LANDSCAPE CONDITIONS AND TRENDS IN AND AROUND YELLOWSTONE AND GRAND TETON NATIONAL PARKS: SUMMARY RESULTS

Produced by the project:

Ecological Condition of US National Parks: Enhancing Decision Support Through Monitoring, Analysis, and Forecasting

Also called:

Park Analysis of Landscapes and Monitoring Support (PALMS)

Sponsored by:

NASA Applications Program: Decision Support through Earth-Sun Science Research Results Project

and

NPS I&M Program

By:

A. Hansen, N. Piekielek, Montana State University
S. Goetz, Woods Hole Research Center
J. Gross, NPS I&M Program
F. Melton, R.Nemani, CSU Monterey Bay / NASA Ames
D. Theobald, Colorado State University

In Cooperation with:

T. Olliff, C. Jean, R. Daley NPS I&M Greater Yellowstone Network
G. Plumb, A. Rodman, R. Renkin, Yellowstone National Park

29 December 2010

Abstract

The goal of this project is to integrate the routine acquisition and analysis of NASA Earth System Science products and other data sources into the NPS I&M decision support systems and use these NASA products to evaluate and forecast ecological condition of US National Parks. The project focuses on four sets of national parks to develop and demonstrate the approach: Sequoia Kings Canyon and Yosemite National Parks, Yellowstone and Grand Teton National Parks, Rocky Mountain National Park, and Delaware Watergap National Recreation Area. This document reports initial findings on landscape trends and conditions in and around Yellowstone and Grand Teton National Parks. After a short introduction, the report highlights initial results for each of the 14 indicators evaluated. The report concludes with a synthesis and interpretation of the trends to identify the primary past and potential future changes to landscape condition that are most relevant to management.

Among the main conclusions are that Yellowstone and Grand Teton National Parks and surroundings represents a wilderness system (relative to most other US National Parks) with ecological processes and species relatively little changed from presettlement times. Hence management options for coping with climate change would seem greater here than in may other systems. However, the topography, climate, and soils, and patterns of land ownership lead to the system exhibiting important interactions between land use and climate change. Ecosystem productivity, biodiversity, private lands, and more intense land uses are concentrated in the small portion of the system that has more favorable soils and climate. Conflicts among the ecological and human components of the system are likely to be exacerbated by climate change (e.g., increased drought, disease, fire, and predator/livestock conflicts). The high valuation of natural amenities by local residents and communities, however, has stimulated considerable progress in cooperative conservation initiatives and this approach shows promise for helping to retain the wilderness condition of these two National Parks. It is important regionally that this be done and that connectivity to other protected in the west be retained because this region is acting as a source for wilderness species that are recolonizing portions of their former range where they had been extirpated.

Table of Contents

Introduction

The need for monitoring and decision support for US National Parks is heightened by the rapid change that is occurring in and around the parks. To address this need, National Park Service (NPS) has developed the Inventory and Monitoring (I&M) Program to provide a framework for collecting and archiving data pertaining to park vital signs including physical, chemical, and biological elements of ecosystem processes within parks. The NPS I&M is increasingly interested in the use of remotely sensed data and ecosystem models to simulate and forecast ecosystem conditions. In this regard**,** NASA data and products can substantially enhance the success of the NPS I&M effort.

The goal of this project is to integrate the routine acquisition and analysis of NASA Earth System Science products and other data sources into the NPS I&M decision support systems and use these NASA products to evaluate and forecast ecological condition of US National Parks, thereby enhancing natural resource management within and surrounding national parks. Specific objectives of this project are:

1. (a) Identify NASA and other products useful as indicators for NPS I&M monitoring and (b) delineate the boundaries of the surrounding protected area centered ecosystems (PACEs) appropriate for monitoring.
2. Add value to these data sets for understanding change through analysis and forecasting.
3. Deliver these products and a means to integrate them into the NPS I&M decision support framework.

The project focuses on four sets of national parks to develop and demonstrate the approach: Sequoia Kings Canyon and Yosemite National Parks, Yellowstone and Grand Teton National Parks, Rocky Mountain National Park, and Delaware Watergap National Recreation Area and Upper Deleware Scenic and Recreational River.

Now in the third and final year of the project, we have reviewed, interpreted, and finalized study results with NPS collaborators through a series of three conference calls. The first reviewed the initial results with core NPS I&M collaborators, the second synthesized a fuller set of results to identify key trends and management challenges, the third presented final results. More information on the project (including overview presentations, progress reports, Standard Operating Procedures, and key publications) can be found at: http://science.nature.nps.gov/im/monitor/lulc/palms/index.cfm.

The goal of this document is to report the landscape trends and conditions in and around Yellowstone and Grand Teton National Parks. The indicators developed by the project and their current status are listed in Table 1. We first present patterns of change in key indicators from past to present and potential future change. We then interpret and synthesize these trends to help inform NPS decision making and management.

Table 1. Indicators being developed for the Yellowstone and Grand Teton National Parks.

Level	Category	Indicator	Resolution	SOP and Reference	Status
Air and Climate	Weather and Climate	Climate gridded daily (dew point, ppt, solar radiation, temp max, temp min, vapor pressure deficit)	1 km; 1994-2009		Completed
		Snow cover	500m, 8 day, 2000-2009		Completed
		Soil wetness	1 km, 2001-2009		Completed
		Phenology (Start of Season based on NDVI, annual anomaly)	1 km; 8 & 16 day; 2000-2009	Melton et al. 2010 Nemani et al. 2008	Completed
		Phenology (Start, length, and end of season based on NDVI)	250 m ; 8 & 16 day; 2000-2009; Yellowstone Watershed	Piekielek et al. in prep.	Completed
Landscape dynamics	Monitoring area	Greater park ecosystem boundaries	30 m	Piekielek et al. 2010a Hansen et al. in review	Completed
	Primary Production	TOPS Gross & Net Primary Productivity (GPP/NPP)	1 km daily and/or monthly summaries; 2000-2008	TOPS SOP Nemani et al. 2008	Completed
	Disturbance Events	Rapid change in Vegetation index	1 km; monthly anomalies / persistent; annual trends; 2000-2008	TOPS SOP Nemani et al. 2008	Completed
	Land Cover	Land Cover and Use	30 m; 1975-1995	Parameter et al. 2003	Completed
		Population Density (decadal)	1 km; 1900-2007	Davis in prep	Completed
		Agricultural Area (decadal)	1 km; 1900-2007	Davis in prep	Completed
		Rural Housing Density (decadal)	1 km; 1860-2007; 2000-2030	Piekielek et al. in prep. Gude et al. 2006	Completed through 1999
	Biodiversity	Pattern of natural landscapes	270 m; time period	Theobald 2009 Theobald 2010	Completed

		Landscape connectivity	270 m; time period	Theobald in prep	Completed
		Ecosystem type composition	30 m Presettlement - present	Piekielek et al. 2010b	Completed
		Indices of habitat (11)	1 km; 1970-2030	Gude et al. 2007	Completed

Summary of Trends in Park Condition

Delineating Protected Area Centered Ecosystems (PACE)

What: Area surrounding park with strong ecological connections to the park.

Why: This area may be important for monitoring, research, and cooperative management to maintain park resources.

Summary: The YELL/GRTE PACE (Fig 1) outside the park was 3.2 times larger than the park area, with at total area of 32362 km^2. The YELL/GRTE PACE was larger than the 9 other park units evaluated (Hansen et al in review) but the ratio of PACE to park area was smaller than for the other units, indicating that the park lands protect a larger proportion of the ecosystem than in other park units (Table 2). The areas mapped for each criteria overlapped substantially in the YELL/GRTE PACE, with 78% of the PACE covered by two or more criteria, a proportion higher than for the other park units evaluated

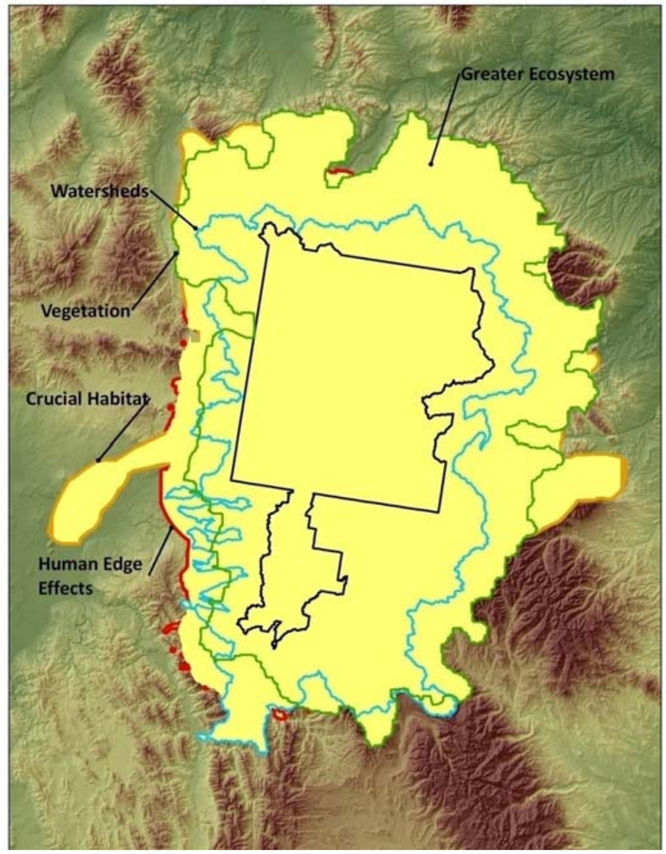


Fig 1. Map of the YELL/GRTE PACE showing the areas included under each of the PACE classification criteria. From Piekielek et al. 2010a.

Table 2. Spatial characteristics of area covered by each criterion used to define the YELL/GRTE Pace including area (km^2) and proportion.

Metric	Total	Criterion				
		Contiguous habitat	Water-shed	Disturbance	Crucial Habitats	Human Edge Effects
Area outside park (km^2	32362	24876	12881	32158	13758	4730
% of PACE uniquely covered		0.25	0.5	11.5	3	3.25

Weather and Climate: 100-year Climate Trends

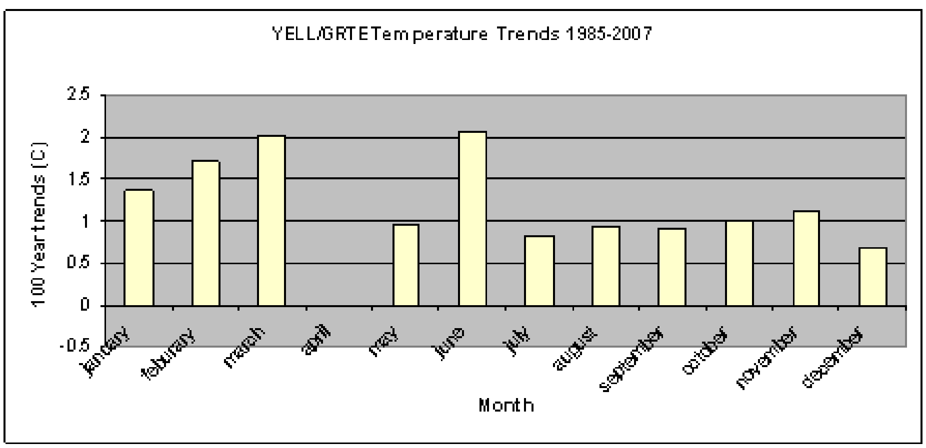
What: 100-year climate trends for YELL/GRTE PACE for the period of 1895-2007 based on PRISM (Daily et al. year) data. From Haas et al. in prep.

