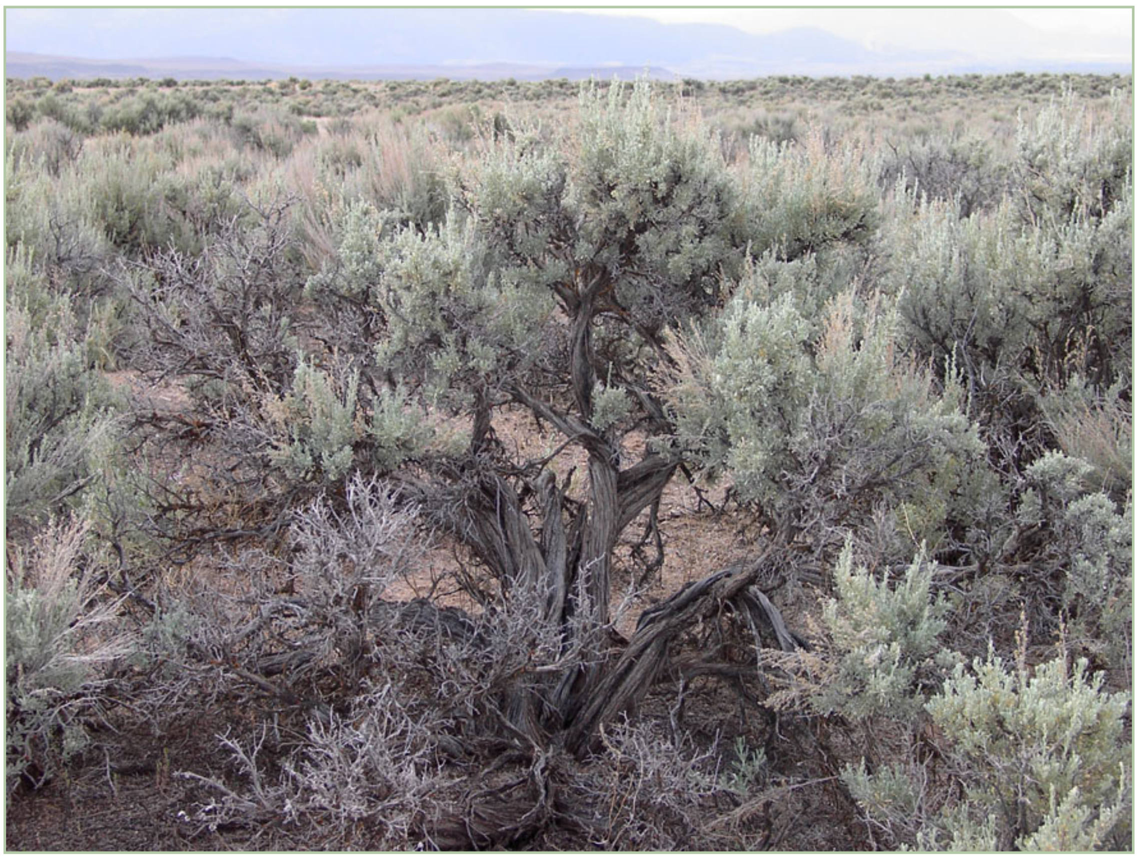
PROCEEDINGS OF THE 16TH WILDLAND SHRUB SYMPOSIUM

THREATS TO SHRUBLAND ECOSYSTEM INTEGRITY

25-27 MAY 2010, UTAH STATE UNIVERSITY, LOGAN



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Abstract
Abstract: The 29 papers in this proceedings are divided into the main organized sessions of the 16th Wildland Shrub Symposium, including the plenary session to introduce the theme of threats to shrubland ecosystem integrity, impacts of energy development and reclamation on ecosystem function, invasive plant ecology. wildlife habitats: impacts and restoration opportunities, historical perspectives in shrublands, ecosystem threats due to fire in the Mojave Desert, and modeling and monitoring of shrubland ecosystems. An overarching goal of the symposium was to make linkages between research and management.

Keywords: wildland shrubs, wildlife habitat, disturbance regimes, restoration, monitoring, energy development impacts

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Sagebrush taken by Thomas Monaco

16th Wildland Shrub Symposium
Threats to Shrubland Ecosystem Integrity
2010 May 18-20
Logan, UT

Compilers:

Thomas A. Monaco
Eugene W. Schupp
Rosemary L. Pendleton
Stanley G. Kitchen
Patsy K. Palacios

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Series Forward

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Shrub Research Consortium

Federal Government:

USDA Forest Service, Rocky Mountain Research Station, Grassland, Shrubland, Desert Ecosystems Program:
- Shrub Sciences Laboratory*, Provo, UT, Stanley G. Kitchen (chair)
- Forestry Sciences Laboratory, Reno, NV, Robin J. Tausch
- Forestry Sciences Laboratory, Albuquerque, NM, Rosemary L. Pendleton

USDA Agricultural Research Service:
- Jornada Experimental Range, Las Cruces, NM, Mary Lucero
- Forage and Range Research Laboratory, Logan, UT Thomas Monaco
- High Plains Grassland Research Station, Cheyenne, WY, D. Terrance Booth
- Exotic and Invasive Weed Research Unit*, Reno, NV

USGS Northern Rocky Mountain Science Center, Bozeman, MT, Richard B. Keigley

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The Shrub Research Consortium (SRC) was formed in 1983 with five charter members (see list). Over time, SRC has grown to its present size of 27 institutional members. The SRC charter had three principal objectives: (1) develop plant materials for shrubland rehabilitation; (2) develop methods of establishing, renewing, and managing shrublands in natural settings; and (3) assist with publication and dissemination of research results. These objectives have been met by a series of symposia sponsored by the Consortium and partners. This publication is the 15th in the series. The 14 previous symposia are listed on the next page. Proceedings of all publications to date have been published by the U.S. Department of Agriculture, Forest Service, Intermountain Research Station and Rocky Mountain Research Station. Each symposium has had a theme, but the executive committee has encouraged attendance and participation by shrubland ecosystem biologists and managers with wider interests than any particular symposium theme—the heart of the Consortium's programs are wildland shrub ecosystem biology, research, and management.

Availability of Previous Wildland Shrub Symposia Proceedings

First: Tiedemann, A. R.; Johnson, K. L., compilers. 1983. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. General Technical Report INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 279 p. Out of print—available from National Technical Information Service as document PB83261537. Contact NTIS at: (800) 553-6847, or order online at: www.ntis.gov.

