Vegetation Dynamics in Yellowstone's Northern Range: 1985 to 1999

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Abstract

An inexpensive and reproducible method for monitoring rangelands over the northern range (NR) of Yellowstone National Park was developed utilizing Landsat imagery. A 1999 map of rangeland vegetation communities was created using boosted classification tree analysis. The 1999 map and a 1985 image were utilized in a change vector analysis resulting in a classified map for 1985. Classification accuracies ranged from 72.30 percent to 83.65 percent for the 1999 map and 72.60 percent to 88.73 percent for the 1985 map, depending upon level of class detail, demonstrating that Landsat-class data can be effectively used for efficient change analysis that maintains accuracy while reducing compound error. Spatial patterns of change were compared to theories from other studies related to change in the NR and were found to be consistent with effects from fire suppression, precipitation, and urban growth but not with trophic cascade from wolves or beaver effects.

Introduction

Scientists and managers in Yellowstone National Park (YNP) are tasked with protecting wildlife (Yellowstone Park Act, 1872), and livestock are not permitted within the boundaries of YNP (aside from horses on some backcountry trails). The northern range (NR) of YNP includes areas within YNP where only wild ungulates range, but also extends beyond the northern border of YNP where domestic livestock utilize rangelands alongside wild ungulates. YNP provides the perfect laboratory to study wild ungulates in their natural environment. Not only do the animals move in and out of YNP at will, they must endure harsh weather and landscapes, natural predators, and outside of the park, hunting. Knowledge of rangeland vegetation in the NR is imperative for research and management of wild ungulates in the area.

Land managers must make decisions about resources, ecological potential, and trends that affect every aspect of an ecosystem, such as plant ecology, small mammals, birds, and large herbivores, and in turn, large predators within areas they manage (Jensen *et al.,* 2001). Accurate vegetation maps that cover different time periods help land managers understand the vegetation in their management areas and observe patterns of change in that vegetation.

Many drivers of ecological change are seen on a landscape scale. Sudden changes might stem from management practices (e.g., clear cuts or prescribed fires), as well as natural phenomena such as lightning caused fires or massive flooding. Gradual changes, such as shifts in vegetation community structure, might be more extensive and result from factors such as management practices (e.g., grazing intensity) and moderate- to long-term climate variation.

Satellite-borne remote sensing data such as Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) are often used to map landscape-scale vegetation such as forest versus non-forest. TM and ETM+ data have been utilized less often for delineating non-forest vegetation communities because of their moderate spatial and low spectral resolutions. The existence of extensive Landsat data archives, however, enables post-hoc change analyses that might otherwise be impossible, as issues regarding change are often not recognized until after the change has taken place when it is no longer possible to obtain real-time measurements.

The development of an inexpensive, accurate, reproducible, and automated procedure for mapping rangeland vegetation at a scale useful for a variety of management needs opens doors for many more important ecological studies in the NR. Scientists and managers are able to monitor the landscape, observe spatial and temporal changes, and make scientifically sound management decisions appropriate for species of concern. The purpose of this research was to: (a) provide YNP with an accurate base map of rangeland vegetation in the NR for 1999, (b) conduct a change detection analysis of rangeland vegetation in the NR from 1985 to 1999, and (c) analyze the patterns of change compared to predicted drivers of change observed through ground-based studies.

Changes in Rangeland Vegetation Communities

Changes at a landscape scale are observed through spatial patterns. The processes that affect those changes are not directly observable with remotely sensed data, but the patterns that the processes reflect can be studied. We can evaluate hypothesized drivers of ecological change by determining whether observed patterns of change are consistent with or divergent from patterns expected from these drivers (Lawrence and Ripple, 2000).

Diverse vectors of change are possible in the NR rangeland vegetation. We examined five different vectors that have been studied in the NR and evaluated the spatial patterns documented in the classification process for consistency with these vectors: (a) fire, (b) climate in terms of temperature and precipitation, (c) beaver (*Castor canadensis*), (d) urban development and loss of agriculture, and (e) trophic cascade due to wolves.

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Wildfire is a catastrophic, sometimes natural, event on a landscape. This study looks at changes over a fourteen-year period from 1985 to 1999. The Yellowstone ecosystem was engulfed by fire during the summer of 1988 and has experienced several smaller fires since then. Some of these fires occurred in the NR. We would expect to see an increase in secondary succession vegetation, i.e., grasslands where brushlands dominated prior to fire, if fire was a vector of change in NR rangeland vegetation (Gotelli, 2001; Van Dyke and Darragh, 2006).

Climate changes are difficult to observe over a fourteen-year period. Differences in precipitation and/or temperature during that time might be normal variation or might represent actual changes in the climate for the area. We might see an increase in wet vegetation if trends indicate increased precipitation, while a decrease in precipitation would show a decrease in wet vegetation and an increase in dry vegetation. The same pattern, however, might result from an increase in temperature.

Studies are currently under way on the return of beaver to YNP and their influence on willow (*Salix spp.*) (Singer *et al.*, 2004). Beavers use willow for food and building materials (Hall, 1960), however, the relationship is symbiotic, allowing willow to thrive with healthy beaver populations (Baker *et al.*, 2005). We would expect to see an increase in willow along riparian corridors with the return of beaver (Hall, 1960; Baker *et al.*, 2005).