Why: 100-year climate trends provide an indication of directionality of climate change over several decades.

Summary: Mean annual temperature has increased by 1.21 C^{o} per 100 years across the PACE (Table 3). Mean annual precipitation has not changed significantly during this period. Warming has been most pronounced in February, March, and June, but has increased significantly in all months except April, September, and December (Fig 2). Precipitation decreased significantly in February and March and increased significantly in August.

Table 3. 100-yr annual temperature and precipitation trends for the period 1895-2007 for the YELL/GRTE PACE based on data from PRISM. February and August. (From Haas et al. in prep).

Park	Temp (C)	PPT (mm)
YELL/GRTE	**1.21 ($p<0.02$)**	**5.43 (NS)**



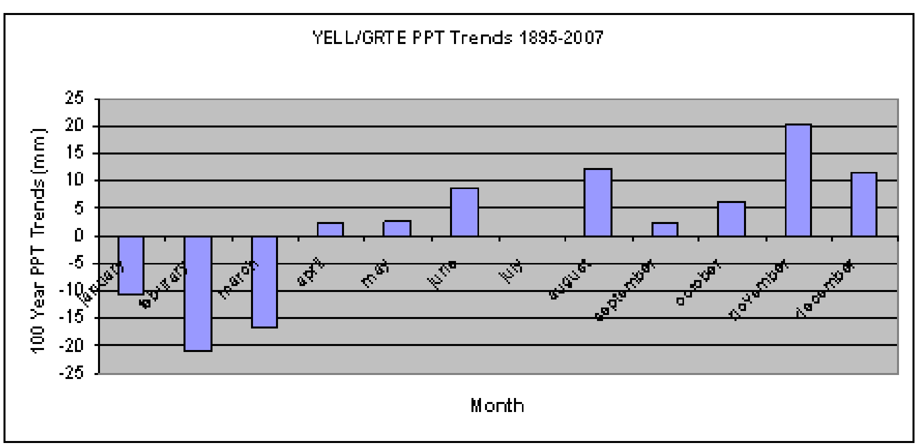


Fig. 2. 100-yr monthly temperature and precipitation trends for the period 1895-2007 for the YELL/GRTE PACE based on data from PRISM. Temperature trends are statistically significant for all months but January, April, August, September, and December. Precipitation trends are significant for February and August. (From Haas et al. in prep).

Weather and Climate: Gridded Climate (1980-2009)

What: Measures spatial patterns in trends and anomalies in temperature and precipitation using interpolated meteorological surfaces from the Terrestrial Observation and Prediction System.

Why: By presenting the distribution of climate trends across latitudinal and elevational gradients, climate trends and anomalies calculated from spatially continuous meteorological surfaces can support interpretation of climate indicators calculated from individual stations or the average of all stations in a region of interest. Meteorological anomalies (relative to historical normals) can also be useful for assessing the magnitude of heat waves, cold snaps, and other short term climate phenomena.

Stressors: Climate change and climate variability

Summary: This indicator has been calculated for GRYN parks and the GRYN PACE region for the 30-year period from 1980-2009, and as expected, indicates that patterns observed in the GRYN parks are similar to patterns within the overall PACE. Trends in the annual average daily maximum temperature indicate an increase for the region, while trends in minimum temperature indicate a decrease in minimum nighttime temperatures since 1980. Trends in precipitation for the region are mixed, though trends in precipitation should be interpreted with caution. The spatial patterns shown in the figure below also capture the variability in trends for the region surrounding the GRYN PACE, emphasizing the importance of evaluating trends from multiple stations surrounding individual parks or I&M networks. This indicator was originally intended to support indicators derived from the NPClime project.

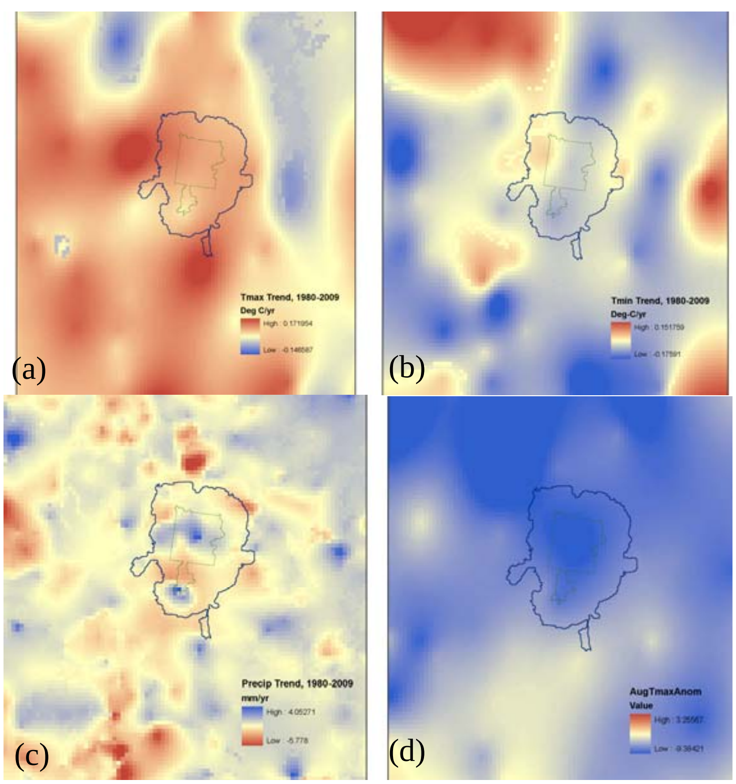


Fig. 3. Trends for the thirty-year period from January 1, 1980 through December 31, 2009 are shown for the annual average daily maximum temperature (a), annual average daily minimum temperature (b), and annual cumulative precipitation (c). In addition, an example of a monthly anomaly map (current conditions relative to historical normals) for maximum temperature is shown for August, 2010.

Weather and Climate: Snow Cover (2001-2009)

What: Graph of snow cover extent and trend in % of park or PACE area with snow cover on Apr 1, as derived from the MODIS satellite snow cover data product.

Why: The timing of snow melt is an important driver of many hydrologic and ecologic processes within parks. One predicted consequence of climate change is a shift toward earlier complete melt of the winter snow pack, affecting runoff patterns and water availability for many parks in the western U.S. This measure provides an indicator designed to supplement indicators derived from station observations, such as measures of the snow water equivalent on April 1.

Stressors: Climate change, drought

Summary: The indicator captures the significant interannual variability in snow cover from 2000-2010 for the GRYN parks and PACE. For the PACE overall, a declining trend in April 1 snow cover is detected, though the trend is heavily influenced by an early snow melt in the spring of 2010. April 1 snow cover over the past decade has typically ranged from 60-90% of the total GRYN PACE, with a value of <5% serving as a significant outlier in 2010. The indicator is intended to supplement measures of snow water equivalent from SNOTEL sites or other monitoring networks within or near the PACE.

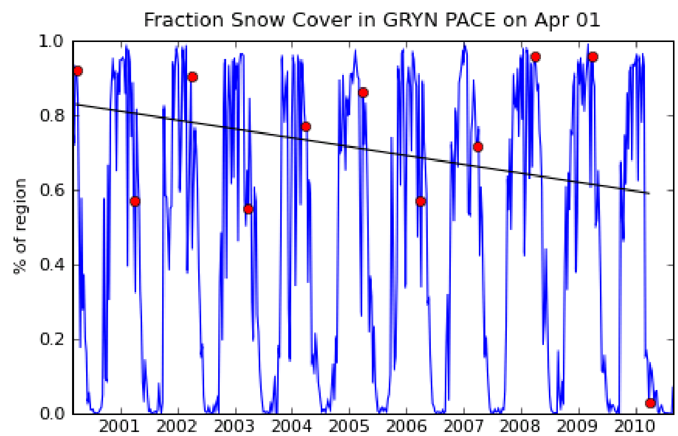


Fig. 4a. Graph of fractional snow cover for GRYN PACE (expressed as % of total area) for 2000-2010, with the trendline shown for April 1 snow cover

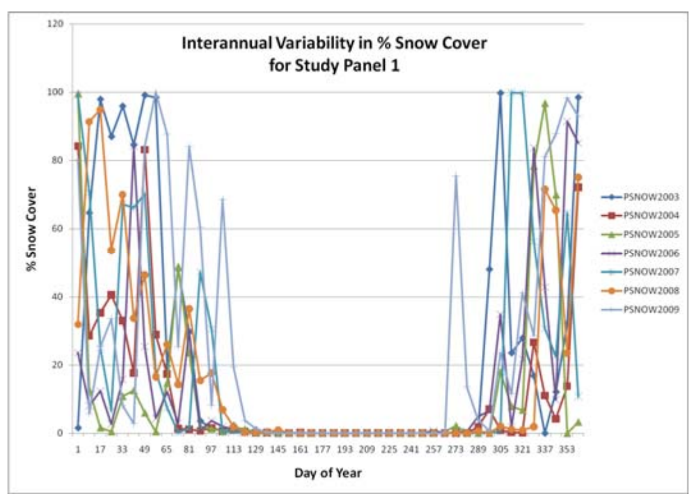


Fig. 4b. Annual timeseries of fractional snow cover for a portion of the GRYN PACE (expressed as % of total area) for 2000-2009, showing significant variability in the timing of snow accumulation and melt. The data are from Panel 1 in Fig. 6).

Weather and Climate: Landscape Phenology

What: Measured trends and anomalies in phenological indicators including the 'start-of-season' (SOS) date, derived from satellite time-series of vegetation index data (Fig 5).

Why: Sustained shifts in vegetation phenology are a predicted consequence of climate change. Satellite derived phenology indicators provide a useful supplement to surface measures, which may track only a subset of plant species.