Second: Tiedemann, A. R.; McArthur, E. D.; Stutz, H. C.; Stevens, R.; Johnson, K. L., compilers. 1984. Proceedings—symposium on the biology of Atriplex and related chenopods; 1983 May 2-6; Provo, UT. General Technical Report INT-172. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 309 p. Out of print—available from National Technical Information Servcie as document PB85116358. Contact NTIS at: (800) 553-6847, or order online at: www.ntis.gov.

Third: McArthur, E. D.; Welch, B. L., compilers. 1986. Proceedings—symposium on the biology and management of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. General Technical Report INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 398 p. Out of print—available from National Technical Information Service as document PB86182318. Contact NTIS at: (800) 553-6847, or order online at: www.ntis.gov.

Fourth: Provenza, F. D.; Flinders, J. T.; McArthur, E. D., compilers. 1987. Proceedings—symposium on plant herbivore interactions; 1985 August 7-9; Snowbird, UT. General Technical Report INT-222. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 179 p. A few copies are available from the Rocky Mountain Research Station; otherwise available from National Technical Information Service as document PB90228578. Contact NTIS at: (800) 553-6847, or order online at: www.ntis.gov.

Fifth: Wallace, A.; McArthur, E. D.; Haferkamp, M. R., compilers. 1989. Proceedings—symposium on shrub ecophysiology and biotechnology; 1987 June 30-July 2; Logan, UT. General Technical Report INT-256. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 183 p. Available from Rocky Mountain Research Station: http://www.fs.fed.us/rm/publications/.

Sixth: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., compilers. 1990. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. General Technical Report INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 351 p. Out of print—available from National Technical Information Service as document PB91117275. Contact NTIS at: (800) 553-6847, or order online at: www.ntis.gov.

Seventh: Clary, W. P.; McArthur, E. D.; Bedunah, D.; Wambolt, C. L., compilers. 1992. Proceedings—symposium on ecology and management of riparian shrub communities; 1991 May 29-31; Sun Valley, ID. General Technical Report INT-289. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 232 p. Out of print—available from National Technical Information Service as document PB92227784. Contact NTIS at: (800) 553-6847, or order online at: www.ntis.gov.

Eighth: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K., compilers. 1995. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. General Technical Report INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 384 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/publications/ or you can download the publication at: http://www.fs.fed.us/rm/pubs_int/int_gtr315.html.

Ninth: Barrow, J. R.; McArthur, E. D.; Sosebee, R. E.; Tausch, R. J., compilers. 1996. Proceedings: shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. General Technical Report INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 275 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/publications/.

Tenth: McArthur, E. D.; Ostler, W. K.; Wambolt, C. L., compilers. 1999. Proceedings: shrubland ecosystem ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 299 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/publications/.

Eleventh: McArthur, E. D.; Fairbanks, D. J, compilers. 2001. Shrubland ecosystem genetics and biodiversity: proceedings; 2000 June 13-15; Provo, UT. Proceedings RMRS-P-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 365 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/publications/ or you can download the publication at: http://www.fs.fed.us/rm/pubs/rmrs_p021.html.

Twelfth: Hild, A. L.; Shaw, N. L.; Meyer, S. E.; Booth, D. T.; McArthur, E. D., compilers. 2004. Seed and soil dynamics in shrubland ecosystems: proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 216 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/publications/ or you can download the publication at: http://www.fs.fed.us/rm/pubs/rmrs_p031.html.

Thirteenth: Sosebee, R. E.; Wester, D. B.; Britton, C. M.; McArthur, E. D.; Kitchen, S.G., comps. 2007. Proceedings: shrubland dynamics--fire and water; 2004 August 10-12; Lubbock, TX. Proceedings RMRS-P-47. Fort Collin, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 173 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/pubs/rmrs_p047.html.

Fourteenth: Kitchen, S. G.; Pendleton, R. L.; Monaco, T. A.; Vernon, J., comps. 2008. Proceedings-Shrublands under fire: disturbance and recovery in a changing world; 2006 June 6-8; Cedar City, UT. Proc. RMRS-P-52. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 190 p. Available from the Rocky Mountain Research Station: http://www.fs.fed.us/rm/pubs/rmrs_p052.html.

Fifteenth: Wambolt, Carl, L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok F.; Keigley, Richard B.; Palacios, Patsy K.; Robinson, Jill A., comps. 2011. Proceedings – Shrublands: Wildlands and Wildlife Habitats; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan Utah, USA. http://www.fs.fed.us/rm/pubs_other/rmrs_2011_wambolt_c001.pdf.

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Daniel J. Manier ASRC Management Services, contracted to USGS Fort Collins Science Center, Fort Collins, Colorado; **Cameron Aldridge** Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado cooperative with USGS Fort Collins Science Center; **Patrick Anderson** USGS Fort Collins Science Center, Fort Collins, Colorado; **Geneva Chong** USGS Northern Rockies Science Center, National Elk Refuge, Jackson, Wyoming; **Collin Homer** USGS Earth Resources Observation Systems Center (EROS), Sioux Falls, South Dakota; **Michael O'Donnell** ASRC Management Services, contracted to USGS Fort Collins Science Center, Fort Collins, Colorado; **Spencer Schell** USGS Fort Collins Science Center, Fort Collins, Colorado

ABSTRACT

For the past several years, USGS has taken a multi-faceted approach to investigating the condition and trends in sagebrush steppe ecosystems. This recent effort builds upon decades of work in semi-arid ecosystems providing a specific, applied focus on the cumulative impacts of expanding human activities across these landscapes. Here, we discuss several on-going projects contributing to these efforts: (1) mapping and monitoring the distribution and condition of shrub steppe communities with local detail at a regional scale, (2) assessing the relationships between specific, land-use features (for example, roads, transmission lines, industrial pads) and invasive plants, including their potential (environmentally defined) distribution across the region, and (3) monitoring the effects of habitat treatments on the ecosystem, including wildlife use and invasive plant abundance. This research is focused on the northern sagebrush steppe, primarily in Wyoming, but also extending into Montana, Colorado, Utah and Idaho. The study area includes a range of sagebrush types (including, Artemisia tridentata *ssp.* tridentata*,* Artemisia tridentata *ssp.* wyomingensis*,* Artemisia tridentata *ssp.* vaseyana*,* Artemisia nova*) and other semi-arid shrubland types (for example,* Sarcobatus vermiculatus*,* Atriplex confertifolia*,* Atriplex gardneri*), impacted by extensive interface between steppe ecosystems and industrial energy activities resulting in a revealing multiple-variable analysis. We use a combination of remote sensing (AWiFS (*[1] Any reference to platforms, data sources, equipment, software, patented or trade-marked methods is for information purposes only. It does not represent endorsement of the U.S.D.I., U.S.G.S. or the authors)*, Landsat and Quickbird platforms), Geographic Information System (GIS) design and data management, and field-based, replicated sampling to generate multiple scales of data representing the distribution of shrub communities for the habitat inventory. Invasive plant sampling focused on the interaction between human infrastructure and weedy plant distributions in southwestern Wyoming, while also capturing spatial variability associated with growing conditions and management across the region. In a separate but linked study, we also sampled native and invasive composition of recent and historic habitat treatments. Here, we summarize findings of this ongoing work, highlighting patterns and relationships between vegetation (native and invasive), land cover, landform, and land-use patterns in the sagebrush steppe.*

