LANDSCAPE CONDITIONS AND TRENDS IN AND AROUND Yellowstone and Grand Teton National Parks: Initial Summary Results

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

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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 this system is that the Yellowstone and Grand Teton National park centered ecosystem 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.

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Introduction

The need for monitoring and decision support for US National Parks is heightened by the rapid change that is occurring in and around 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 park-centered ecosystems (PCE) 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.

Now in the third and final year of the project, we are reviewing, interpreting, and finalizing 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 will synthesize interpret a fuller set of results to identify key trends and management challenges, the third will present final results to the fuller NPS staff associated with each park. More information on the project (including overview presentations, progress reports, Standard Operating Proceedures, 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 being 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	Phenology (NDVI, annual anomaly)	1 km (all); 8 & 16 day; 2000-2008	Melton et al. 2010 Nemani et al. 2008	Initial results currently being reviewed (available at: tops web site)
		Climate gridded daily	1 km; 2000-2008		
		Climate scenarios (monthly)	12 km; 2010-20??		
Landscape dynamics	Monitoring area	Greater park ecosystem boundaries	30 m	Piekielek et al. 2010a Hansen et al. in review	Completed
	Primary Production	GPP/NPP TOPS GPP	1 km daily and/or monthly summaries; 2000-2008	TOPS SOP Nemani et al. 2008	Initial results currently being reviewed (available at: tops web site)
	Extreme Disturbance Events	Fire effects via changes in NDVI/EVI, FPAR/LAI	1 km; monthly anomalies / persistent; annual trends; 2000-2008	TOPS SOP Nemani et al. 2008	Initial results currently being reviewed (available at: tops web site)
	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, being updated to 2008
	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

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

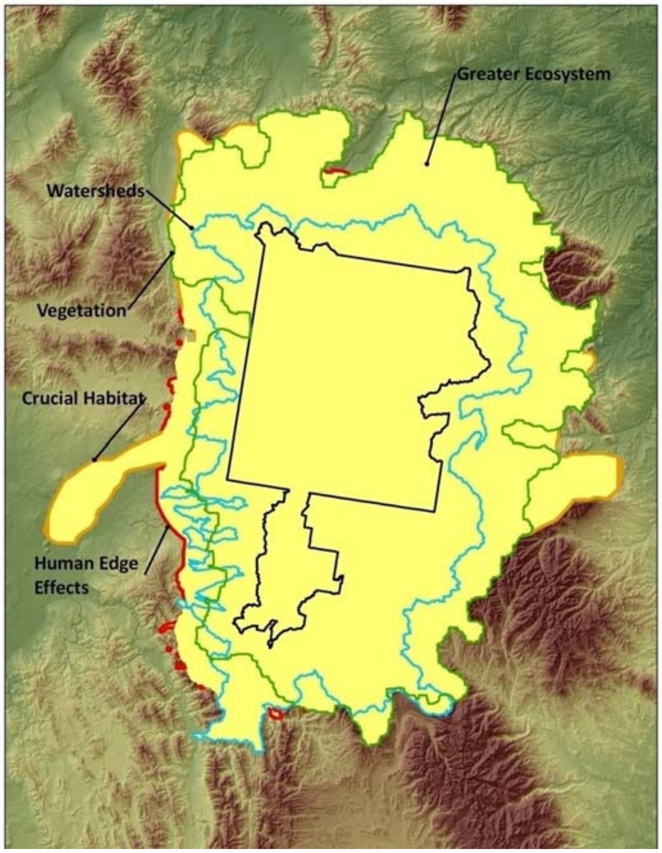

Fig 1. Map of the YELL/GRTE PACE showing the areas included under each of the PACE classification criteria. From Piekielek et al. 2010a.

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: Landscape Phenology

What: Measures trends and anomalies in phonological indicators including the 'start-of-season' (SOS) date, derived from satellite time-series of vegetation index data (Fig 2).