Stressors: Climate change, land use change, drought

Summary: All 10 land cover types used in this analysis display a trend towards later SOS dates over the last 10 years. This appears to be driven primarily by late starts of season during years 2008 and 2009. As a point of reference, the average SOS date for the GRYN PACE (May 1) for 2000-2009 is shown by the dashed vertical lines in the NDVI timeseries plot. The SOS date for 2003-2006 were all within a few days of average. Year 2007 displayed the earliest SOS which occurred in mid-April, and year 2008 displayed the latest SOS date which occurred in mid to late May. Presumably the late SOS for year 2008 was driven by a large mountain snowpack from winter 2007/08. These results are averaged over large areas and across elevation and other environmental gradients which affect land surface phenology; it represents a very coarse response over a short time-period. Table 4 shows the 10-year observed linear trend in SOS date as derived from the satellite vegetation index used to calculate it, for the YELL/GRTE PACE area. Due to the short length of the data record and the significant interannual variability, the trends should be interpreted with caution.

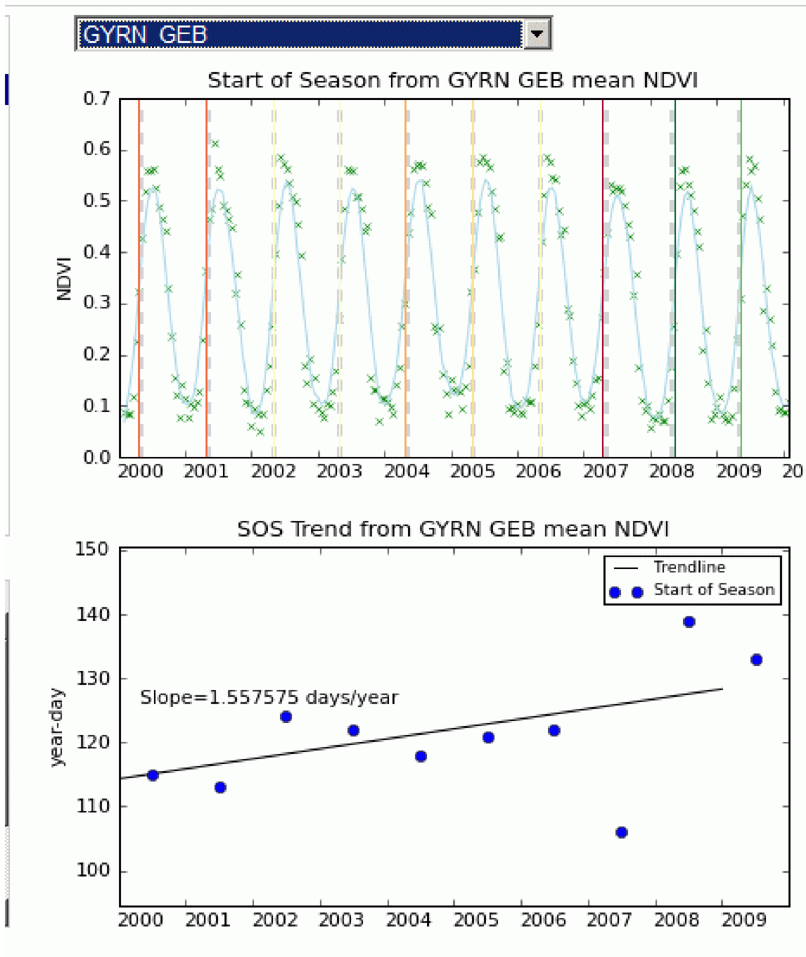


Fig. 5. SOS trends within the YELL/GRTE PACE during 2000 – 2009.

Land surface phenology represents the vegetative response to seasonal changes in temperature and light and water availability all of which are tied to climate and in some cases land use. The data for YELL/GRTE PACE show substantial variation in SOS for the last three years with SOS in 2007 being 35 days earlier than in 2008. These results likely reflect interannual variation in climate with earlier snow melt and warmer spring temperatures driving earlier SOS. Due to interannual and known decadal variation in climate in this region, the 10-year MODIS NDVI record is not long enough to reflect the 100-year climate warming described above.

Table 4. 10-year trends in SOS by land cover type.

MODIS Land cover type	10-Year SOS Trend
Evergreen needleleaf forest	1.55
Deciduous broadleaf forest	1.31
Mixed forest	1.25
Closed shrublands	1.13
Open shrublands	1.47
Woody savanna	1.35
Savanna	1.2
Grasslands	1.07
Cropland/natural vegetation mosaic	0.39

Weather and Climate: Grassland Phenology in the Yellowstone Watershed:

What: Spatial variation in several phenology metrics in grasslands across the Yellowstone Watershed, land use effects on phenology, and interannual variation.

Why: YNP and GRYN staff suspect that ungulate distributions and migrations in the Yellowstone Northern Range have been changing under the influence of climate and land use change. This initial analysis is aimed at quantifying the seasonal patterns of grassland production (key forage for ungulates), effects of land use, and interannual variability as driven by climate.

Stressors: Climate change, land use change, drought

Summary: Phenology of natural grasslands varies with watershed position in the upper Yellowstone River Basin (Fig 6). Lower positions in the Paradise Valley have: an earlier start of season (SOS), a higher total annual NDVI, and often have a later end of season (EOS) (Fig 7 and 8). Locations of higher elevation in the watershed, in the Yellowstone Northern Range for example, have higher peak NDVI during July and August. The timing of SOS is likely limited by snow cover and cool temperatures throughout the basin. Reductions in NDVI in summer are likely due to moisture stress, which occurs earlier lower in the basin and does not occur higher in the basin (study panels 5 and 6). These patterns suggest that ungulates will find forage over the annual cycle by occupying locations lower in the basin to capitalize on the earliest green forage, gradually moving to higher positions in the basin during spring and summer to take advantage of the high summer forage productivity there, and then returning back to lower basin positions in winter as snow limits access to forage at high elevation.

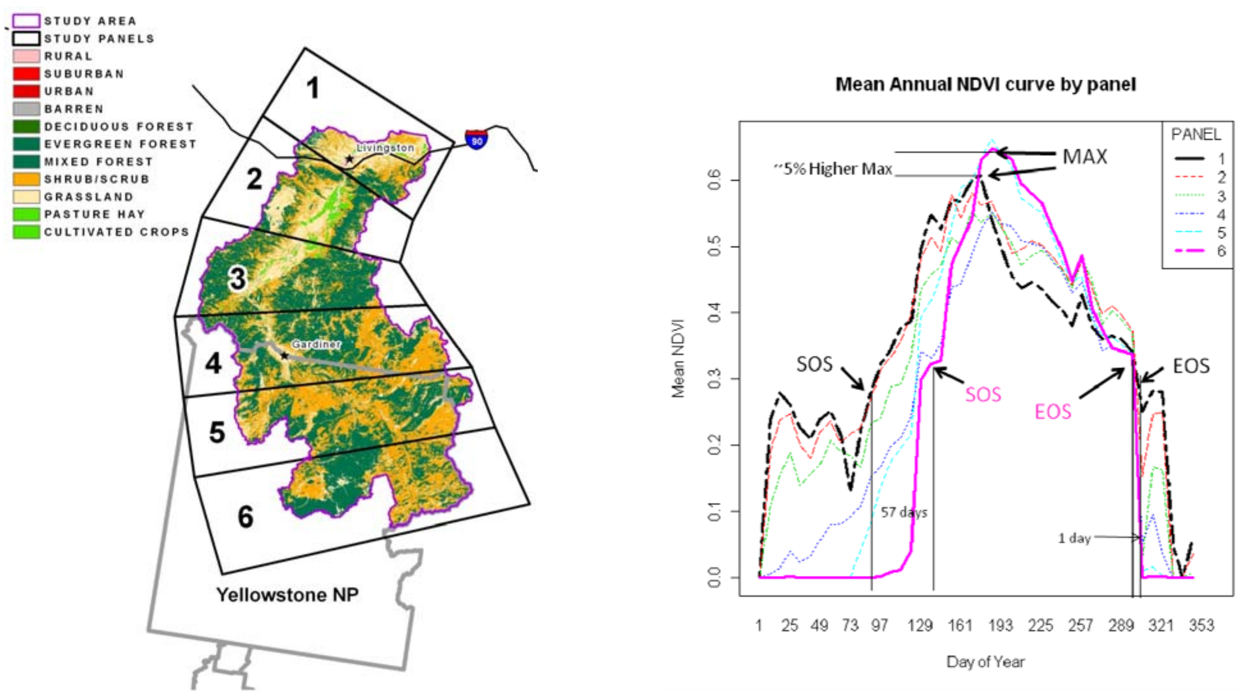


Fig. 6. Phenology metrics vary with position in Yellowstone River Watershed.

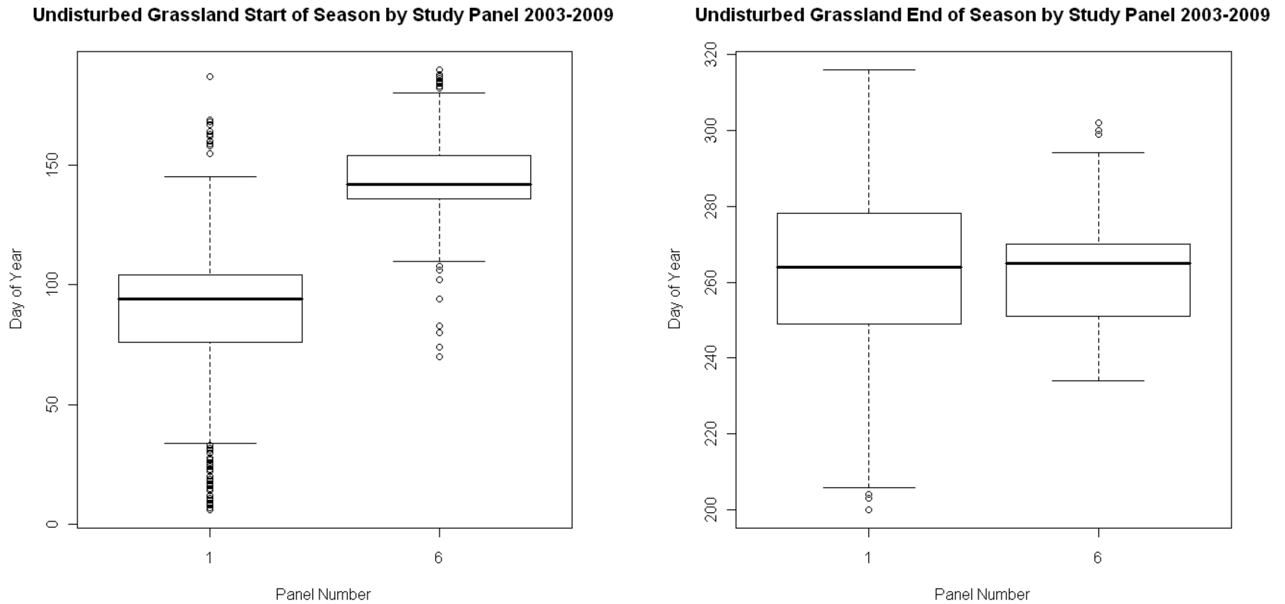


Fig 7. Start of season is much earlier in panel 1, end of season similar to panel 6.
Distributions of SOS and EOS are statistically significantly different from each other.