There has been an exponential increase in human development outside YNP in the Paradise Valley (Greater Yellowstone Coalition, 2000). This development is reflected by more residential development along with decreasing agricultural land use (Parmenter *et al.,* 2003). Many ranches have been sold and subdivided for new housing communities. These changes should be reflected in an observed increase in developed area and a decrease in agricultural land since 1985.

Finally, the theory of trophic cascade proposed by several researchers at YNP (Mao *et al.*, 2005; Ripple and Beschta, 2007) asserts that the reintroduction of wolves (*Canis lupus*) to YNP in 1995 and 1996 has affected the movement of elk (*Cervus canadensis*) in their habitats and thus their use of certain species for food, specifically edge and riparian species. It is hypothesized that the elk can no longer browse at their leisure and must stay out of open areas for fear of being trapped by wolves. Aspen (*Populus tremuloides*) overstory has declined greatly in the last century (Despain, 1990; Meagher and Houston, 1998). Scientists in YNP believe that species such as willow and aspen will be utilized less by the elk, therefore will grow at greater rates than in previous years (Beyer *et al.*, 2007; Ripple and Beschta, 2007). We would expect to observe an increase in the aspen class if this hypothesis is true, although these changes might not yet be highly evident due to the short time span between wolf reintroduction (1995) and land-cover classification (1999).

Methodology

Study Area

The NR of YNP encompasses the 152,665 ha area of the Yellowstone and Lamar River basins that is utilized by wintering ungulates. The NR covers an area just south of Emigrant, Montana, through Gardiner, Montana, then Mammoth Hot Springs, Wyoming, to Cooke City, Montana (Figure 1). Elevation ranges from 1,500 to 3,209 m. Habitat types range from grassland and shrubland to forest community types (Despain, 1990). Average precipitation over the last 30 years has been 25 to 30 cm in the lower elevations and up to 152 cm in the higher elevations (Yellowstone National Park, 2000). One third of the NR (approximately 53,200 ha) is located on public and private land outside of YNP.

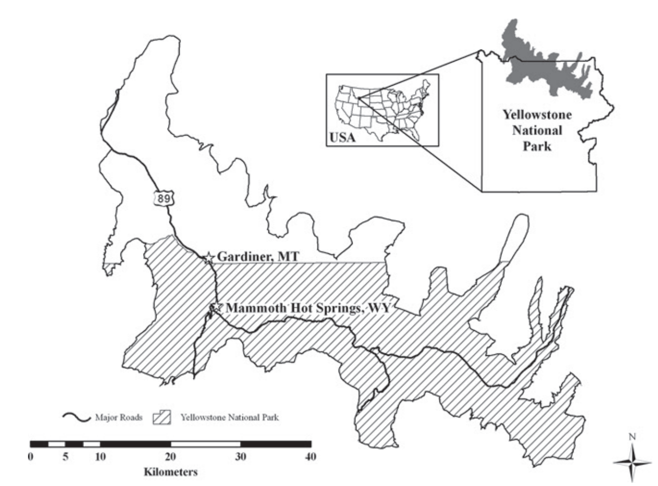

Figure 1. Yellowstone Northern Range study area.

Classification of 1999 Images

The year 1999 was selected for the base map because of the high quality of the imagery (i.e., no clouds or smoke) and the availability of concurrent aerial photographs for reference data. A five-level hierarchical classification scheme was used, ranging from very broad vegetation types, such as woodland, shrubland, or herbaceous vegetation (Level 1), to specific vegetation types and communities, such as aspen, tufted hairgrass/sedge (*Deschampsia cespitosa*/*Carex spp.*), or big sagebrush/Idaho fescue (*Artemisia tridentata*/*Festuca idahoensis*) (Level 5) (Table 1). This multi-level classification scheme is flexible, can be used in diverse studies, including studies on pronghorn habitat use (Level 5) or studies on successional changes in edge habitat (i.e., grassland to shrubland, Level 1), and is consistent with previous aerial photo-based maps of YNP vegetation (Despain, 1990). Forest, water, geothermal, developed, snow, and agricultural classes were extracted from previously-derived data maintained by YNP and are not listed in Table 1. Twenty-one Level 5 classes were used in the classification process, but the final output maps have 27 classes to include the previously derived data. Levels 1 through 4 of the classification hierarchy are based on the Federal Geographic Data Committee National Vegetation Classification Standard and Level 5 is based on the Despain habitat types (Despain, 1990; Federal Geographic Data Committee, 1997).

Landsat ETM+ satellite images from 18 July and 15 September were acquired for the study. Using multiple dates of imagery for one classification has been shown to improve accuracy by capturing variations in phenology (Tucker *et al.*, 1985; Reed *et al.*, 1994, Lawrence and Wright, 2001, Lawrence *et al.*, 2006). The images were transformed in several different ways to produce derived spectral components that were used in the classification in addition to the original spectral bands. These derived components included all components from standardized principal components analysis (PCA) from the two dates of imagery combined, the normalized difference vegetation index (NDVI), tasseled cap (TC) transformation (Huang *et al.*, 2002), and the difference in spectral values between the two dates for each spectral band. Ancillary GIS data added to the dataset included elevation,