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 record (by recent standards), late starts of season during years 2008 and 2009. As a point of reference, SOS was calculated as occurring in early May during year 2006 and this was average for the study period. Years 2005 and 2003 were also near average for date of SOS. 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 all averaged over large areas and across elevation and other environmental gradients which we know affect land surface phenology; it represents a very coarse response over a short time-period. Table 3 shows the variability of SOS and the vegetation index used to calculate it, for the YELL/GRTE PACE area over the last 10 years.

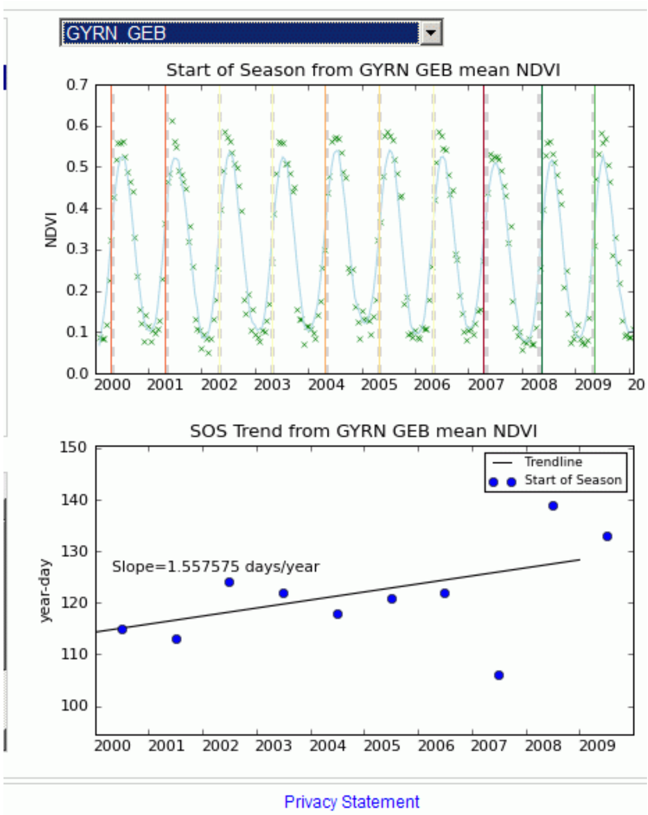

Figure 2. SOS trends for YELL/GRTE PACE boundary 2000 – 2009

Discusssion:
In its broadest sense, land surface phenology is thought to be a 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. Given the broad array of different vegetation traits and life-history strategies it is expected that the phonological response of vegetation communities to climate varies. However, this is an evolving field of research and few details are very well understood. Within the YELL/GRTE PACE boundary figure xx shows a response by MODIS land cover type to climate variability over the last 10 years. Evergreen needleleaf forest appears to have had the greatest phonological response while the cropland/natural vegetation mosaic displayed the smallest shift towards later SOS. Given that evergreen needleleaf land covers occur principally at higher elevation and cropland/natural vegetation mosaic at lower elevation, this seems to be consistent with the idea that climate variability, and hence phonological response, is dependent on elevation and a host of other biophysical factors. In this case if it is mountain winter snowpack that's driving a shift towards later SOS as is suggested in the summary above, then land covers at higher elevation should display the largest shift while those at lower elevation should display the smallest shifts towards later SOS. The figure below appears to be consistent with this hypothesis. To date much of the research on land surface phenology has focused on change detection at the continental to global scales. More research is needed at the local to regional scale to better understand the relationships between vegetation community phonologies and climate, biophysical and land use factors.

Table 3. 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
Permanent wetlands	15.96*
Cropland/natural vegetation mosaic	0.39

*this result appears to be influenced by a poor trend fit

Further PALMS research:
An additional PALMS research project is currently underway to discover the relationship between grassland phenology and biophysical, climate and land use factors in the upper Yellowstone River watershed including portions of Yellowstone National Park down to the area of Livingston, MT. Using similar data and methods as are presented here at finer spatial and temporal scales, along with local data on land use, this project will determine the proportion of variation in vegetation indices explained by variation in climate, elevation, slope, aspect, parent material and land use. By discovering the aforementioned relationships, scientists and land managers will be better able to anticipate and respond to the likely impacts of future land use and climate change on the spatio-temporal pattern of grassland productivity in the northern part of the YELL/GRTE PACE.