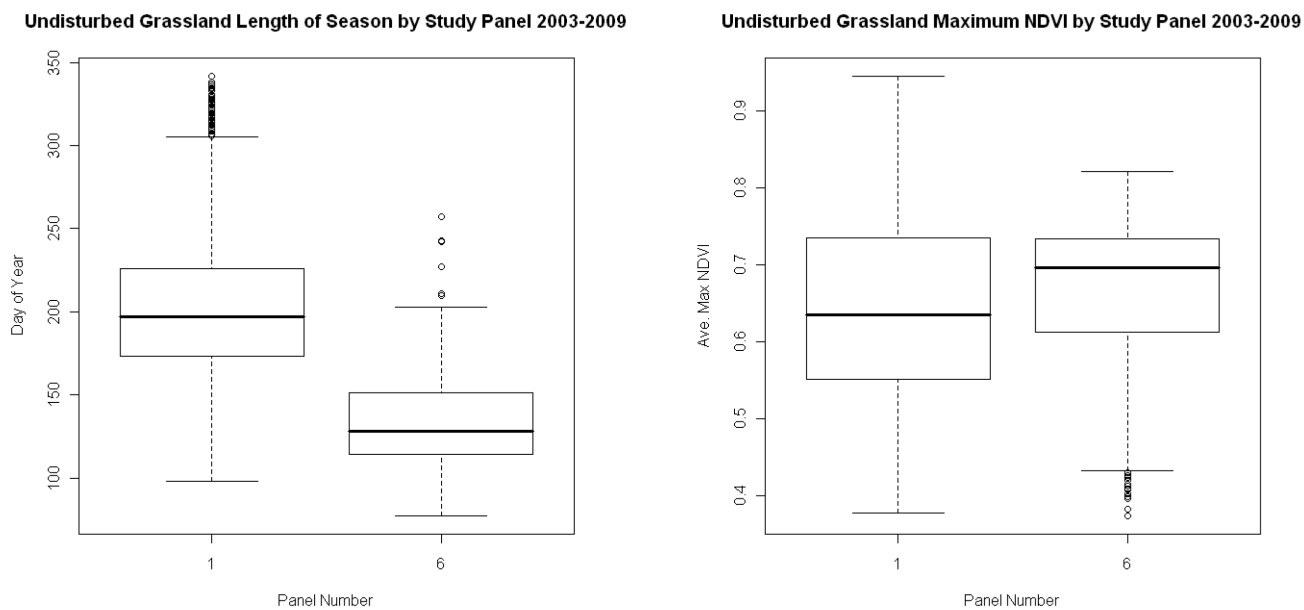


Fig. 8. Length of season is longer in panel 1, maximum annual NDVI is somewhat higher in panel 6.
Distributions of LOS and MAX are statistically significantly different from each other.

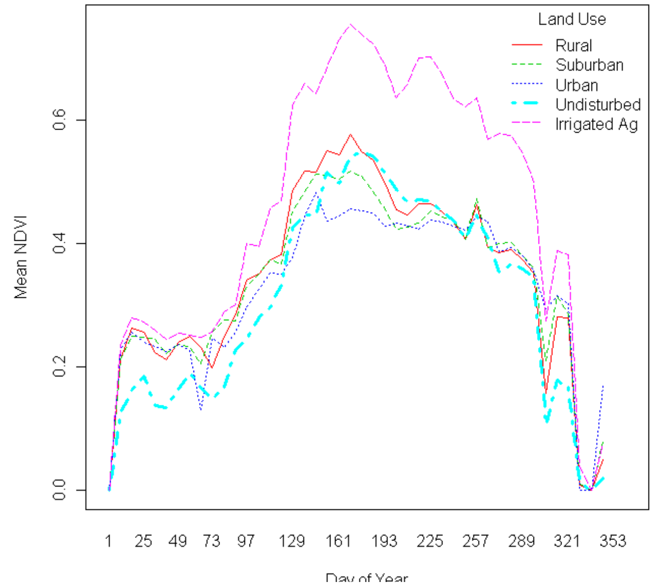


Fig. 9. Human land uses modify grassland productivity and phenology.

Rural residential, suburban, urban and irrigated agricultural areas in the Paradise valley differ from natural grasslands in their annual phenologies and total annual productivities (Fig 9 and 10). Residential land uses have an earlier SOS, later EOS, and longer LOS, whereas irrigated agriculture has far greater total annual productivity. These modifications from a natural state are likely due to the introduction of non-native species and other management action including irrigation, fertilization, mowing/harvest, and landscape placement of the areas of more intense land use. The effect on total NDVI is especially strong for irrigated agriculture. These patterns suggest that land use has altered forage availability for ungulates by providing higher levels for longer periods of the growing season in the Paradise Valley than has occurred naturally. This may lead to a concentration of ungulates on private lands during spring and fall and a reduced migration to the upper basin in summer.

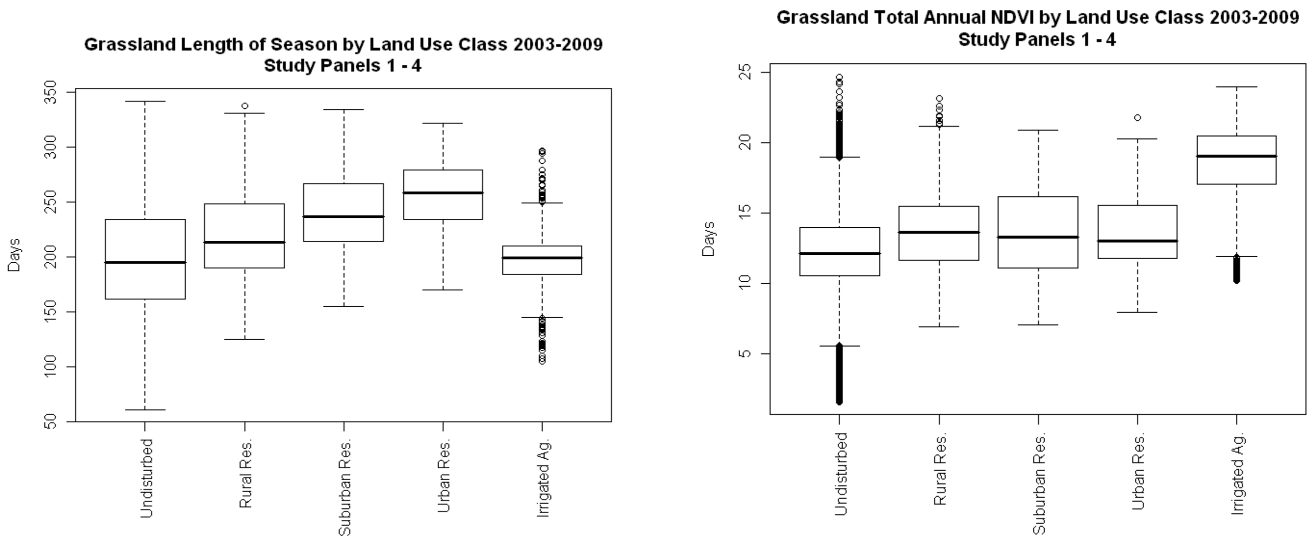


Fig. 10. Human land use modifies the timing and total productivity of grasslands in different ways. Distributions of ag and rural LOS are not statistically different from each other. Distributions of urban, suburban and rural TOTAL productivity are NOT statistically different from each other.

Ecosystem Productivity: Gross Primary Production

What: Estimates ecosystem productivity in terms of Gross Primary Production Gross primary production (GPP) and measures patterns and trends in GPP.

Why: GPP provides an indicator of ecosystem condition that integrates interactions between climate, vegetation, soils and other aspects of the physical environment. Sustained trends in seasonal or annual GPP may provide a leading indicator of climate change impacts.

Stressors: Climate change, land use change, drought, wildfire, insect infestations

Summary: Annual average GPP varied substantially during the 2000-2009 period of record, being nearly 35% higher in 2004 than in 2008. As with phenology, ecosystem productivity varies with interannual variation in climate. The apparent trend over the period of record is a decline of 0.025 kg Carbon/m^2 per year, though due to the limited data record length, this trend should be interpreted with caution. The decline was greatest for deciduous broadleaf forest, mixed forest, and savanna and least for open shrublands, grasslands, and cropland/natural vegetation mosaic.

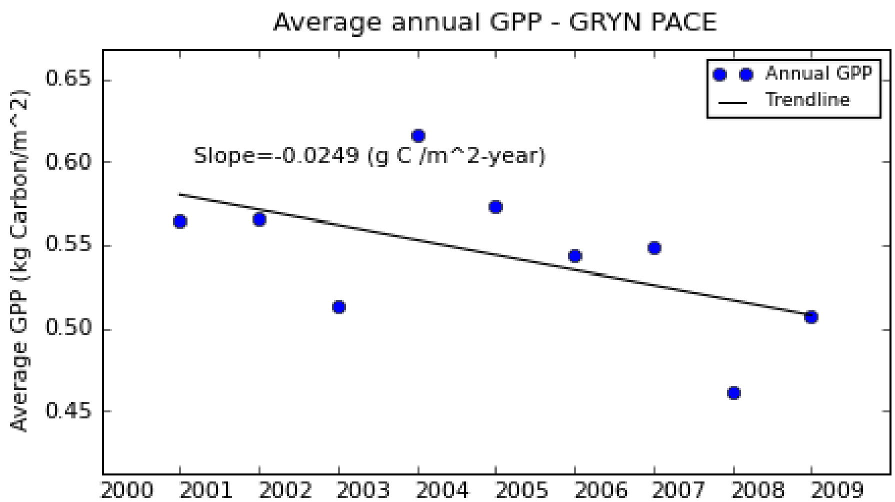


Fig. 11. Cumulative GPP for the YELL/GRTE PACE region for 2001-2009. Linear trend line provided for reference.

Table 5. 10-year trends in GPP (kg Carbon/m^2/yr) by land cover type.