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INTRODUCTION

Beginning in 2005, a multi-partner, long-term, science and management cooperative, the Wyoming Landscape Conservation Initiative, was created to coordinate efforts of public and private land managers across a vast and heterogeneous landscape. The U.S. Geological Survey, building on a foundation of several overlapping but uncoordinated programs of research and management across the region, is working to assess, monitor, and enhance ecological understanding of aquatic and terrestrial habitats across southwestern Wyoming,. Here, we discuss the results and implications of three projects aimed at vegetation distribution and conditions across the region. This includes building an understanding of the distribution and condition of sagebrush habitats across this large and heterogeneous landscape, including mapping of dominant vegetation and weed distributions and assessment of the role of management treatments in distribution of native vegetation, weeds and wildlife.

A foundational component of this research has been the development and implementation of multiple-scale mapping of plant cover without using type classifications. By using a combination of field collections nested within three scales of remote sensing data (QuickBird, 2.5 meter resolution, Landsat, 30 meter resolution, and AWiFS, 56 meter resolution), we developed the connections between surface patterns and spectral responses to estimate cover for a suite of eight soil and vegetation classes. Initiated for the WLCI (Wyoming Landscape Conservation Initiative), this effort began with a sub-state region, expanded to include all of Wyoming and it is now being applied across the sagebrush steppe. This information forms the most comprehensive remote sensing based assessment of sagebrush communities to date. Following tests of accuracy, change detection and repeatability, these methods, used to determine the current status, may be adopted as the core of monitoring the distribution and condition of shrub steppe communities. Importantly, for the current assessment, and for subsequent monitoring, these methods provide locally relevant detail (30 m resolution) at a regional scale (state-wide and larger).

With a clarified picture of the distribution of sagebrush communities across the study region, we remain faced with questions about the condition and productivity of these ecosystems. To begin to address these questions, we estimated the distribution of two landscape-scale drivers of change within natural and managed areas: biotic invasions induced by land use and management activities that intentionally altered habitat conditions. We assessed the relationships between specific, land-use features (for example, roads, transmission lines, industrial pads) and invasive plants, including their potential (environmentally defined) distribution across the region as an indicator of the extent of anthropogenic influences beyond the footprint of roads, urban and exurban domestic developments, agricultural fields, and energy infrastructure (oil, gas, and coal-bed methane). This required an accurate depiction of the distribution of these surface disturbances (land-use conversions, industrial sites, treatment locations), however these data were not consistently available, therefore, a large part of this process has been development of accurate representation of human activities across the landscape. Beyond delineation, our research focus is the biotic implication of these features within and beyond their boundaries.

While major shifts in land use may be tracked though mapping and monitoring the distribution of human infrastructure (for example, roads, zoning, urban areas), the widespread, long-term practice of conducting habitat treatments by land management agencies has been untracked, poorly documented, and the impacts have not been well assessed. While individual treatments may be small (in areal extent), many are not, and the accumulation of treated areas across the landscape since initiation (circa 1940s) can be locally significant. Furthermore, understanding potential benefits and risks associated with particular treatment techniques is needed for adaptive management. Based on this need, we were able to use recently developed information (Wyoming Wildlife Consultants, LLC, unpublished data) to identify and locate historic treatments in southwest Wyoming, which we began sampling in 2010 (vegetation cover and composition). Wyoming Wildlife Consultants conducted parallel studies of wildlife use of these treated areas. The objective of this on-going work is to determine the long-term, persistent effects of these habitat treatments, especially the effects of habitat treatments on the ecosystem, including wildlife use and native and invasive plant abundance and structure.

STUDY AREA

The focal region for our research included over 7.7 million hectares (19 million acres) with variable environmental and land-use patterns including Green River and Great Divide Basins and several adjacent, smaller basins (figure 1). In addition, due to interest of land mangers, the sagebrush mapping project was extended beyond these initial boundaries across the State of Wyoming. The research and management interests discussed here focus on the northern sagebrush steppe, primarily in Wyoming, but the potential implications and applications of these results may be extended into similar areas of Montana, Colorado, Utah and Idaho. The study area included a range of sagebrush types typical of northern, shrub-steppe. A majority of the region was dominated by

Wyoming sagebrush (*Artemisia tridentata* ssp. w*yomingensis*) interspersed with salt-flats dominated by greasewood (*Sarcobatus vermiculatus*) and saltbush (*Atriplex gardnerii*) and varying abundances of rabbitbrush (primarily *Chrysothamnus viscidiflorus*). Throughout the region, native bunchgrasses such as bluebunch wheatgrass (*Pseudoroegnaria spicata*) and needlegrass (*Achnatherum contractum, A. hymenoides*) mix with native and introduced wheatgrasses, including crested wheatgrass (*Agropyron cristatum* var. *cristatum A. cristatum* var. *desertorum*), bottlebrush squirreltail (*Elymus elymoides*), and western wheatgrass (*Pascopyrum smithii*). Importantly, there was also a wide-spread but heterogeneous distribution of annual, biennial, and perennial weedy plants including annual bromes (*Bromus tectorum, B. arvensis*), desert alyssum (*Alyssum desertorum*), halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola tragus*), and tumble mustard (*Sisymbrium altissimum*). Invasive plants can alter the composition, productivity and forage quality of the ecosystem, making the distribution of these species, both across the range and within specific treatments, important for assessing and managing habitat conditions.