Weather and Climate: Gridded Climate

Weather and Climate: Climate Scenarios

Ecosystem Productivity: Gross Primary Production

Extreme Disturbance Events: NDVI Anomalies

[All the above are in progress]

Land Cover: Land Cover and Use

What: Metrics of land cover and use 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 3). Rate of population growth was relatively rapid during 1909-1920 as EuroAmericans settled in the area, slowed during the following decades and increased rapidly since the 1970s. Area in agriculture expanded rapidly from 1900 to 1920, remained relatively constant till 1990, then decreased slightly (Fig 4). Rural home development has been the fastest increasing land use type in recent decades. The development was dramatic in the 1970s, 1990s, and during 2000-2005 (Figure 5 a and b) .

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 6). Only 12% of the PACE outside of the parks is private lands. Despite agricultural and residential development, the majoriety of these private lands remains in the lowest housing density class, which indicates a low level of development (Fig 7). Both population size and rural home density are expected to increase dramatically from present to 2040 (Fig 8 and 9).

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 10). However, growth in home density since 1940 is moderate relative to the other PACES.

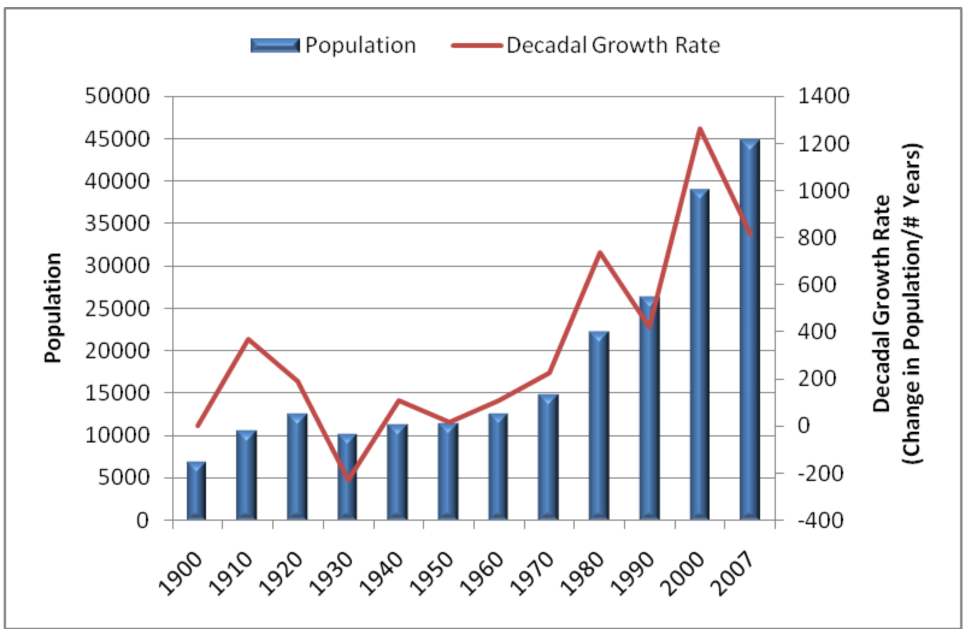

Fig 3. Change in human population size and rate of change across the YELL/GRTE PACE 1900-2007. From Daves in prep.