Table 1. Rangeland Vegetation Classification Hierarchy

Level 1	Level 2	Level 3	Level 4	Level 5
Woodland	Deciduous woodland	Deciduous woodland - Dry	Cold-deciduous woodland	Aspen (*Populus tremuloides*)
		Deciduous woodland - Wet	Temporarily flooded cold-deciduous woodland	Cottonwood (*Populus spp.*)
Shrubland	Evergreen shrubland	Evergreen shrubland - Dry	Lowland microphyllous evergreen shrubland	Big sagebrush/bluebunch wheatgrass (*Artemisia tridentata/Agropyron spicatum*)
				Big sagebrush/Idaho fescue (*Artemisia tridentata/Festuca idahoensis*)
				Big sagebrush/Idaho fescue-sticky geranium phase (*Artemisia tridentata/Festuca idahoensis - Geranium viscosissimum* phase)
	Deciduous shrubland	Deciduous shrubland - Wet	Temporarily flooded cold-deciduous shrubland	Shrubby cinquefoil-silversage/tufted hairgrass (*Potentilla fruticosa Artemisia cana/Deschampsia cespitosa*)
			Seasonally flooded cold-deciduous shrubland	Willow/sedge (*Salix spp./Carex spp.*)
Herbaceous vegetation	Perennial graminoid vegetation	Perennial graminoid vegetation - Dry	Perennial grass crops (hayland, pastureland)	Agriculture
				Crested wheatgrass (Exotic) (*Agropyron cristatum*)
				Mustard (Exotic) (*Chorispora tenella*)
				Russian thistle (Exotic) (*Salsola australis*)
			Medium-tall bunch temperate or subpolar grassland	Smooth brome (Exotic) (*Bromus inermis*)
				Bluebunch wheatgrass/Sandberg's bluegrass-needle-and-thread phase (*Agropyron spicatum/Poa secunda -Stipa comata* phase)
				Idaho fescue/bearded wheatgrass (*Festuca idahoensis/Agropyron caninum*)
				Idaho fescue/bearded wheatgrass-sticky geranium phase (*Festuca idahoensis/ Agropyron caninum - idahoen Geranium viscosissimum*
				Idaho fescue/bluebunch wheatgrass (*Festuca idahoensis/Agropyron spicatum*)
				Idaho fescue/Richardson's needlegrass (*Festuca idahoensis/Stipa richardsonii*)
				Mudflow mosaic
		Perennial graminoid vegetation - Dry	Temporarily flooded temperate or subpolar grassland	Silver sage/Idaho fescue, Idaho fescue/ tufted hairgrass (*Artemisia cana/Festuca idahoensis, Festuca idahoensis/ Deschampsia cespitosa*)
				Tufted hairgrass/sedge (*Deschampsia cespitosa/Carex spp.*)
			Seasonally flooded temperate or subpolar	Sedge bogs (*Carex spp.*)
Sparse vegetation	Boulder, gravel, cobble, or talus sparse vegetation	Boulder, gravel, cobble, or talus sparse vegetation - Dry	Lowland or submontane talus/scree	Talus

slope, and aspect (N, S, E, W, NE, SE, SW, NW, and flat) derived from a 30 m digital elevation model and a layer depicting distance from streams utilizing the USGS National Hydrography Dataset. Training and validation data were collected in three ways: (a) in the field by drawing polygons on high-resolution color infrared (CIR) aerial photographs flown in August 1998, (b) in-office photo interpretation, and (c) in the field with a handheld GPS unit. None of the scenes in the available 1998 imagery were cloud-free, and in most cases were greater than 70 percent cloud covered. There were no catastrophic weather or fire events from 1998 to 1999, so training data from the 1998 photos could be used on cloud-free imagery from 1999. We initially collected 5,206 sites, and 3,604 of those sites were used for training data.

Classification was conducted using boosted classification trees (Quinlan, 1993) to produce an initial classification at Level 5 (21 classes). Subsequently, when there was confusion primarily between two classes (e.g., cottonwood (*Populus spp.*) versus willow; although other classes might also be represented in the terminal nodes), the data relating to those predicted classes were extracted from the training data and separate boosted classification trees of 21 classes were produced for that sub-dataset. By reclassifying with 21 classes rather than just the 2 that were confused, the error from other classes that were incorrectly classified in the initial attempt is reduced. Results from the classifications were applied to the imagery using the United States Geological Survey (USGS) NLCD tool for ERDAS Imagine® to create thematic maps (Plate 1a).

Validation data consisted of 1,602 class-stratified random sites. The vegetation information from these valida-