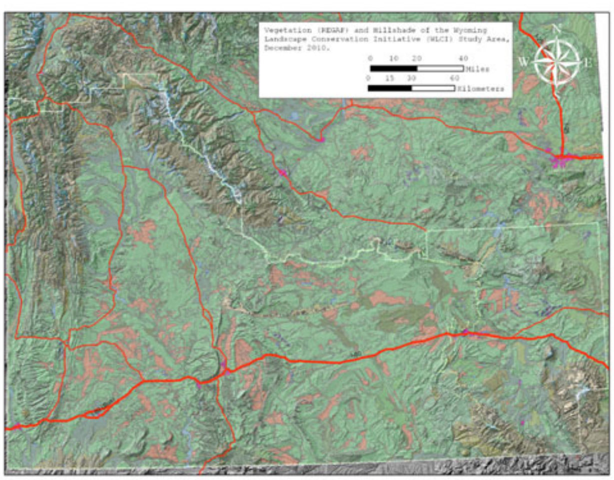

Figure 1. The Wyoming Landscape Conservation Initiative Area and the State of Wyoming, U.S.A. Shades of green and beige represent dominant vegetation types. Bright green is sagebrush steppe (dominates the scene); dark beige areas within the sagebrush steppe are more arid, desert shrub and saltbush flats. Light beige, within the central basin, represents active sand-dunes. Foothills woodlands are represented by olive, and are also recognizable by topographic relief depicted in the underlying topographic hillshade, with higher elevation forests appearing in dark green above the band of foothills. Red-lines represent major highways.

The climate is dry continental, with mean annual precipitation totals of 10 to 13 inches being typical (Western Regional Climate Center, www.wrcc.dri.edu) For much of the region mean maximum temperatures in July range from 85° to 95°F, with mean minimum in January typically between 5° and 10°F (ibid). Our samples are distributed across heterogeneity in soils, geology, topography, climate, hydrology, and dominant vegetation in addition to differences in land-use attributes that were targeted by design.

This region has historically supported (circa 1900) agricultural and natural resource extraction economies. Despite concerns about the welfare of wildlife and ecosystems, increasing energy demand and expanding infrastructure results in continuing impact by extensive, and often intensive, industrial energy activities. Thus, modern disturbances and landscape fragmentation are being superimposed on a long-history of land-use impacts. Understanding the current interactions of naturally determined and anthropogenically influenced environmental conditions is critical for successful conservation, restoration and management of these semi-arid landscapes.

Multi-Scale Sagebrush Mapping And Resource Inventory

METHODS

We developed methods to combine three scales of satellite imagery (2.4-m QuickBird, 30-m Landsat TM, and 56-m AWiFS) using limited but rigorous and directed ground sampling to produce continuous predictions for eight sagebrush steppe vegetation components across the state of Wyoming.

High resolution QuickBird (QB) images each covering 64 km^2 were segmented into patches to distribute field sampling sites across polygons representing spectral variations in the target area. Each image was also classified into 30 unsupervised classes, and the majority class in each segmented polygon was determined. To correlate surface conditions with remotely detected variability across the image, we systematically sampled polygons in each spectral class. Typically two polygons were sampled from each majority class, for a minimum of 60 sampling locations per QB footprint.

The composition of vegetation, bare ground and litter in each polygon were assessed using ocular estimation of 1-m^2 quadrats. Fourteen (14) quadrats were divided evenly (5m apart) along two 30-m transects (7 per transect; figure 2); these values were averaged to define the cover of the site. Transects were aligned parallel, but offset (creating a parallelogram footprint) with a maximum of 20 m separation between transects. These sample units were distributed across the 64 km^2 footprint, with replicates, to develop field data to represent spectral variability across the scene. Canopy cover of vegetation was estimated in 5 percent increments based on a conceptual “similar-to-satellite” interpretation, such that only the top-most layer of cover was recorded and the sum of all primary cover components could not exceed 100 percent. Shrubs and trees (if present) were identified to the species level, with sagebrush (*Artemisia* spp.) further distinguished to the subspecies level. Heights of shrub and tree species were estimated based on measurement of the tallest green vegetation (excluding seed stalks) of each species within each quadrat.

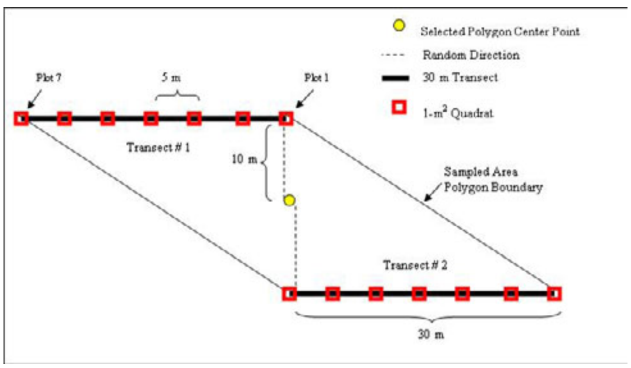

Figure 2. Physical layout of replicated field plots used to develop cover estimates for training Quickbird spectral signatures. This array was replicated within each unique spectral group (number per scene varies due to heterogeneity) within each targeted Quickbird scene (8km x 8km).

To apply the field data to the remotely sensed imagery, we defined sampled areas as the polygon created by connecting the start and end points of both transects at each location. For each component we calculated the mean value across the 14 quadrats, and these mean values were assigned to all QB pixels falling within a sampled area.

Using regression tree analysis to identify empirical relations between the component values and the QB data (typically all four 2.4-m spectral bands and three additional bands of ratio indices), we classified the proportion of each of the components occurring within each entire QB image on a per-pixel basis. These per-pixel QB predictions were then resampled to 30-m Landsat and 56-m AWiFs pixels to provide the component training data for the model predictions at these larger scales. A number of additional data layers (image band ratios, ratio differences between image dates, ancillary topographic data) were also provided to the regression tree for model building.

RESULTS AND DISCUSSION

We produced continuous predictions for eight sagebrush steppe vegetation components across the state of Wyoming using three spatial scales of remotely sensed imagery. The four primary components were percent bare ground, percent herbaceous (grass and forb), percent litter, and percent shrub, which taken together represent 100 percent of all cover in a tree-less environment. The four secondary components include three subsets of percent shrub, including all sagebrush (*Artemisia* spp.), all big sagebrush (*A. tridentata*) subspecies, and only Wyoming sagebrush, as well as mean shrub height. Predictions revealed that bare ground had the most even distribution across the entire range; this is not surprising on this semi-arid landscape. Herbaceous vegetation and litter cover exhibited similarly broad ranges and distributions, especially when compared to shrub cover which is less uniform. Wyoming sagebrush had the most limited range of the variables we modeled.