MODIS Land Cover Type	10-Year GPP Trend
Evergreen needleleaf forest	-0.04
Deciduous broadleaf forest	-0.09
Mixed forest	-0.07
Closed shrublands	-0.03
Open shrublands	-0.01
Woody savanna	-0.05
Savanna	-0.07
Grasslands	-0.01
Cropland/natural vegetation mosaic	-0.01

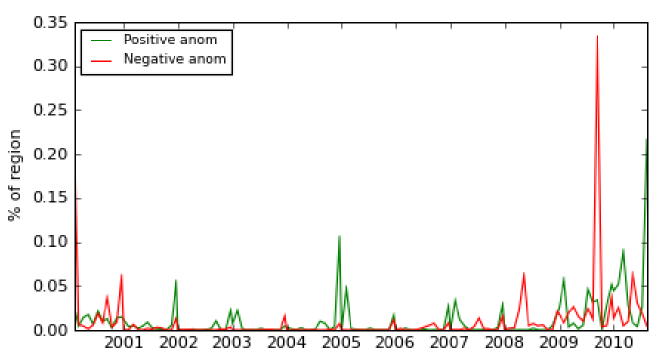
Landscape Dynamics / Disturbance Events: Vegetation Index Anomalies

What: Summarizes indicators of change in vegetation conditions derived from MODIS Normalized Difference Vegetation Index data to detect spatial and temporal patterns in change.

Why: The MODIS NDVI product provides an indicator of vegetation condition calculated from daily MODIS observations over the GRYN PACE. Tracking changes in NDVI relative to average conditions provides an indicator of temporal and spatial patterns in changes in vegetation condition. Sustained shifts from historical normals may provide an indicator of import changes in park landscape conditions. This indicator is intended to complement Landsat-based indicators of landscape dynamics, which capture higher spatial resolution changes at an annual timestep.

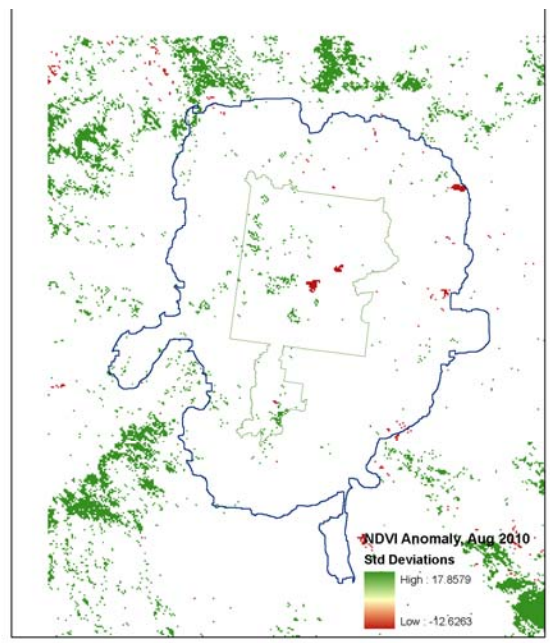
Stressors: Land use change, drought, wildfire, insect infestations

Summary: Standardized anomalies used to identify short-term and persistent changes in landscape conditions indicate relatively few normalized in NDVI for the period from 2001-2009, with generally less than 5% of the park experiencing an anomaly that departs from historical normals by more than 2.0 standard deviations (Figure a). A recent anomaly map from August, 2010, shows both significant positive and negative anomalies within the GRYN park boundaries and surrounding PACE (b). Significant anomalies should be tracked over time if proximate causes are not already known (e.g., fire, land use change, or late snowfall).



(a)

Fig. 12. The fraction of the GRYN PACE exhibiting an NDVI anomaly departing from historical normals (calculated using 2001-2008 as the baseline) by more than two standard deviations (a), and a normalized NDVI anomaly map for July, 2010, showing anomalies greater than 2.0 standard deviations for GRYN PACE (b).



(b) Normalized NDVI Anomaly for August, 2010 (units are in standard deviations)

Land Cover: Land Cover and Use

What: Metrics of population size, area in agriculture, and rural residential development and change over time.
Why: These data provided indication of the challenges in maintaining park condition given the land use characteristics of the surrounding PACE
Summary: The region was sparsely populated prior to 1900 (Fig 13). Rate of population growth was relatively rapid during 1909-1920 as EuroAmericans settled in the area, slowed during the following decades and increased rapidly in the 1970s and 1990s. Area in agriculture expanded rapidly from 1900 to 1920, remained relatively constant till 1990, then decreased slightly (Fig 14). Rural home development has been the fastest increasing land use type in recent decades. This development was dramatic in the 1970s, 1990s, and during 2000-2005 (Fig 15 a and b).

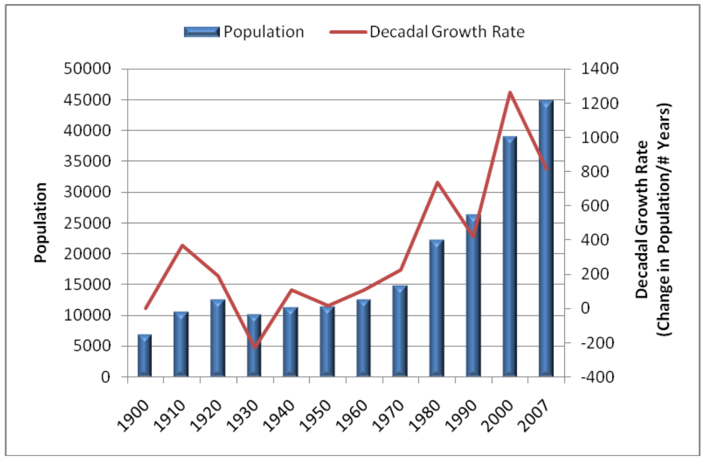


Fig 33. Change in human population size and rate of change across the YELL/GRTE PACE 1900-2007. From Daves in prep.

The National Parks are largely surrounded by public lands. Hence, the private lands where agriculture and human settlement can take place tends to be more distant from park boundaries, largely in valley bottom settings with more favorable climate and soils (Fig 16). Only 12% of the PACE outside of the parks is private lands. Despite agricultural and residential development, the majority of these private lands remain in the lowest housing density class, which indicates a low level of development (Fig 17). Both population size and rural home density are expected to increase dramatically in the future. Population size across the PACE is predicted to increase from the 450,000 in 2010 to 750,000 by 2040 (Davis et al. in prep). Rural residential development was predicted to increase between 27% (slow growth scenario) and 234% (fast growth scenario) between 2000 and 2010 by Gude et al. (2006).

Relative to the other PACES examined thus far, the YELL/GRTE PACE is notable in being dominated by public land, has relatively low rates of development of those private lands (Fig 8). However, growth in home density since 1940 is moderate relative to the other PACES.

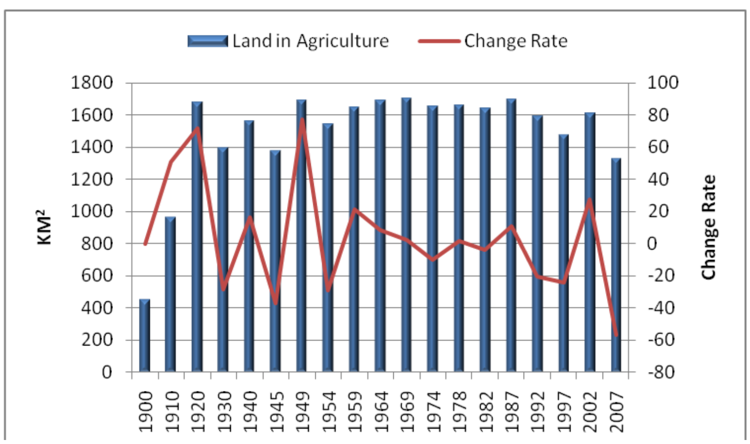


Fig 14. The area of agricultural land in the primary counties of the park-centered ecosystem of Yellowstone and Grand Teton national parks, 1900 – 2007. From Davis in prep.

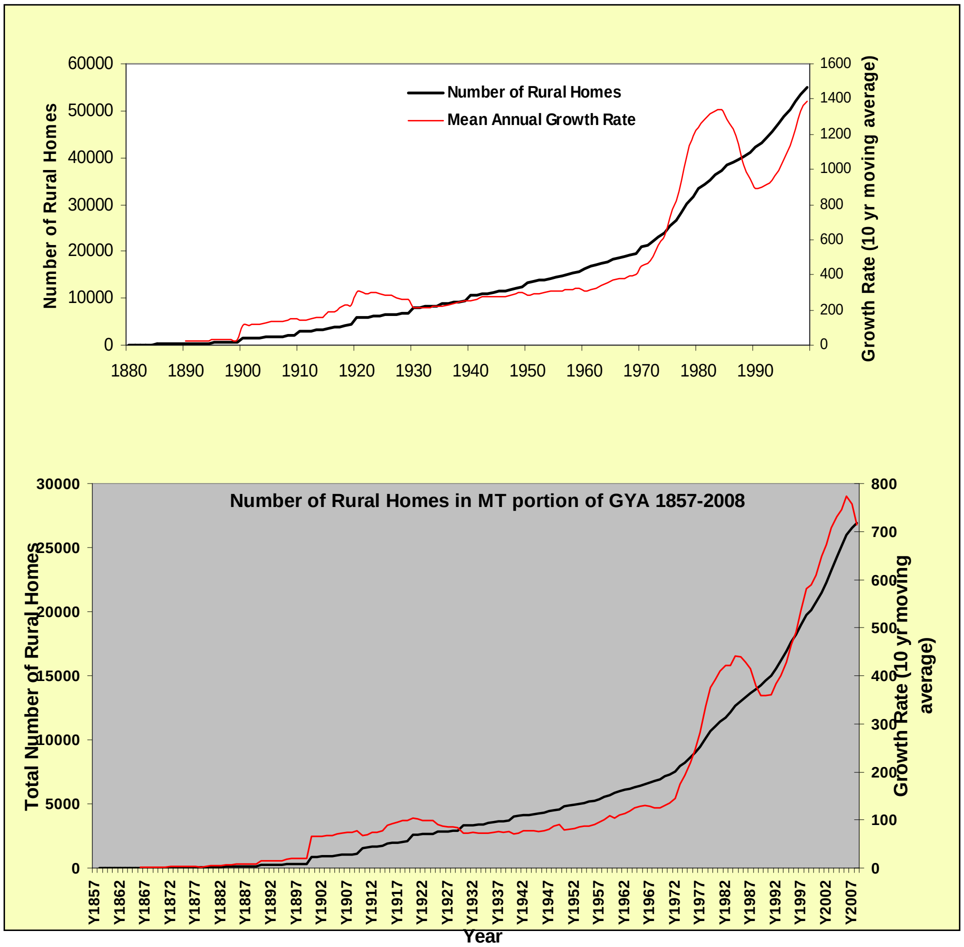


Fig. 5. Number of rural homes and rates of increase in the 20 counties of the Greater Yellowstone Ecosystem 1880-1999 (top). Number of rural homes and rates of increase in the Montana counties of the GYE during 1850-2007, presented to provide indication of trends during the 2000-2007 period. From Gude et al. 2006, Pielielek et al. in prep.