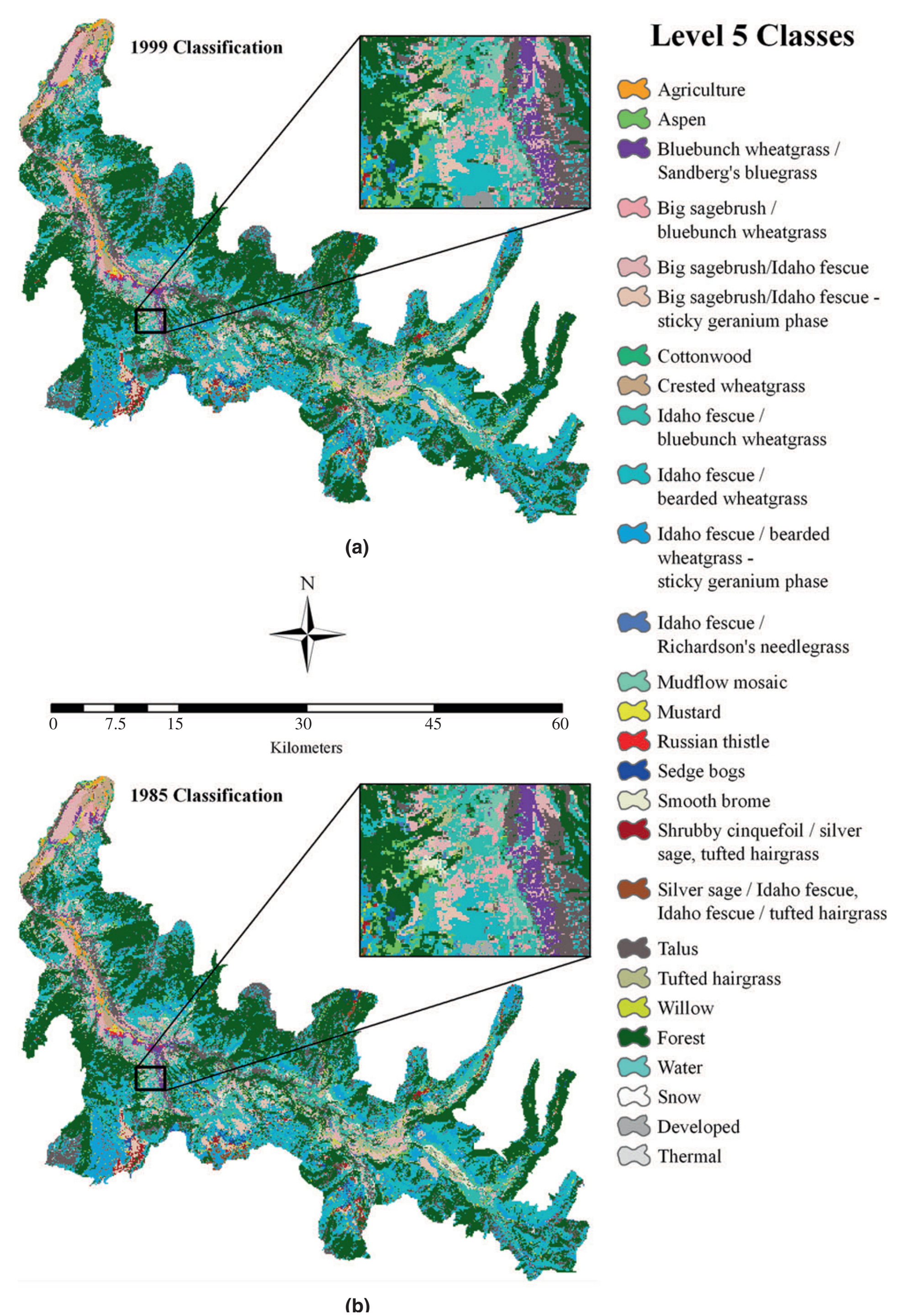

Plate 1. Final 27-class classifications of the Northern Range: (a) 1999 Classification, and (b) 1985 Classification.

tion sites was used as reference data to compare to the output of the classification. Error matrices (Congalton, 2001) were created for Level 5 to determine the overall map accuracies at the most detailed level. The error matrices for Levels 1 through 4 were created by combining classes from the Level 5 error matrix (i.e., the Level 1 class, Woodland, is made up of Level 5 classes, Aspen and Cottonwood). A Kappa statistic was calculated for each level of the hierarchy in each of the iterations.

Classification and Change Vector Analysis of 1985 image

A Landsat TM image from 16 September 1985 was acquired for the change analysis. The 1985 image was geometrically registered to the September 1999 image using a first-order polynomial nearest neighbor resampling method with 15 ground control points (RMSE = 0.196). The same spectral transformations applied to the 1999 imagery were applied to the 1985 imagery, except PCA consisted of a single date, and no image differencing was available because only one date of imagery was used. The 1985 TM imagery was converted to top-of-atmosphere reflectance, enabling us to use TC coefficients developed for ETM+ imagery, thereby standardizing the TC components between 1985 and 1999 and accounting for between sensor differences.

Change vector analysis (CVA) is a rule-based change detection method that examines the angle and magnitude of change between dates in spectral space (Lambin and Strahler, 1994; Parmenter *et al.*, 2003). CVA measures spectral change based on the shortest distance in spectral space between two dates using the Pythagorean Theorem (Equation 1), often the TC components, brightness, greenness, and wetness (Malila, 1980; Allen and Kupfer, 2000; Allen and Kupfer, 2001). By combining these three TC bands with CVA procedures, definitive biophysical differences can be detected rather than being confused with inherent spectral variations, thus reducing much of the uncertainty and making the results easier to interpret (Allen and Kupfer, 2000; Parmenter *et al.*, 2003):

$$\text{Change Magnitude} = ((B_1 - B_2)^2 + (G_1 - G_2)^2 + (W_1 - W_2)^2)^{0.5} \quad (1)$$

where $_{1,2}$ refer to the September 1999 and the 1985 images, respectively, B = brightness, G = greenness, and W = wetness. This change detection method has not been commonly combined with classification tree analysis; nevertheless, CVA was considered well-suited for change detection of this nature.