Prediction accuracy varied by imagery type, image, and component. We used, root mean square error (RMSE, in the units of the component prediction) a useful measure of model accuracy to compare results. At the QB level, RMSE values ranged from 4.76 for sagebrush to 10.16 for bare ground, with 7.95 for shrub height. Accuracy at the Landsat and AWiFS scales were generally more variable than at the QB scale. Landsat RMSE values ranged from 5.46 for sagebrush to 15.54 for bare ground, with 11.2 for shrub height. AWiFS RMSE values ranged from 6.11 for sagebrush to 16.14 for bare ground, with 10.18 for shrub height.

We found that our component predictions outperformed those generated by LANDFIRE (Rollins and others 2006), the only comparable large-area product. For the shrub component the RMSE of our model prediction was 6.04, as compared to 12.64 for LANDFIRE, and for herbaceous the RMSE was 12.89, versus 14.63 for LANDFIRE.

We believe our Landsat and AWiFS predictions provided enough detail for local application, span areas broad enough for ecosystem analysis, and provide a quantitative and repeatable framework for future monitoring. Research applying our component estimates to current and historical vegetation change, climate variation, sage grouse habitat distribution, and grazing trends are currently underway.

Land Use And Invasive Plants

METHODS

We developed data for species distributions using a sample of 123 sites distributed across the landscape, representing several ecological types and multiple land-use features. An important value created by the spatial modeling approach is leveraging the information contained in expensive field samples by projecting distribution estimates beyond sample sites. Here, we minimized the negative effects of projecting onto unsampled landscapes by including our sampled area within the projected area, thereby reducing the assumptions and errors associated with extrapolation to unsampled climate and landscape associations (Rodder and Lotters 2010). We developed a stratified-random sample design using a spatially explicit representation of anthropogenic features distributed across the WLCI study area (7.7 million hectares), which also captured important environmental variability by crossing geologic and soil types, precipitation and temperature gradients, and various topographic patterns.

We sampled paired, 1000m-long by 1m-wide belt-transects that were extended perpendicular to the margin of a target feature (in all cases except "control" sites); these were generally extended in divergent or opposite directions to capture community and species diversity across the site. Each $1m^2$ was examined and all identifiable invasive plants were recorded, confirming the presence or absence of 30 species identified in county, federal and state noxious weed lists. We post-processed sites to add attributes representing environmental characteristics in a GIS (geographic information system, ESRI ArcMap 9.3) by associating sample locations with existing information (for example, surface geology, dominant vegetation and road density). This combination allowed subsequent analyses including these variables as covariates of weed abundance. Based on observed distributions of species, we were forced to immediately revise our initial hypothesis that all species would show a linear or curvilinear decreasing relationship with increasing distance, because simple graphs demonstrated otherwise, for some species. We tested linear and log-linear transformed distance as predictors of species abundance using generalized linear models (R Development Core Team 2010) and discovered nearly ubiquitous, significant relationship between plot distance [increasing distance from anthropogenic features; $p<0.05$ in all cases except log-linear for halogeton and linear for perennial pepperweed (*Lepidium perfoliatum)* which were not significant.] However, we also tested the contribution of potential environmental predictors, and discovered that the model fit was improved by adding an environmental covariate in all cases; this was generally the dominant surface geology or vegetation type.

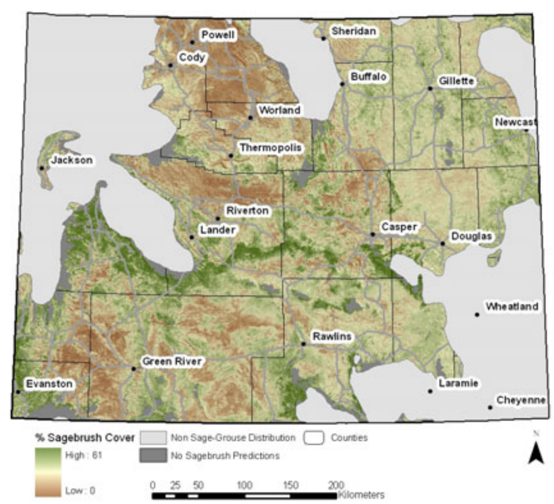

Figure 3. Continuous prediction of sagebrush cover (all species and subspecies combined) in Wyoming, U.S.A.

RESULTS AND DISCUSSION

We found clear connections between the distribution of several, prominent invasive plants and widespread rural land-use features including all classes of roads (highways, major and minor unpaved thoroughfares, spurs and driveways and double-tracks), active and reclaimed well-pads, pipelines and transmission lines.

We found the greatest richness of invasive plants associated with informal roads (double-track, two-track; figure 3) which likely receive variable, seasonal use, but little to no weed management. Active well-pads (oil, natural gas, and/or coal-bed methane), pipelines, and primary (county roads and similar, thoroughfares) and tertiary (short gravel spurs, driveways and dead-ends) roads contained a greater richness than the ambient conditions estimated by Control sites (figure 4). It is important to note that our "Control" sites do not offer unbiased, undisturbed data for comparisons. These sites were located more than 1000m, continually along their entire length, from any neighboring anthropogenic features, but they were embedded within utilized landscapes. Therefore, the data from these sites offered a basis for relative assessment of specific features as well as evidence of the wide-distribution of invasive plants.

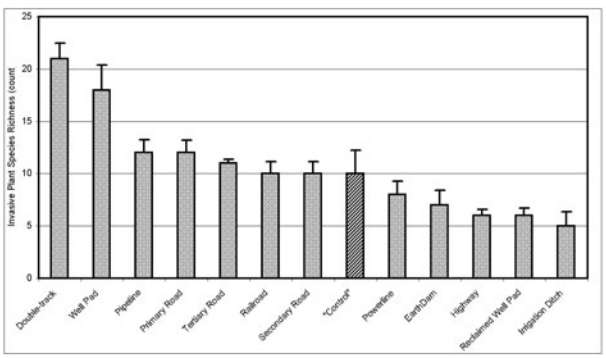

Figure 4. Observed richness (species count) of invasive plants relative to anthropogenic features within a rural, southwestern Wyoming landscape. Control sites were located more than 1000 m from the nearest anthropogenic feature; however these are clearly not "weed free" controls. These sites were surrounded by various intensities of land-use (especially roads and well pads), so rather than a true control, these sites document the "background" levels of invasion across the "untrammeled" landscape.