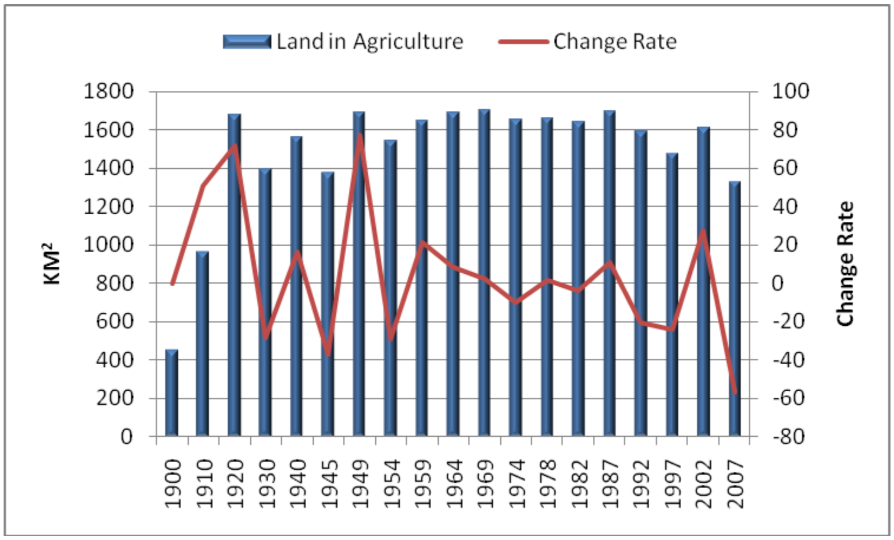

Fig 4. The area of agricultural land in the primary counties of the park-centered ecosystem of Yellowstone and Grand Teton national parks, 1900 – 2007. From Davis in prep.