A change magnitude threshold value was determined interactively using expert knowledge of known locations of change and no change. Residual atmospheric and radiometric differences between the two years of imagery were accounted for in this manner. The threshold delineated where pixels were assumed to have remained the same over time within the image. Only the pixels that were potentially changed between the dates were separately classified for the 1985 image, with the remaining pixels retaining their class values from the 1999 classification. It was necessary to reclassify 10.5 percent of the image to ensure that all changes were detected. Locations that were determined to be unchanged from 1985 to 1999 were used as training data for the potentially changed locations in the 1985 image. The unchanged training data from 1985 were used to produce boosted classification trees that were applied to the potentially changed 1985 pixels using the USGS NLCD tool in Imagine®, creating a 27-class map for 1985 (Plate 1b).

High-resolution (1:9 600) aerial photos from 1986 were used for accuracy assessment. Aerial photos from 1985 were not available, but there had been no catastrophic weather or fire events between 1985 and 1986. The available photos did not cover the entire NR, resulting in a reduced accuracy assessment compared to 1999. A total of 269 stratified random validation sites on 38 photos were used to determine the accuracies of the 1985 classification. An error matrix was created for Level 5 to demonstrate the overall accuracies at the most detailed level. The error matrices for Levels 1 through 4 were created by combining classes from the Level 5 error matrix. A Kappa statistic was also calculated for each level of the hierarchy. Two sets of aerial photos from 1986 and 1998 were visually compared in addition to the accuracy assessment, specifically in areas where change was known to have occurred and areas where the change threshold indicated changes did not happen. One hundred random sites were examined on the paired photos. A full accuracy assessment on the change detection of 27 classes was impractical as the error matrix would have 729 classes (each of the 27 classes could either stay the same, or theoretically, change to any of the other 26 classes). To test the accuracy of the change detection analysis from 1985 to 1999, four dominant change classes were designated for the error matrix: (a) no change in shrubland, (b) increase in shrubland (change from herbaceous to shrubland), (c) decrease in shrubland (change from shrubland to herbaceous), and (d) no change in herbaceous. Thirty random sites were identified on the 1998 photos for each of the four change classes. Spatial patterns of change were examined to determine whether they were consistent with the expected effects of fire, climate, beaver, human development, and trophic cascade.

Results

Results reported below focus primarily on the broadest level of the hierarchy (Level 1). Error matrices for Levels 2 through 5 can be accessed by contacting the corresponding author.

1999 Classification Results

Overall accuracies were calculated with error matrices (the results for all levels of the 1999 classification are found in Table 2). The final classified map for 1999 included 27 classes (Plate 1a). The overall accuracies increased with decreased detail in the classification hierarchy. The overall Level 5 accuracy for the 1999 map was 72.30 percent, and for Level 1 was 83.65 percent. The largest decrease in accuracy was from Level 3 to Level 4, where the hierarchy begins distinguishing among plant communities.

User's accuracies for the 1999 Level 1 classification ranged from 78.18 percent for shrubland to 85.22 percent for herbaceous vegetation (Table 3). For the Level 5 classification, user's accuracies ranged from 40.91 percent for big sagebrush/Idaho fescue: sticky geranium phase (*Geranium viscosissimum* phase) to 100 percent for Russian thistle (*Salsola australis*), sedge bogs, shrubby cinquefoil-silver sage (*Potentilla fruticosa-Artemisia cana*)/tufted hairgrass, and silver sage /Idaho fescue, Idaho fescue/tufted hairgrass (Table 4).

TABLE 2. OVERALL ACCURACIES FOR EACH LEVEL OF THE CLASSIFICATION HIERARCHY FOR BOTH 1985 AND 1999

Level	1985 Accuracy	1985 Kappa	1999 Accuracy	1999 Kappa
1	88.73%	0.798	83.65%	0.689
2	88.73%	0.809	82.27%	0.674
3	84.31%	0.774	78.53%	0.675
4	79.90%	0.781	73.66%	0.722
5	72.60%	0.714	72.30%	0.722

Table 3. Error Matrices using Classified and Reference Data for the 1999 and 1985 Level 1 Classifications

Classified Data	Reference Data					
	Sparse Veg	Herbaceous Veg	Shrubland	Woodland		User's Accuracy
1999 Classification						
Sparse Veg	73	7	8	0	73/88	82.95%
Herbaceous Veg	0	928	141	20	928/1089	85.22%
Shrubland	0	51	215	9	215/275	78.18%
Woodland	0	9	17	124	124/150	82.67%
	73/73	928/995	215/381	124/153		
Producer's Accuracy	100.00%	93.27%	56.43%	81.05%		
Overall Accuracy	***83.65%***		Kappa = 0.689			
1985 Classification						
Sparse Veg	12	1	1	0	12/14	85.71%
Herbaceous Veg	1	113	5	2	113/121	93.39%
Shrubland	1	10	46	0	46/57	80.70%
Woodland	0	0	2	10	10/12	83.33%
	12/14	113/124	46/54	10/12		
Producer's Accuracy	85.71%	91.13%	85.19%	83.33%		
Overall Accuracy	***88.73%***		Kappa = 0.798			