Although many species were not found in sufficient abundance, within our sampling design, to model individual feature-distance relationships, analysis of several abundant, recurring species reveals important patterns and distinctions in their local distributions. Generalized linear models revealed a significant, inverse relationship between distance (and log-linear transformed distance) from a given feature and abundance of cheatgrass, halogeton, perennial pepperweed, flixweed, desert alyssum and Russian thistle (Pr>F, 0.0000001, 0.0271, 0.0441, 0.000007, 0.0001, .0001, respectively). However, the abundance of weeds, taken in sum, did not decline with increasing distance (Pr>F, 0.3276) indicating the widespread abundance of weeds across many parts of this landscape. Weedy plants adjacent to major roads (primary roads) displayed the anticipated exponential decay curve (figure 5a) with the greatest abundance of invaders falling within 200 meters of the road and measurable abundance approaching zero near 400 meters. The distribution of weeds associated with secondary roads (large unpaved routes), tertiary roads and informal roads precluded fitting linear or curvilinear trends due to distance effect (figure 5). Thus, while some species did appear to decline in abundance between 400-600 meters away from targeted features, the expanse of invasion extended well beyond these distances, with little to no sign of decline. Of particular concern for managers in this region are annual bromes, especially cheatgrass (*Bromus tectorum*; also known as downy brome).

Cheatgrass has come to dominate vast, formerly sagebrush dominated, landscapes in neighboring regions, such as the Great Basin (Knapp 1996; Chambers and others 2007), making the species a major management concern across the Intermountain basins and northern steppe (Monsen and Shaw 2000). We found a wide distribution of cheatgrass in southwestern Wyoming, but it is not clear that the distribution of infrastructure is having an effect on these distributions, because although it exhibited a significant distance relationship, cheatgrass was observed in large abundances beyond 500m from the nearest feature. Our samples disclosed recognizable abundance of occurrences near features, and demonstrate decreasing abundance with increasing distance, as anticipated, when considering interactions with a single feature, such as informal, two-track roads (figure 6). However, in many cases, other road classes for example, weed occurrence is sustained at a distance greater than 500m from the nearest anthropogenic features (figure 6). This suggests that another, widespread environmental condition or activity is also responsible for driving the patterns of cheatgrass distribution and dominance in this region. Ongoing research is aimed at discerning the important driving factors for predicting, and restricting, the distribution of invasive plants relative to a combination of environmental factors.

Composition In Historic Habitat Treatments

BACKGROUND AND METHODS

Federal and state agencies and nongovernmental organizations have been funding habitat treatments across southwestern Wyoming for many years. There is a general recognition that monitoring of past and current habitat treatments have lacked designs and standardized approaches necessary for summarizing the effectiveness of current and past habitat treatments across spatial and temporal scales (Hughes and others 2000; Connelly and others 2004). Monitoring of restoration and habitat treatments is essential to determine their performance in order to make improvements and develop best management practices to help guide the design and development of future habitat treatments and to improve the ability of these treatments to meet landscape conservation objectives locally, and across the landscape. To accomplish this multi-scale goal, we included field measurement of vegetation, soil and wildlife use (as indicated by fecal deposits), with remote sensing approaches for estimating plant productivity and phenology. Within this region, interactions between Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter referred to as sage-grouse) and habitat conditions are critical for management planning, therefore direct estimates of wildlife response to treated habitats and developed and reclaimed habitats will inform adaptive management of wildlife habitats.