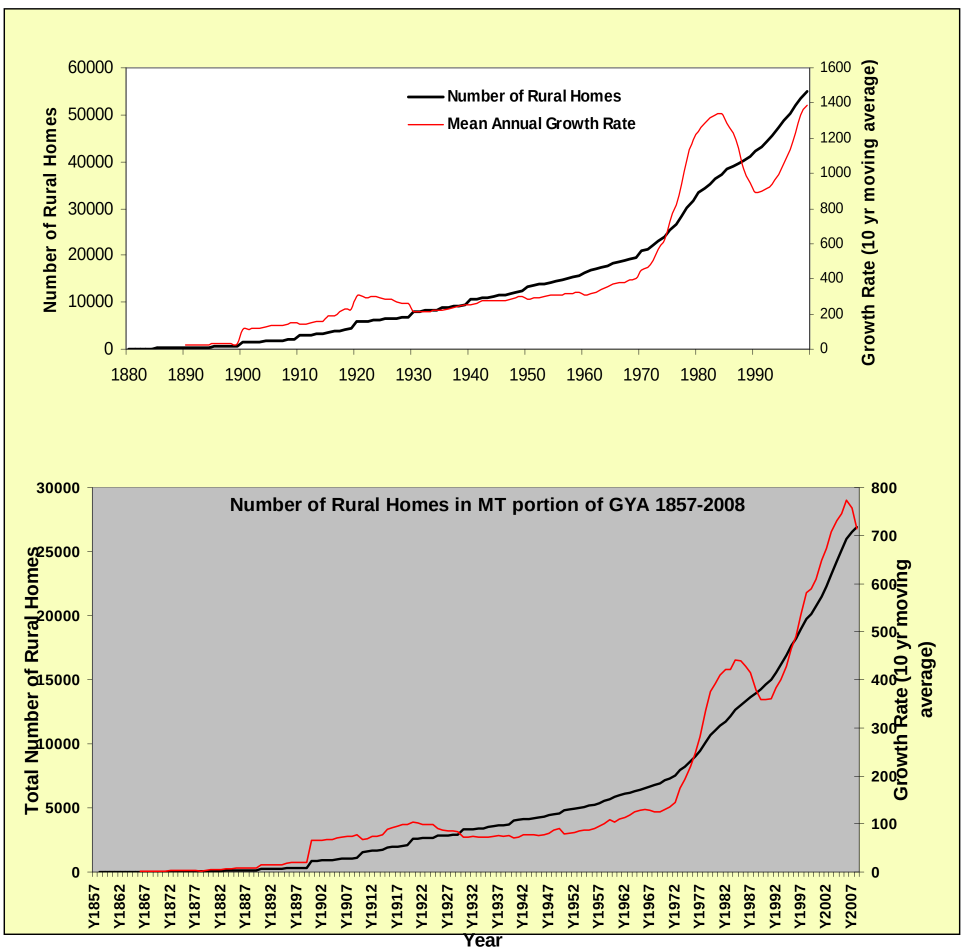

Fig. 5. Number of rural homes and rates of increase in the 20 counties of the Greater Yellowstone Ecosystem 1880-1999 (top). Number of rural homes and rates of increase in the Montana counties of the GYE during 1850-2007, presented to provide indication of trends during the 2000-2007 period. From Gude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

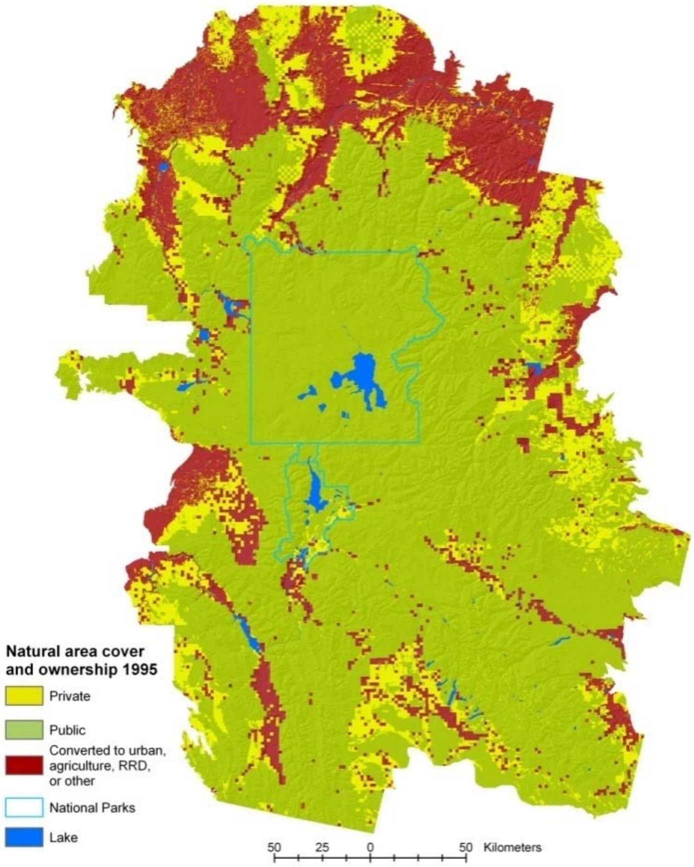

Fig. 6. Distribution of public and private lands and areas converted to developed land use types across the GYE as of 1999.

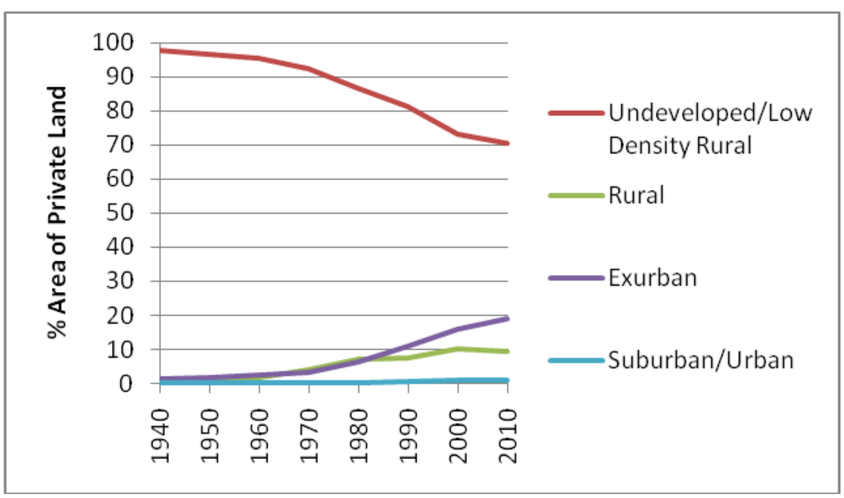

Fig. 7. Hecatres within each housing density class within the PCE for Yellowstone and Grand Teton national parks, 1940 – 2010. From Davis in prep.

