	no	Quad map name

Appendix III: Beyond NAWMA

While adoption of Beyond NAWMA requires more time than simply mapping, the modifications to the NAWMA mapping standards presented below increases the value of the non-native plant information collected on a landscape. By combining mapping and plot sampling, Beyond NAWMA provides a thorough description of patterns of plant invasions and is sensitive to changes in pattern and composition of species when implemented over time.

Location. The 'gross area' of patches should be recorded with a Geographic Positioning Unit (GPS) by actually delimiting the perimeter of a patch or linear infestation rather than documenting the center as the required 'location' field. If the infestation is smaller than 10-m in diameter then the size and center location of the patch should be recorded. Advances in hand-held computer technology allow users to log data directly into hand-held computers, or field-digitize infestations directly into spatial displays without actually walking patch perimeters. This technique produces accurate data and saves time. Delimiting the population size and location allows for a better understanding of the spread of populations, the reaction of these populations to control efforts, and how infestations might overlap with other areas of importance to management of the landscape.

Cover. The methods for assessing cover by the NAWMA standards need to be augmented by quantitative and repeatable methods. The use of broad cover classes for cover (e.g. 0-5 % or 75-100%) does not provide useful information for detecting early invasion (<1% cover) or change over time. Furthermore, estimations of cover across large patches can be complicated by varying degrees of inclusive patch delineation. Techniques that measure small areas, such as Daubenmire plots or the Parker Loop, sacrifice accuracy and completeness (see Stohlgren et al., 1998). We recommend the use of a circular 168-m^2 plot (7.32-m radius) with three 1-m^2 nested quadrats (Appendix III for details). This technique requires a greater investment of time than many of the other methods suggested for measuring cover, but the described plot does not have to be placed at every sampling location. The plot should be established periodically, in every 10th to 20th point, line, or polygon infestation mapped. The frequency of plot sampling can be adjusted depending on the rigor of mapping effort and the infestation intensity. Cover at all other mapped locations should be estimated as described in the NAWMA standards.

Area Searched. It is equally important to record the regions searched that did not contain non-native plant species. This could be recording searched locations and describing the intensity and habitats searched in the area. Tracking the areas searched is invaluable to evaluation of a weed mapping effort. In addition to identifying gaps in mapping efforts, this record provides a general understanding of locations that may be resistant to invasion, and is essential to the evaluation of subsequent mapping efforts.

Ancillary Data. Ancillary data is easy to collect and should be recorded every time a non-native individual or patch is encountered. The following variables should be recorded:

· slope, aspect, and elevation. These variables can be obtained from digital elevation models, but field measurements provide more accurate information.

· geologic features. Soil descriptions and collection (color and texture descriptions, if have means), topography (hillside, distance to road, wetland, or stream, etc.).

- distance to water (permanent streams, lakes, coast in km
- distance to nearest road
- disturbance features (e.g., recent fire, flood, small mammal disturbance).

Understanding attributes of invaded areas can be as informative as locating the invasions themselves. Collection of abiotic variables increases the utility and comparability of information across landscapes, and promotes the prediction of invasive species occurrence and distribution. Understanding the attributes of an invaded habitat might be indicative of similar invaded areas, or those places vulnerable to invasion. Predictive spatial models that generate this information rely on the abiotic characteristics of invaded sites.