Table 4. Producer's and User's Accuracies for the 1999 Level 5 Classification

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Aspen	90	51	49	54.44%	96.08%
Bluebunch wheatgrass/Sandberg's bluegrass – needle-and-thread phase	87	96	62	71.26%	64.58%
Big sagebrush/bluebunch wheatgrass	77	42	40	51.95%	95.24%
Big sagebrush/Idaho fescue	91	59	28	30.77%	47.46%
Big sagebrush/Idaho fescue – sticky geranium phase	70	88	36	51.43%	40.91%
Cottonwood	89	99	75	84.27%	75.76%
Crested wheatgrass	81	123	81	100.00%	65.85%
Idaho fescue/bluebunch wheatgrass	113	208	101	89.38%	48.56%
Idaho fescue/bearded wheatgrass	68	74	64	94.12%	86.49%
Idaho fescue/bearded wheatgrass – sticky geranium phase	70	78	67	95.71%	85.90%
Idaho fescue/Richardson's needlegrass	88	90	73	82.95%	81.11%
Mudflow mosaic	92	107	92	100.00%	85.98%
Mustard	68	57	49	72.06%	85.96%
Russian thistle	67	53	53	79.10%	100.00%
Sedge bogs	51	22	22	43.14%	100.00%
Smooth brome	72	70	61	84.72%	87.14%
Shrubby cinquefoil-silver sage/tufted hairgrass	60	12	12	20.00%	100.00%
Silver sage/Idaho fescue, Idaho fescue/tufted hairgrass	50	9	9	18.00%	100.00%
Talus	73	88	73	100.00%	82.95%
Tufted hairgrass/sedge	91	102	66	72.53%	64.71%
Willow/sedge	83	74	66	79.52%	89.19%
Totals	1602	1602	1180		

Producer's accuracies for the 1999 Level 1 classification ranged from 56.43 percent for shrubland to 100 percent for sparse vegetation (Table 3). Producer's accuracies for the 1999 Level 5 classification ranged from 18.00 percent for silver sage/Idaho fescue, Idaho fescue/tufted hairgrass to 100 percent for crested wheatgrass (*Agropyron cristatum*), mudflow mosaic, and talus (Table 4).

Primary areas of confusion in the Level 5 classification were among classes with substantial grass components, most likely because the grasses had similar spectral responses. Big sagebrush/Idaho fescue was confused with bluebunch wheatgrass/Sandberg's bluegrass, i.e., needle-and-thread phase (*Agropyron spicatum/Poa secunda - Stipa comata* phase), Idaho fescue/bluebunch wheatgrass, big sagebrush/Idaho fescue - sticky geranium phase was confused with tufted hairgrass, and silver sage/Idaho fescue, Idaho fescue/tufted hairgrass was confused with Idaho fescue/bluebunch wheatgrass.

Shrubby cinquefoil - silver sage/tufted hairgrass and silver sage/Idaho fescue, Idaho fescue/tufted hairgrass had extremely low producer's accuracies and 100 percent user's accuracies. This indicated that very few of the pixels were classified as these classes when they should have been. Shrubby cinquefoil - silver sage/tufted hairgrass was confused with big sagebrush/Idaho fescue - sticky geranium phase and crested wheatgrass, while silver sage/Idaho fescue, Idaho fescue/tufted hairgrass was confused with Idaho fescue/bluebunch wheatgrass. Finally, Idaho fescue/bluebunch wheatgrass was confused with big sagebrush/Idaho fescue and silver sage/Idaho fescue, Idaho fescue/tufted hairgrass, resulting in a fairly low user's accuracy.

1985 Classification Results

The overall accuracies for all levels of the 1985 classification increased with decreased detail in the classification hierarchy, similar to the 1999 classification (Table 2). The overall Level 5 accuracy for the 1985 map was 72.60 percent and for Level 1 was 88.73 percent. The higher accuracies in 1985 compared with 1999 were within sampling error, thus there was no significant differences from the 1999 classification. The largest decrease in accuracy for 1985 was between Level 4 and Level 5, where the number of classes increased from 10 to 27 classes.

The user's accuracies for the 1985 classification ranged from 80.70 percent for shrubland to 93.39 percent for herbaceous vegetation for Level 1 (Table 3), and from 53.85 percent for thermal areas to 100 percent for agriculture, aspen, crested wheatgrass, and water for Level 5 (Table 5). The producer's accuracies for the 1985 classification ranged from 83.33 percent for woodland to 91.13 percent for herbaceous vegetation for Level 1 (Table 3) and from 16.67 percent for crested wheatgrass to 100 percent for mudflow mosaic, Russian thistle, and developed areas for Level 5 (Table 5). The most confusion again was found among classes with Idaho fescue and between cottonwood and willow.

Change Detection Results

The values of the change in magnitude between the 1985 and 1999 images ranged from 0.004 to 1.079 and the threshold where change occurred was chosen at 0.173. The categories of pixels with change values less than 0.173 were assumed to have remained the same and these pixels were utilized as training data for the 1985 classification. In the 1985 image, 10.5 percent was reclassified, while approximately 95 percent of the NR remained unchanged from 1985 to 1999; thus, approximately half of the potentially changed pixels in the 1985 image were reclassified to the same categories as the 1999 classification and the remainder were classified into different categories.