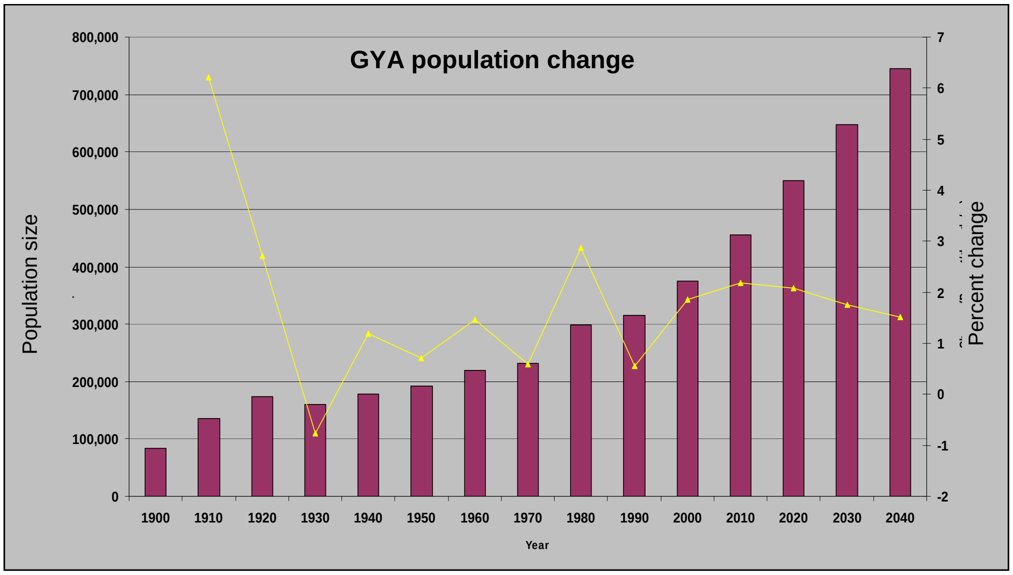

Fig. 8. Past and projected future population size and rates of change to 2040. Davis in prep.