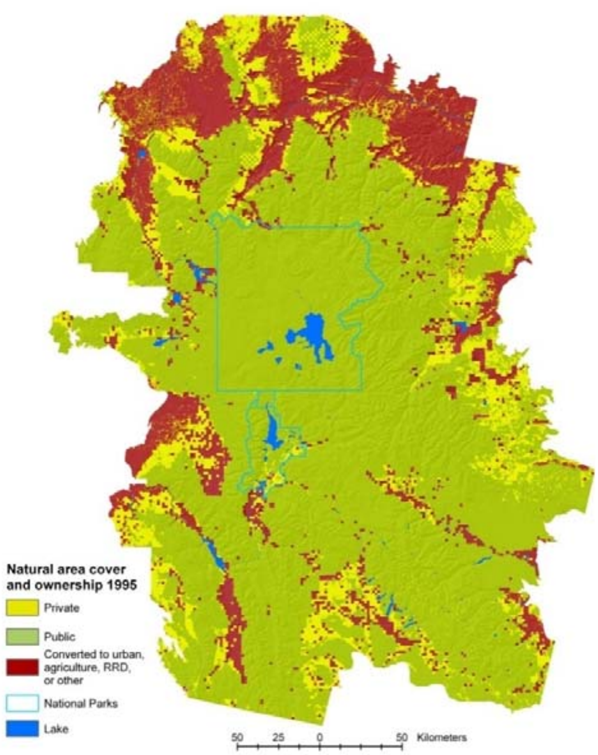


Fig. 16. Distribution of public and private lands and areas converted to developed land use types across the GYE as of 1999.

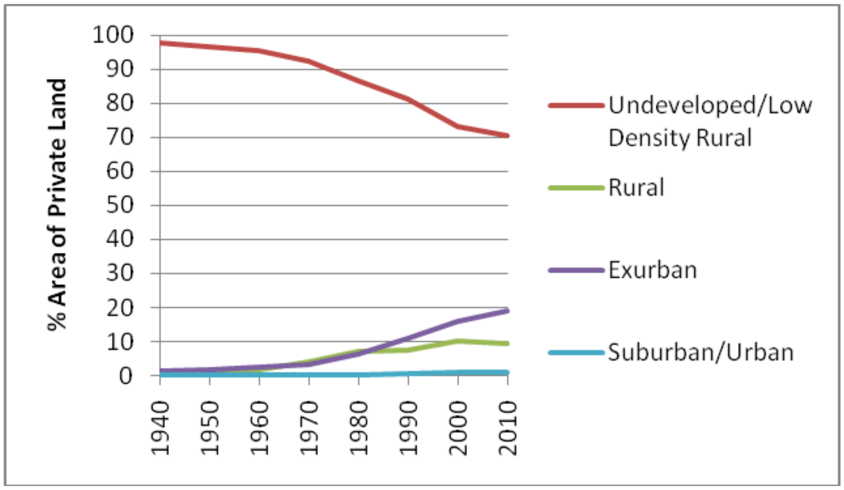


Fig 17. Proportion of private land within each housing density class within the PACE for Yellowstone and Grand Teton National Parks, 1940 – 2010. From Davis in review.

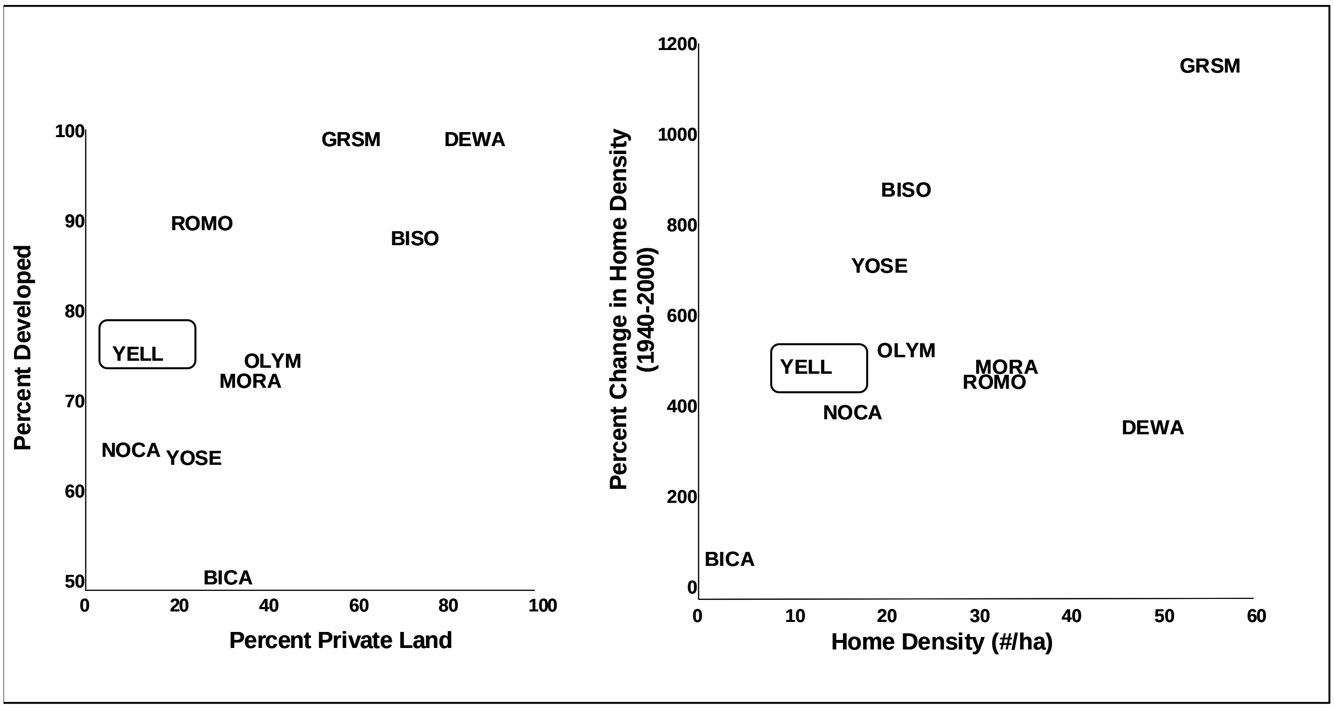


Fig 18. Location of the protected area centered ecosystems along gradients in land ownership and land development (home densities of >0.031 units/ha, roads, or agriculture lands) (left) and home density (units/ha) and percent change in home density from 1940 to 2000 (right). Developed lands included buffers of 1000 m adjacent agriculture or home densities>0.031 units/ha and 500 m of primary roads railroads and 100 m of secondary roads.

Biodiversity: Patterns of Natural Landscapes

What: The Pattern of Natural Landscapes indicator quantifies the fragmentation of natural landscapes by human-modified land cover types. The strengths of this indicator is that it is characterizes natural landscape pattern using robust, multi-scale approach based on the proportion (P) of natural cover types and does not require delineation of patches.

Why: This metric can be used to quantify change in naturalness for a place over time or compare places at a given time.

Summary: Yellowstone and Grand Teton National Parks and immediate surrounding lands are high in the natural index, with lower values in the surrounding agricultural areas, especially the Snake River Valley south west of the parks (Fig 19). Relative to other parks across the US, both Yellowstone and Grand Teton National Parks and the surrounding ecoregions are high in naturalness (Fig 20).

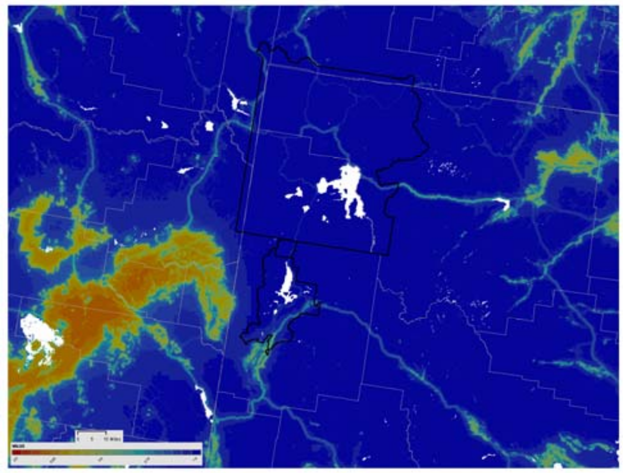


Fig 19. Pattern of Natural Landscapes in 2001. High NL values are shown in blue, areas dominated by urban and/or cropland agriculture appear as highly modified areas, shown in red. From Theobald 2010.

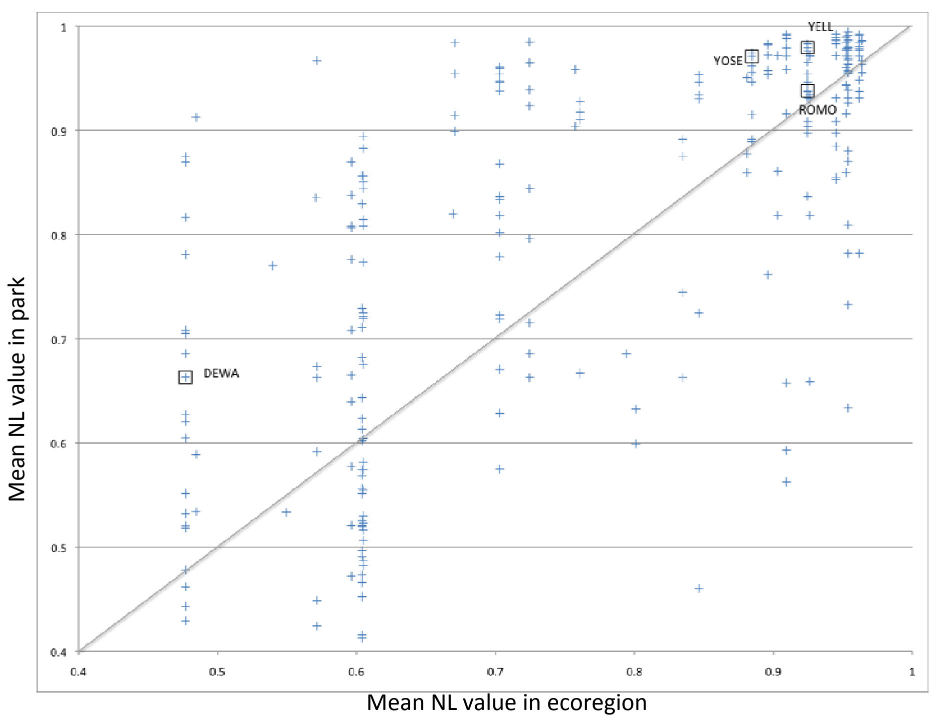


Fig 20. Mean Natural Landscape Metric values for US National Parks and surrounding ecoregions in 2001. From Theobald et al. 2010.