Overall accuracy of the change detection analysis was 73.33 percent (Table 6). The change detection process was fairly successful at distinguishing areas of change from areas of no change within the shrubland and herbaceous vegetation

Table 5. Producer's and User's Accuracies for the 1985 Level 5 Classification

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Agriculture	4	2	2	50.00%	100.00%
Aspen	5	4	4	80.00%	100.00%
Bluebunch wheatgrass/Sandberg's bluegrass – needle-and-thread phase	13	14	9	69.23%	64.29%
Big sagebrush/bluebunch wheatgrass	9	11	8	88.89%	72.73%
Big sagebrush/Idaho fescue	14	13	9	64.29%	69.23%
Big sagebrush/Idaho fescue – sticky geranium phase	17	16	13	76.47%	81.25%
Cottonwood	8	8	6	75.00%	75.00%
Crested Wheatgrass	6	1	1	16.67%	100.00%
Idaho fescue/bluebunch wheatgrass	15	16	12	80.00%	75.00%
Idaho fescue/bearded wheatgrass	19	19	11	57.89%	57.89%
Idaho fescue/bearded wheatgrass – sticky geranium phase	15	14	8	53.33%	57.14%
Idaho fescue/Richardson's needlegrass	7	7	6	85.71%	85.71%
Mudflow mosaic	7	10	7	100.00%	70.00%
Mustard	13	9	8	61.54%	88.89%
Russian thistle	7	8	7	100.00%	87.50%
Sedge bogs	10	9	7	70.00%	77.78%
Smooth brome	8	8	5	62.50%	62.50%
Shrubby cinquefoil-silver sage/tufted hairgrass	8	10	7	87.50%	70.00%
Silver sage/Idaho fescue, Idaho fescue/ tufted hairgrass	5	4	3	60.00%	75.00%
Talus	17	15	12	70.59%	80.00%
Tufted hairgrass/sedge	7	9	5	71.43%	55.56%
Willow/sedge	7	9	6	85.71%	66.67%
Forest	14	16	10	71.43%	62.50%
Water	8	6	6	75.00%	100.00%
Snow	4	0	4	—	—
Developed	13	18	13	100.00%	72.22%
Thermal	9	13	7	77.78%	53.85%
Totals	281	281	204		

Table 6. Change Detection Error Matrix. NC Refers to No Change Classes

Classified Data	Reference Data					
	NC - Shrub	Shrub Increase	Shrub Decrease	NC - Herb		User's accuracy
NC - Shrub	22	4	2	2	22/30	73.33%
Shrub Increase	2	24	3	1	24/30	80.00%
Shrub Decrease	2	5	21	2	21/30	70.00%
NC - Herb	1	3	5	21	21/30	70.00%
	22/27	24/36	21/31	21/26		
Producer's accuracy	81.48%	66.67%	67.74%	80.77%		
Overall Accuracy	*73.33%*		Kappa = 0.644			

Table 7. Increases and Decreases in Level 5 Classes between 1985 and 1999

Class	1985	1999	Difference	NR % change
Forest	570351	588208	17857	1.05%
Aspen	38072	41583	3511	0.21%
Talus	155055	156938	1883	0.11%
Water	9418	11221	1803	0.11%
Big sagebrush/bluebunch wheatgrass	24324	25012	688	0.04%
Silver sage/Idaho fescue, Idaho fescue/tufted hairgrass	8243	8838	595	0.04%
Shrubby cinquefoil – silver sage/tufted hairgrass	18710	19177	467	0.03%
Thermal	1493	1827	334	0.02%
Developed	1706	2011	305	0.02%
Cottonwood	13111	13357	246	0.01%
Idaho fescue/Richardson's needlegrass	5128	5333	205	0.01%
Snow	529	629	100	0.01%
Mustard	2683	2722	39	0.00%
Sedge bogs	5973	6012	39	0.00%
Russian thistle	1454	1273	−181	−0.01%
Smooth Brome	15472	15228	−244	−0.01%
Mudflow mosaic	8925	8671	−254	−0.01%
Willow	16015	15738	−277	−0.02%
Agriculture	7287	6849	−438	−0.03%
Big sagebrush/Idaho fescue	63300	62356	−944	−0.06%
Bluebunch wheatgrass/ Sandberg's bluegrass – needle-and-thread phase	15302	14324	−978	−0.06%
Tufted hairgrass	25939	24672	−1267	−0.07%
Big sagebrush/Idaho fescue – sticky geranium phase	60297	58706	−1591	−0.09%
Crested wheatgrass	20611	18789	−1822	−0.11%
Idaho fescue/bluebunch wheatgrass	131923	129186	−2737	−0.16%
Idaho fescue/bearded wheatgrass – sticky geranium phase	170072	163367	−6705	−0.40%
Idaho fescue/bearded wheatgrass	304949	294315	−10634	−0.63%
Total number of pixels classified	1696342			

classes of Level 1. The presence of no markedly low accuracies shows that the CVA threshold value was not too high.

Generally, there was a decrease in grasslands and a relative increase in shrublands (Table 7). While both dry and wet vegetation decreased slightly, dry vegetation saw more decrease than wet vegetation. Willow experienced a very minor decrease and aspen saw the greatest increase in the classes after forest. Finally, developed areas increased while agricultural areas decreased.

Discussion

The overall accuracies for the 1985 and 1999 classifications were quite similar (Table 2), which is not surprising since the 1999 data were used to train the 1985 data, and a fairly small percentage of the 1999 image was reclassified. The classifications were moderately to very successful, depending on level. Landsat data are not expected to classify at species levels (Lillesand *et al.*, 2008), so the results were quite good, although some similar types (especially those containing Idaho fescue) were confused.