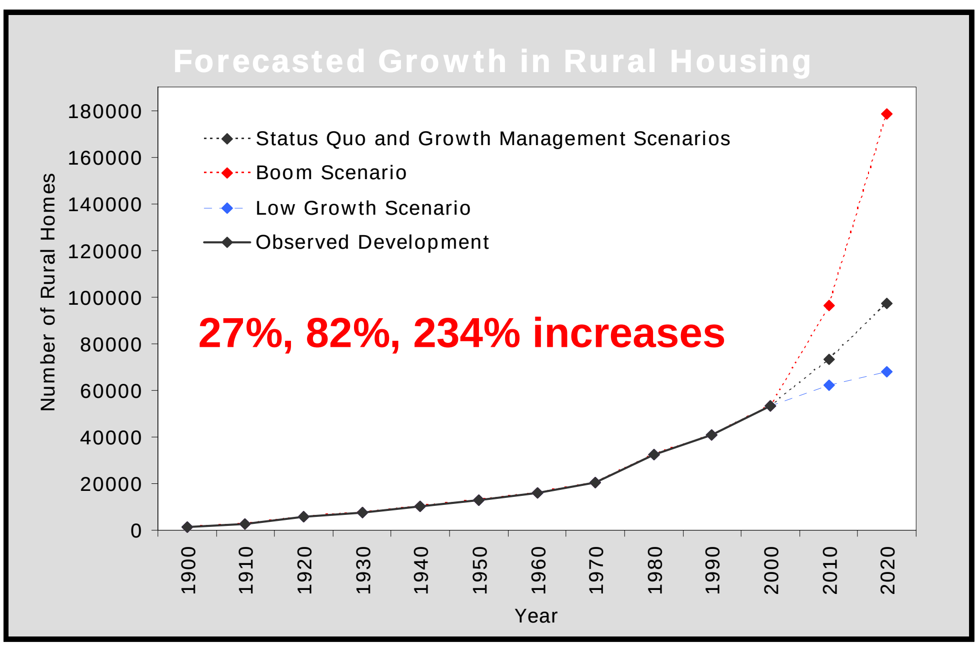

Fig 9. Past and projected future rural home number under three future scenarios. From Gude et al. 2006.

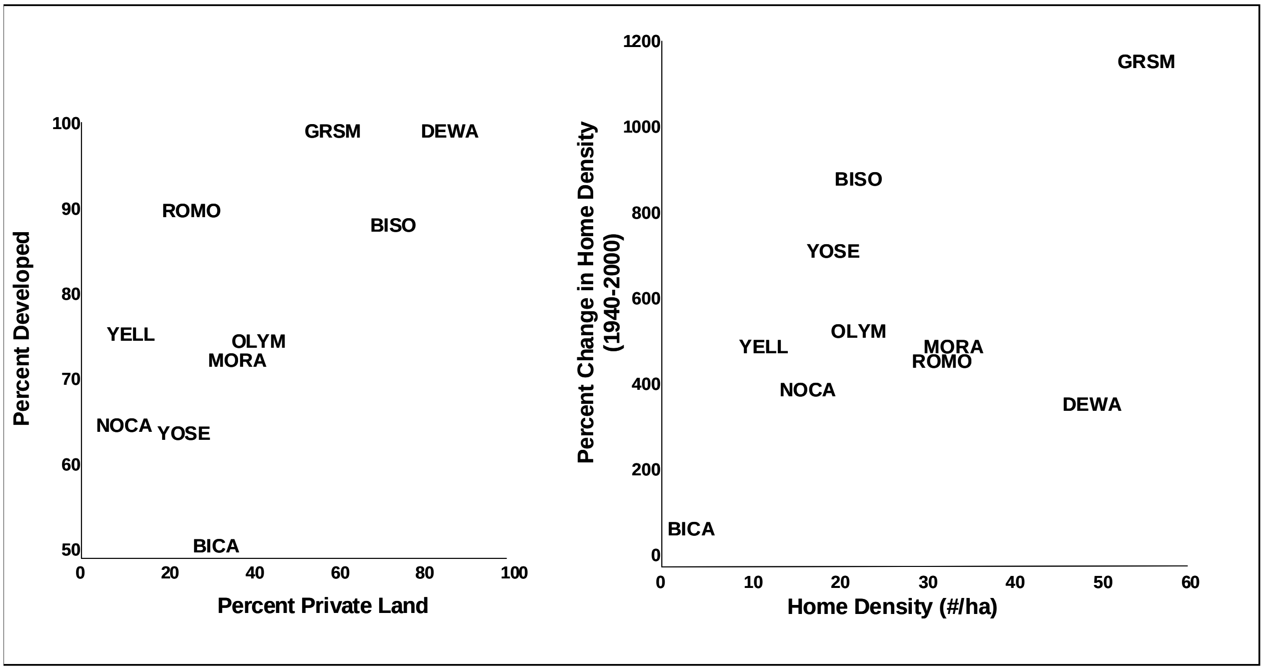

Fig 10. Location of the protected area centered ecosystems along gradients in land ownership and land development (home densities of >0.031 units/ha, roads, or agriculture lands) (left) and home density (units/ha) and percent change in home density from 1940 to 2000 (right).

Note: 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.
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Biodiversity: Patterns of Natural Landscapes

What: Measures the natural landscape context (Fig 11).
Why: Movement of plants & animals and ecological processes connect to adjacent landscapes beyond the park boundary.
Summary: YELL/GRTE scores higher than its ecoregion (Fig 12) and is declining very slowly from 0.9795 in 1992 to 0.9793 in 2001 to 0.9791 in 2030.