Biodiversity: Landscape Connectivity

What: Measures the connectivity of natural landscapes. The method estimates the variable resistance of wildlife movement using naturalness as a proxy for permeability. Percolation theory is used to identify possible paths. Then, least cost distance paths based on degree of human modification are selected. Finally, dendritic flow pathways are estimated using flow accumulation tools typically used for hydrologic analysis.
Why: Movement of plants and animals and ecological processes connect to adjacent landscapes and beyond the park boundaries.
Summary: YELL/GRTE is situated on a pathway that provides much grater than average connectivity (in the top 90-95% compared nationwide) and serves as a key location of connectivity in the Northern Rockies region (Fig 21).

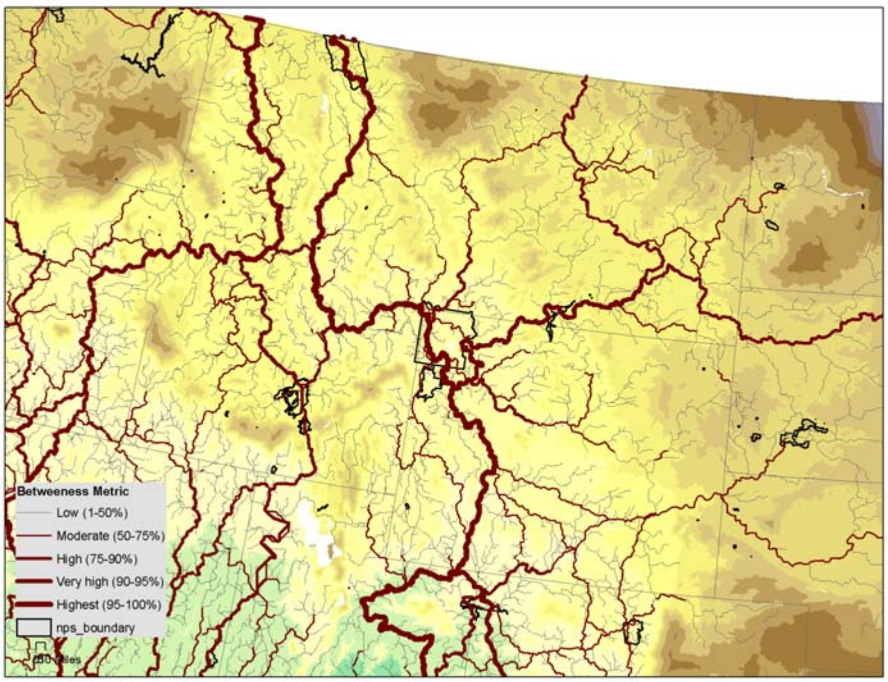
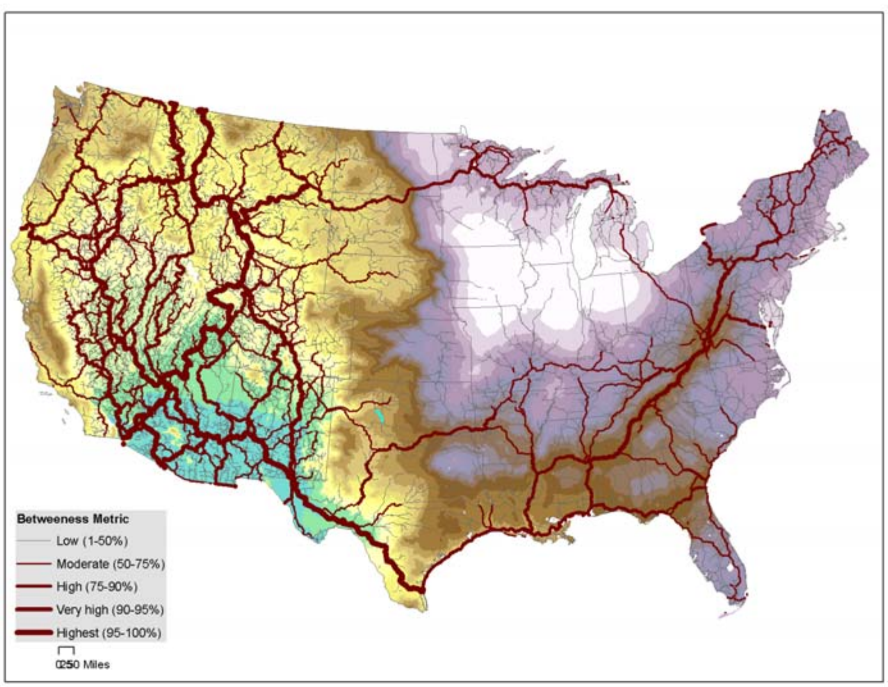


Fig 21. Thicker red lines show more cumulative movement assuming animals are moving across the landscape avoiding human-modified areas, for Yellowstone region (above) and US (below). The brown to green color gradient represents the average cost-distance



Biodiversity: Ecosystem Type Composition

What: Estimates reduction in area of potential pre-EuroAmerican settlement ecosystem types due to current land use (Fig 22). The pre-settlement distributions of ecosystem types are estimated based on biophysical factors. The current distributions exclude locations of human-modified land cover types.
Why: Ecosystem types of greatest proportional loss are candidates for focused conservation, management and restoration.
Summary: Reductions in most ecosystem types across the YELL/GRTE PACE due to land use change have been minor for most ecosystem types (Fig xx, Table xx). There has been little land use development on public lands, thus ecosystem types primarily located on public lands have undergone little reduction in area (e.g., Whitebark pine, Douglas fir), Both the lodgepole pine and sagebrush types, however, are well represented on private lands. They have lost 33% and 19% of the estimated pre-settlement areas, respectively. Within private lands, most ecosystem types have been substantially reduced in area, with Lodgepole pine, Grassland, Deciduous, and Sagebrush exhibiting losses of 33-57%. Mean patch size has decreased substantially in more than half of the ecosystem types. Mean distance to the next nearest patch of the same ecosystem type has decreased as an artifact of there being more but smaller patches on the landscape.

Pre-European settlement **Present Day**

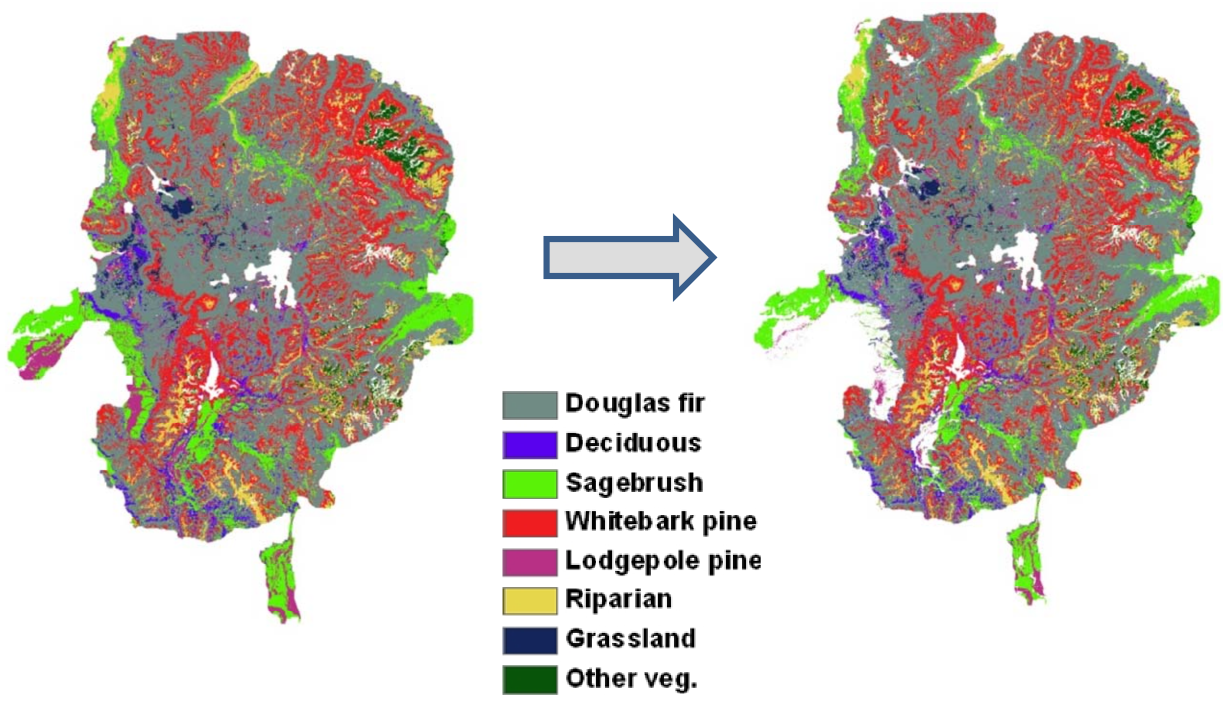


Fig 22. Locations of ecosystem types within the YELL and GRTE PACE from Pre-European settlement to present day. From Piekielek et al. 2010b.

Table 6. Proportional changes in aerial extent of ecosystem types within the YELL and GRTE PACE from Pre-European settlement to present day.

Ecosystem Type	Hectares (thousands)	% Loss total	% Loss pvt land	% Loss Pub. land	% Mean patch size change	% Mean Nearest neighbor change
Douglas fir	1985	2	21	1	-40	-29
Deciduous	148	7	36	2	-30	-28
Sagebrush	459	19	33	3	-75	-59
Whitebark pine	911	1	25	0	-14	-14
Lodgepole pine	183	33	57	6	-74	-58
Riparian	245	4	22	0	-25	-25
Grassland	51	6	47	3	-44	-41
Other natural veg.	99	1	26	0	-9	-12
Mean		**9**	**33**	**2**	**-39**	**-33**

Biodiversity: Habitat Type Composition

What: Estimates reduction in area of key habitats from pre-settlement levels due to past and projected future exurban development.
Why: Habitat types of greatest proportional loss are candidates for focused conservation, management and restoration.
Summary: The percentage of habitat impacted by exurban development in 1980 ranged from 2.0% to 11.8%, for pronghorn habitat and the integrated index, respectively (Table 7). In 1999, the range was from 3.35% to 23.24%. The forecasted percentage of habitat impacted in the 2020 status quo scenario ranged from 5.83% to 29.93%; in the low growth scenario, the range was from 5.05% to 25.84%; and in the 2020 boom scenario, the range was from 7.58% to 40.66%. In the 2020 status quo scenario, five of the 12 biodiversity responses were forecasted to experience degradation in more than 20% of their area due to exurban development. These responses include: bird hotspots, riparian areas, potential migration corridors, and irreplaceable areas. The integrated index, constructed from these four responses, was also impacted in more than 20% of its extent.

Table 7. The percentage of area impacted by exurban development, defined as one home per 0.4–16.2 ha, presented for each element of biodiversity. From Gude et al. 2007.