We believe the CVA process was critical to the success of our 1985 classification and change detection. CVA reduced compound error that would have been present if we had conducted two independent classifications. Only 10 percent of the study area was classified twice, therefore 90 percent retained the same error structure for both dates, subject only to changes that might have been missed by the CVA threshold. The determination of the threshold of change is crucial to the success of this process as a different threshold might have reduced the accuracy of the 1985 image classification. Furthermore, the errors in the reclassified 10 percent were not entirely independent of the 1999 classification, because the 1999 classification was used as training data for the 1985 classification, which also relates to the other substantial advantage of using CVA for this study. The use of the 1999 classification for training data in the 1985 classification obviated the need for separate training data for the 1985 classification. This saved substantial time, as collecting training data was the most time intensive aspect of the study, but more importantly made the study possible. It was obviously not possible to collect field data for the 1985 classification and the aerial photography record was incomplete. Without the use of CVA to define unchanged locations for training, therefore, we would not have been able to generate sufficient training data to conduct a successful historical classification.

Vectors of Vegetation Change

Level 5 classes of note that increased were aspen and forest. Level 5 classes of note that decreased were crested wheatgrass, Russian thistle, and Idaho fescue/bearded wheatgrass (including the sticky geranium phase). The largest changes within the entire NR were in the forest and Idaho fescue/bearded wheatgrass classes, although only the forest class changed by more than 1 percent.

Why did certain classes change in the manner they did? To answer this question, we can examine the five possible vectors of change mentioned earlier. We might attribute the majority of the changes to fire, since it is a natural successional event. Even with the catastrophic fire events of 1988, however, only 37.6 percent of the NR was burned between 1985 and 1999, and the majority of the areas burned were forested. Thus our analysis was not consistent with fire playing a major role in change during the study period. Rather than the effect of fire on the NR, however, we might be seeing the effect of the lack of fire in certain areas, e.g., succession of grassland to shrubland and forest, on the vegetation of the NR. A study in YNP indicated that human-induced suppression of fire might be a contributing factor to vegetation change (Ripple and Larsen, 2000).

Our analysis was consistent with precipitation playing a possible role in change over the fourteen-year study period. The average temperature ranges between years in YNP weather data (Yellowstone National Park, 1999) do not signify a drastic change in climate trends during that period. The precipitation data provided, however, indicate that there was one-third less precipitation in 1985 than in 1999. The increased precipitation levels in September of 1999, as well as the remains of snow in the high country, might have lengthened the growing season and increased the water levels in rivers and lakes, explaining the increase in some wet vegetation classes and the decrease in many of the dry vegetation classes in the study. This scenario represents only the vegetation during that growing season, and does not provide evidence of climate change.

Changes in the willow class were inconsistent with beaver playing a role in changing the population. An increase was expected, but on the contrary, a very slight decrease of willow was indicated in the change detection (−0.02 percent) (Table 7), but it was hardly enough to warrant concern. After further consideration, it is possible that elk interaction with willow is the predominant factor in its decrease (Bilyeu *et al.*, 2008).

Human development as a vector of change during the study period was supported by our analysis. The slight increase in developed areas is easily explained by the increase in human development outside YNP. New homes were added to the landscape every year, decreasing the amount of uninterrupted rangeland in the NR. The decrease in agricultural land-use can be explained by this increase in human development as well. In addition, several exotic species that have been used in agriculture (crested wheatgrass and mustard (*Chorispora tenella*)) have decreased within YNP. This can be attributed to the intensive exotic plant removal program YNP has instigated, especially along road and trail corridors near the north entrance.

Aspen exhibited the largest increase of non-forest classes in the NR (0.21 percent; Table 7). This was possibly consistent with our expectations of aspen increase due to less utilization by elk. With these data we cannot definitively say the increase was caused by trophic cascade, however, we cannot ignore the possibility that elk are avoiding open areas near aspen as a result of wolf predation and therefore are not consuming aspen at historical rates.

Conclusions

The results of this study support the hypothesis that an accurate, inexpensive, and reproducible method for mapping rangeland vegetation communities over the NR and detecting change over time could be developed. Utilizing Landsat satellite imagery, decision trees, and boosting can produce accurate rangeland vegetation maps, even at very specific levels. Good training and validation data are needed for this process to work well. Time spent in the field is imperative for collecting good data. Utilizing a boosting algorithm to map the rangeland vegetation for the 1999 base map was an efficient and effective method to classify Landsat imagery and predict the output accuracy.

An effective vegetation mapping procedure is important for monitoring ecosystem change at multiple levels, from the broadest vegetation types (forest, woodland, or shrubland) to the most specific types (aspen, tufted hairgrass/sedge, or big sagebrush/Idaho fescue). Changes within the NR can be monitored as often as needed by the establishment of the 1999 base map. With Landsat imagery available as far back as 1972, ecosystem-wide changes can be investigated for more than a quarter century. Providing a highly accurate base map is the first step in giving YNP resource managers and scientists useful tools to study the ecosystem and factors that induce change. The 1985 map and the results of the change detection analysis also will be tools for these land managers. The classes of greatest change will provide starting points for managers to monitor, while the change detection method will allow for the same type of analysis for future images of the area.

Landsat TM data hopefully will continue to be collected regularly (USGS, 2005). Thousands of Landsat images are available over a 35 year period, making Landsat and the Landsat Data Continuity Mission reasonable choices for continuing change detection studies in the NR.

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