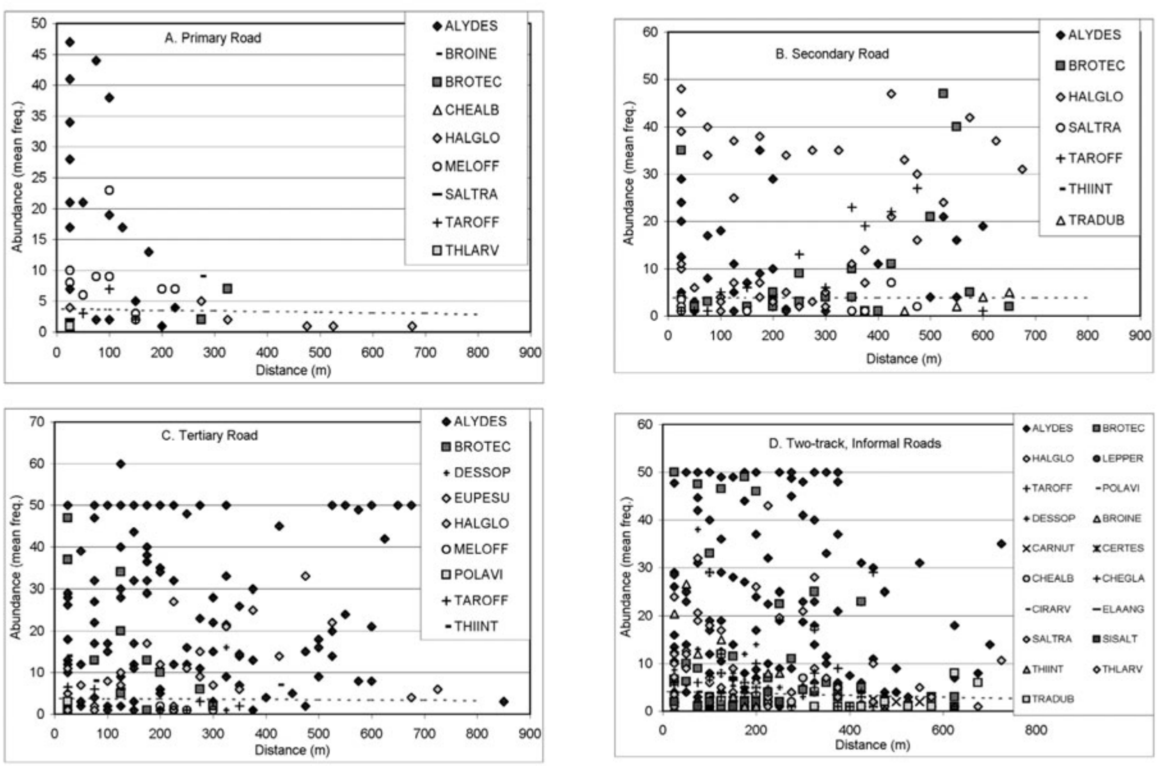

Figure 5 (a-d). Simple distributions of invasive plants observed in proximity to four (4) different sized road classes in southwestern Wyoming, U.S.A. The x-axis depicts the distance from a target feature based on observation of each 1m^2, aggregated into 25 m segments for each abundance estimate. Species abbreviations represent genus and specific epitaph, namely ALYDES (*Alyssum desertoides*), BROINE (*Bromus inermis*), BROTEC (*Bromus tectorum*), CARNUT (*Carduus nutans*), CERTES (*Ceratocephala testiculata*), CHEALB (*Chenopodium album*), CHEGLA (*Chenopodium glaucum*), CIRARV (*Cirsium arvense*), DESSOP (*Descurania sophia*), ELAANG (*Elaeagnus angustifolia*), EUPESU (*Euphorbia esula*), HALGLO (*Halogeton glomeratus*), LEPPER (*Lepidium perfoliatum*), MELOFF (*Melilotus officinale*), POLAVI (*Polygonum aviculare*), SALTRA (*Salsola tragus*), SISALT (*Sysimbrium altimissium*), TAROFF (*Taraxacum officinale*), THIINT (*Thinopyrum intermedium*), THLARV (*Thlaspi arvense*), TRADUB (*Tragopogon dubius*).

Our remote sensing approach was guided by the need to identify cover and productivity associated with historic treatments and the additional fact that these sites were distributed across the landscape with high variability in documentation as well as environmental conditions. Greenness indices such as the normalized difference vegetation index (NDVI) can be acquired by satellite over large areas at relatively coarse scales, however this approach may miss important details, such as the period of rapid green-up following snow-free days (which may only be detectable at finer spatial and temporal scales). This period of early, green-up can influence habitat use (for example, elk movement, sage-grouse activity, etc.), so it could be an important indicator of seasonal habitat condition on treated and untreated areas.

To enhance our resolution of this phenomenon, we are developing field-plot level, near-surface sensors to closely monitor changes in vegetation. In addition to detecting cheatgrass, this approach could provide important details of seasonal forage availability, for example, to determine when to stop elk feeding on state feed-grounds, where earlier feeding end dates are associated with reduced Brucellosis prevalence (Cross and others 2007). In addition, near-surface sensing platforms can target specific species (for example, perennial grasses or shrubs) or features (for example, bare soil, which is likely to show green-up by annuals including weeds), which remote sensing cannot, and specific species may be more or less palatable and thus more or less likely to provide forage/habitat for animal species of interest.

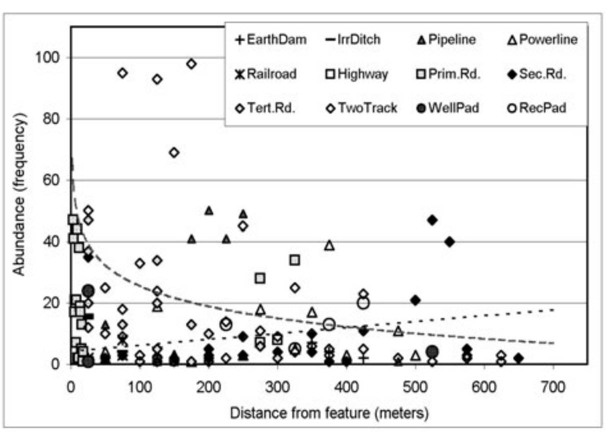

Figure 6. The distribution of cheatgrass (*Bromus tectorum*) relative to rural, land-use features in southwestern, Wyoming. The curve (dashed-line) demonstrates the negative, log-linear relationship between distance and abundance of cheatgrass. Whereas, the straight line (dotted-line) clearly demonstrates, with a positive trend, that cheatgrass abundance did not decrease in abundance relative to all features. Variability in these distributions demonstrate the influence of other environmental factors. Sampled features (with abbreviation) include small, earthen dams (EarthDam), irrigation ditches (IrrDitch), oil and gas pipelines (Pipeline), overhead electrical lines (Powerline), Railroad, Highways, primary, paved thoroughfares (Prim.Rd.), large gravel roads (Sec.Rd.), small (short) gravel roads, driveways, spurs and access roads (Tert.Rd.), informal, unmaintained roads (Two-Track), active oil and gas facilities (WellPad) and reclaimed, former oil and gas facilities (RecPad).

As climate driven changes (for example, earlier snow melt) interact with vegetation, we expect plant phenology to shift in response to water availability and suitable growing conditions. This may make forage available earlier, for example, but it may also result in earlier senescence, or shifts in dominance to less-palatable, weedy species. To monitor these interactions, we established 50 multi-scale vegetation plots (Barnett and others 2007) in the vicinity of the Fall Creek feed-ground near Pinedale, Wyoming. These sites included burned and herbicide treated areas. We collected reflectance data from native and non-native vegetation using 14 mantis platforms (an adjustable tripod structure mounted with a multispectral camera to collect spectral reflectance data like a satellite from surface environments) during the 2010 growing season. We used “ground-truth” plot and reflectance data to measure correlations with remotely sensed data. We established an additional 30 plots in 5 historic treatment areas on and around the Pinedale Anticline to measure differences in plant species composition and cover as well as exposure of bare mineral soil.

Our remote sensing efforts were complimented by field research into composition and wildlife utilization. Since 1990, numerous restoration and enhancement projects have been implemented in the Little Mountain Ecosystem area (south of Rock Springs, Wyoming). Many of these projects involved prescribed burns to reduce sagebrush cover, increase herbaceous cover, increase other mountain shrub species (for example serviceberry, antelope bitterbrush), and retard the expansion of junipers into sagebrush. Wildfires and prescribed burns have been linked with the expansion of cheatgrass in similar systems in the Great Basin; however, in some situations burning has been documented to support more stable plant communities that resist cheatgrass and other invasive plant species (Shinneman and Baker, 2009). We worked with land management agencies to map burn treatments in the Little Mountain area (approximately 25 miles south of Rock Springs, Wyoming) from 1990 through 2008. Using the design and sampling methods described in the previous section (Land Use and Invasive Plants), we sampled 22 vegetation transects (June through August) that were randomly distributed across burn treatments. We augmented the methodology described in the previous section at 17 of the 22 sites to include soil sampling (for determining soil texture and chemistry) and document the presence of biological soil crusts. Biological soil crusts, which can be disturbed through burning, are thought to help resist invasive species (Ponzetti and others 2007); therefore, a lack of crust may be associated with increased invasion potential. Sage-grouse pellet count surveys were conducted on two treatments, mowing and Tebuthiuron (herbicide, brand name "Spike"™), applied to sagebrush habitats in southwest Wyoming to ascertain use patterns and long-term trends associated with sage-grouse and treatment characteristics and gradients of energy development. Treatments were conducted on federal lands within the Moxa Arch Natural Gas Development near Granger, Wyoming. Treatment sites (implemented during 1997 through 2002) represented upland habitats dominated by Wyoming big sagebrush within areas selected by sage-grouse for nesting and early brood rearing. During 2009, forty-four 100-m by 4-m belt transects were randomly selected at mowed and Tebuthiuron applied treatment sites to evaluate sage-grouse use and the role of treated patch size, treated patch shape, and patch distance to lek (an assembly area for communal courtship display) or nesting habitat, and energy infrastructure.