	Percentage of habitat impacted by exurban development						
Response	1980	1999	Status quo 2020†	Low growth 2020	Boom 2020	Moderate growth management 2020	Aggressive growth management 2020
Pronghorn range	2.00	3.35	5.83	5.05	7.58	6.06	4.73
Moose range	2.73	5.49	7.96	6.83	11.11	7.24	6.26
Grasslands	2.99	5.57	8.36	7.02	11.97	8.01	6.87
Grizzly range	3.13	5.98	8.52	7.68	10.70	7.74	6.88
Douglas-fir	2.91	6.01	8.85	7.07	13.31	7.82	7.09
Elk winter range	2.36	6.26	9.98	8.61	13.47	9.00	7.23
Aspen	5.55	13.92	19.53	15.58	28.39	18.74	17.60
Bird hotspots	8.42	16.91	23.20	19.23	34.36	21.04	20.23
Riparian habitat	10.22	17.30	23.64	19.43	31.27	22.45	18.77
Corridors	8.89	18.79	24.43	20.83	35.38	22.96	21.80
Irreplaceable areas	11.41	23.15	29.61	25.69	40.08	30.88	26.92
Integrated index	11.80	23.24	29.93	25.84	40.66	29.28	26.43

Notes: Areas were considered to be impacted if they overlapped with sections containing exurban housing densities. Areas within a one-section buffer (1.61 km) of exurban housing were also considered impacted.
† Responses are ranked by the proportion impacted in the status quo 2020 scenario.

Story Lines Emerging from Trends

Spatial Patterning of the Biophysical Environment

The GYE is centered on a plateau and mountain system, hence it includes high variation in elevation. Climate varies accordingly with colder temperatures, high precipitation, and shorter growing seasons at higher elevations and warmer temperatures, lower precipitation, and longer growing seasons at lower elevations, especially in valley bottoms. The geologic history of the area has lead to spatial patterning of soils, ranging from nutrient poor volcanic soils on the Yellowstone Plateau, to moderately fertile volcanic and granatic soils in some of the mountain ranges, to highly productive soils on some of the valley bottoms. Consequently primary productivity is highest in valley bottoms with adequate summer precipitation and at lower treeline. The natural fire regime varies from higher frequency and lower severity at low elevations to lower frequency and higher severity at higher elevations. The distribution of ecosystem types varies with these gradients in topography, climate, and disturbance with the Yellowstone Plateau and surrounding mountains dominated by whitebark pine and lodgepole pine types, more fertile midslopes by Douglas-fir, and valley bottoms by riparian deciduous, grassland and sagebrush types.

Characteristics of Communities and Species

The fauna of the GYE is unique primarily in its completeness. Unlike nearly any other location in the 48 contiguous US, all species of birds and mammals present in pre-European settlement times are currently present and all are thought to have viable populations. The remote location of the GYE, the harsh climate and terrain, and the early establishment of Yellowstone National Park, slowed human development and allowed for the persistence and restoration of species such as bison (*bison bison*), elk (*Cervus canadensis*), grizzly bear (*Ursus horribilis*), wolverine (*Gulo luscus*), whooping crane (*Grus americana*), and trumpeter swan (Cygnus buccinator) that were pushed to extinction in most places by European expansion in the 1800s. The only species to become extinct in the GYE, the gray wolf (C*anus lupis*), was successfully reintroduced in 1995. The GYE is a reservoir for such species and acts as a subcontinental source area with individuals dispersing to other protected areas where their populations were previously extirpated, providing the potential for restoration of populations in these areas. Examples include wolves and wolverines dispersing from GYE to the vicinity of Rocky Mountain National Park.

The faunal community is characterized by a high degree of adaptation for coping with environmental heterogeneity in space and time. Many species specialize on particular habitat types and seral stages. Maintenance of adequate area of suitable habitat and disturbances to initiate succession are management concerns. Landscape settings with mesic climate, water, and high primary productivity are relatively rare in GYE and support high species abundances and high species richness. They may also be population source areas necessary for the viability of GYE-wide populations of some species. Many resident species cope with the high level of spatial and temporal heterogeneity of the GYE through seasonal movements and pronounced migrations. Top carnivores such as grizzly bear and wolverine tend to have low population densities and very large home ranges. Dispersal among subpopulations within GYE and between GYE and other ecosystems is likely important for population viability for many species, hence connectivity is important. Keystone species such as elk, wolves, and beaver shape ecosystem function and composition and the population dynamics of other species. Hence the population sizes of such species influence the degree of cascading effects to other trophic levels of the ecosystem.

Climate Change.

Climate has varied in GYE at decadal, centennial, and millennial time scales. The gradual warming during the Holocene was reversed during the Little Ice Age (1650-1890), with coldest, wettest conditions occurring from about 1860-1890. Rapid warming has occurred in the last century with about a 1.2^0 C (2^0 F) rise during the 1900s. Hence, the period of European settlement in the GYE was the coldest and wettest in about 14,000 years and the current period of management is within a rapid warming phase. Precipitation has not changed significantly over the past century. The warming has been most rapid in winter. The consequences of this recent climate change includes reduced winter snowpack, earlier snowmelt and peak runoff, increased summer low flows, and likely reduced surface water and soil moisture in summer.

Land Allocation and Use

Yellowstone and Grand Teton National Parks are largely surrounded by national forests and other public lands. Hence, only 12% of the YELL/GRTE PACE is private land. EuroAmerican settlement of these private lands was slow during the 1800-1970 period. Hence, the region retained low human densities and a wilderness character. Many of the initial settlers were farmers, and fertile valley bottoms with access to water were converted to agriculture. The remaining wilderness, wildlife, rivers, scenery, and other natural amenities attracted many immigrants starting in the 1970s and the population of the area has grown rapidly since then. Many of these new residents have chosen to live in rural areas and rural residential development has outpaced population growth and is the fastest increasing land use type in the area. These trends of increased population and rural residential development are projected in continue in the future.

Interactions among Biophysical Patterns, Biodiversity, Humans, and Climate Change.

The large proportion of public lands and relatively low human population size in the YELL/GRTE PACE result in less conflict between ecological and social objectives than in around many US National Parks. The spatial patterning of the YELL/GRTE system, however, leads to more conflict that would be expected based on human population density. Land uses such as agriculture, urban, and rural residential development are concentrated in the same small portion of the landscape that is favorable in climate and soils, high in primary productivity, and represents hotspots for biodiversity and population source areas for some species. Increasing evidence indicates that human activities associated with these land uses can have negative influence on ecosystem process and biodiversity. These impacts include habitat destruction and fragmentation, alteration of ecological processes such as natural disturbance and primary productivity, change in biotic interactions including increased weeds, disease, and mesocarnivore communities which can over prey on other species, and displacement and death of wildlife leading to elevated mortality of, for example, the grizzly bear.

Climate change is likely to increase conflict between the people and ecosystems in this region. Reduced water yield is increasing competition for water between human uses and fish and wildlife. Increased wildfire increasing threatens rural homes and constrains the management of fire for ecological benefits. Reduced forage productivity in uplands under climate warming and increased productivity in valley bottoms from irrigation and rural homes is resulting in shifts of ungulate populations to valley bottoms where hunting opportunities are more constrained, possibly leading to increased exchange of disease among livestock and native ungulates and increased conflict between top predators and ranchers.

The value of natural amenities to the socioeconomic well-being of local residents and communities is increasingly recognized. Consequently, many initiatives to conserve these natural amenities such as conservation easement and open-space programs have been enacted. There is increased opportunity to forward conservation goals via cooperative education and management across public and private stakeholders.

Key Current and Emerging Management Challenges

- Destruction and fragmentation of key ecosystem and habitat types due to development on private lands.
- Ecological impacts of increased residential development near public lands including spread of weeds, disease, and wildlife persecution.
- Direct effects on climate change on ecological systems such as forest die-off and altered fire regimes.
- Interactive effects of climate change and land use on ecological systems such as changes in fire regimes and in ungulate distributions.
- Maintaining connectivity with other protected areas across the region to maintain viable populations locally and to provide sources for recolonization of species extirpated elsewhere.
- Capitalizing on the high value placed on natural amenities by local communities by enhancing cooperative research, education, and conservation initiatives with varied public and private shakeholders.

References

Davis, C.. In Prep. Land Use Change around US National Parks. Ph.D. Dissertation. Montana State University, Bozeman.

Gude, P.H., A.J. Hansen, R. Rasker, B. Maxwell. 2006. Rate and drivers of rural residential development in the Greater Yellowstone. Landscape and Urban Planning 77:131-151.

Gude, P.H., A.J. Hansen, D.A. Jones. 2007. Biodiversity consequences of alternative future land use scenarios in Greater Yellowstone. Ecological Applications, 17(4), 1004-1018.

Haas, J, S Running, A Hansen, C Davis. In Prep. Climate change across US National Parks: 1895-2007.

Hansen, A.J., C. Davis, N. Piekielek, J. Gross, D. Theobald, S. Goetz, F. Melton, R. DeFries. In Review. Delineating the ecosystems containing protected areas for monitoring and management. BioScience.

Jones, D.A., A.J. Hansen, K. Bly, K. Doherty, J.P. Verschuyl, J.I. Paugh, R. Carle, and S.J. Story. 2009. Monitoring land use and cover around parks: a conceptual approach. Remote Sensing of Environment, 113:1346-1356.

Melton, F., S. Hiatt, G. Zhang, R. Nemani. 2010. PALMS SOP- Estimating Landscape Indicators of Phenology from Satellite Observations: Start of Season. Ecological Forecasting Lab, NASA Ames Research Center.

Nemani, R, Hashimoto, H, Votava, P, Melton, F., Wang, W, Michaelis, A, Mutch, L., Milesi, C, Hiatt, S, and White, M. 2008. Monitoring and forecasting ecosystem dynamics using the Terrestrial Observation and Prediction System (TOPS). Remote Sensing of Environment 113(2009):1497-1509.

Parmenter, A.P., A. Hansen, R. Kennedy, W. Cohen, U. Langner, R. Lawrence, B. Maxwell, A. Gallant, R. Aspinall. 2003. Land Use and Land Cover Change in the Greater Yellowstone Ecosystem: 1975-95. Ecological Applications 13(3):687-703.

Piekielek, N.B., C. Davis and A. Hansen 2010a. PALMS SOP - Estimating Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO.

Piekielek, N.B., C. Davis and A. Hansen 2010b. PALMS SOP - Ecosystem type change and fragmentation: from pre Euro-American settlement to present day. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO.

Theobald, D.M. 2009. PALMS SOP – Landscape dynamics, pattern of natural landscapes. Natural Resource Inventory and Monitoring Program. National Park Service, Fort Collins, CO.

Theobald, D.M., 2010. Estimating natural landscape changes from 1992 to 2030 in the conterminous US. Landscape Ecology. Published online: 01 May 2010.