RESULTS AND DISCUSSION

Preliminary results from the near-surface reflectance measurements indicated that we can track major phenological events such as flowering in addition to green-up and senescence using remote sensors. Vegetation plot sampling data representing one treated area (1960; figure 7) suggested that the sagebrush reduction treatment effects persist. Although not statistically significant the percent cover of Wyoming big sagebrush was lower in the treated (16 percent) than untreated area (27 percent), and total vegetation cover followed the same pattern (33 percent cover treated vs. 54 percent cover untreated) and the difference was actually visible in remotely sensed imagery (figure 7). The percent cover of bare soil was significantly greater in the treated area (56 percent treated vs. 23 percent untreated; $p < 0.01$).

Preliminary results from assessments of burn treatments indicated a mixed response to cheatgrass invasion. Cheatgrass occurred in all transects but the frequency within subplots varied. Sixteen transects had a sandy loam texture while only one transect was classified as having a sandy clay loam. Subplot frequency of cheatgrass will be compared to duration since treatment and with soil nutrients and carbon/nitrogen ratios in future analyses

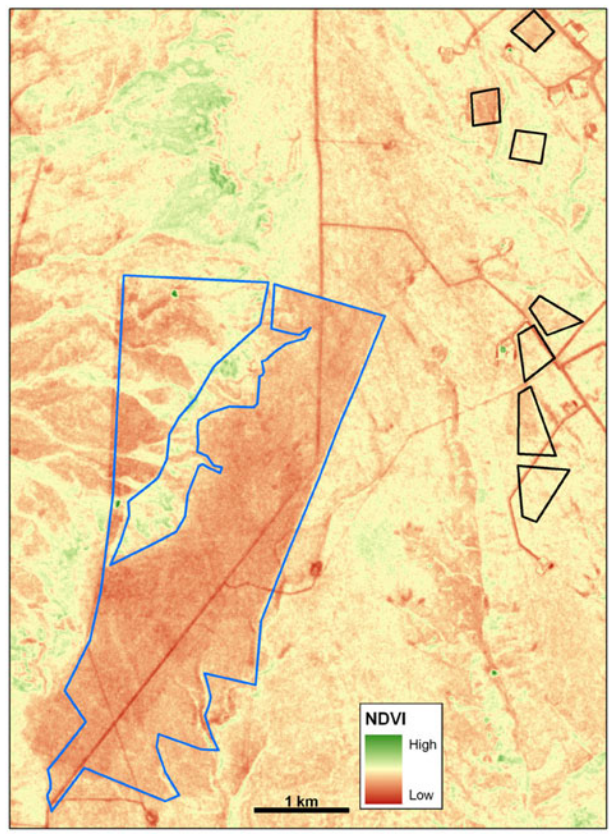

Figure 7. The normalized difference vegetation index (NDVI) is an indicator of greenness and standing vegetation. In this 2007 SPOT satellite image of an area that was sprayed with herbicide in 1960 (large, irregular black outlined area) the treated area is less green (index displayed as red) than the surrounding, untreated area. Note that roads and portions of well pads are also red (little or no vegetation). Image prepared by Mark Drummond, USGS.

Sage-grouse use surveys indicated that they are using mowed and Tebuthiuron treated areas and areas adjacent to energy infrastructure, however use appears to be connected to prior occupancy. Sage-grouse use surveys also indicated that they are using large open areas in the center of treatments less frequently than the edge of treatments near the cover provided by untreated sagebrush. Treated sites were most frequently used by sage-grouse during nesting and brood rearing with limited use during fall and winter. Future analyses will include the expansion of additional treatment areas (sampling conducted during 2010) to evaluate if differences exist between treatment types, season of use, proximity to leks and prolonged effects of energy infrastructure.

CONCLUSIONS

While there is a lot of sagebrush on the map, much of it is fragmented, manipulated and impacted by biological invasions induced by perpetual and widespread surface disturbances. The extent of the "sagebrush sea" was greatly reduced in extent before this research began (Connelly and others 2004), making understanding and effective management of these lands important for wildlife conservation. By using a combination of field sampling and remote sensor platforms, we developed detailed cover estimations for shrub habitat components across large regions (State of Wyoming) that accurately depict the current distribution of sagebrush and associated habitats. These data greatly improved the resolution, accuracy and information content of existing products, exhibiting detailed projections within 10 percent of actual cover in most locations. Continuous cover projections, as compared to type-mapping, provide a comprehensive perspective of the heterogeneous distribution of vegetation, litter and bare ground within sagebrush communities, identifying areas of both high and low cover. In the future, it is hoped that these methods, and data, will form a baseline for monitoring changes on this landscape. The U.S. Geological Survey has initiated research applying our component estimates to current and historical vegetation change, climate variation, sage grouse habitat distribution, and grazing trends.

The potential distribution of weeds, especially annual grasses, across the sagebrush steppe is widespread with intense local infestations. Our data showed increased abundance of noxious, invasive plants adjacent to anthropogenic features, especially roads and well pads. However, surveying a wide region and variety of invaders brings recognition that there is not a single profile for invasive plants, even across a consolidated, semi-arid region. For the most abundant, problematic species such as cheatgrass, desert alyssum and halogeton, it was not clear that the distribution of infrastructure remains an important driver of distributions because these species were often observed to be abundant hundreds of meters away from the nearest feature. While the distance effect was significant for most of these cases (linear *and* log-linear), residual variability in these models indicated that other, widespread environmental conditions or activities were also responsible for patterns of invasive plant distribution in this region. Treated sites were most frequently used by sage-grouse during nesting and brood rearing with limited use during fall and winter, and surveys also indicated that they used large open areas less frequently than the edge of treatments. Results also indicated a mixed response of treatments to cheatgrass invasion, however weeds were observed on every treated site. Clearly there are potentially important interactions between habitat distributions, habitat treatments, invasive plants and use of habitats by wildlife. These studies begin to elucidate these patterns and their interactions.

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