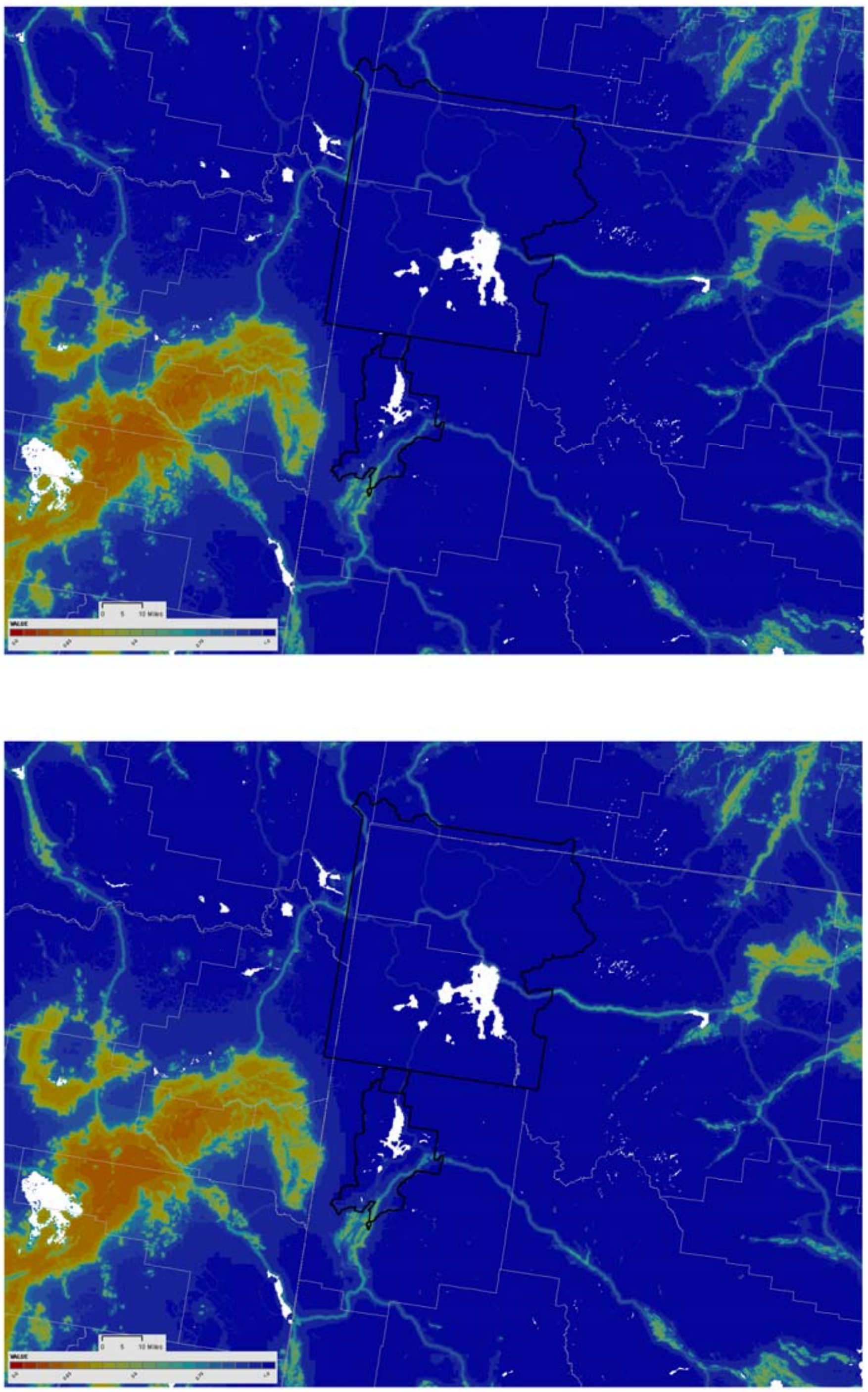
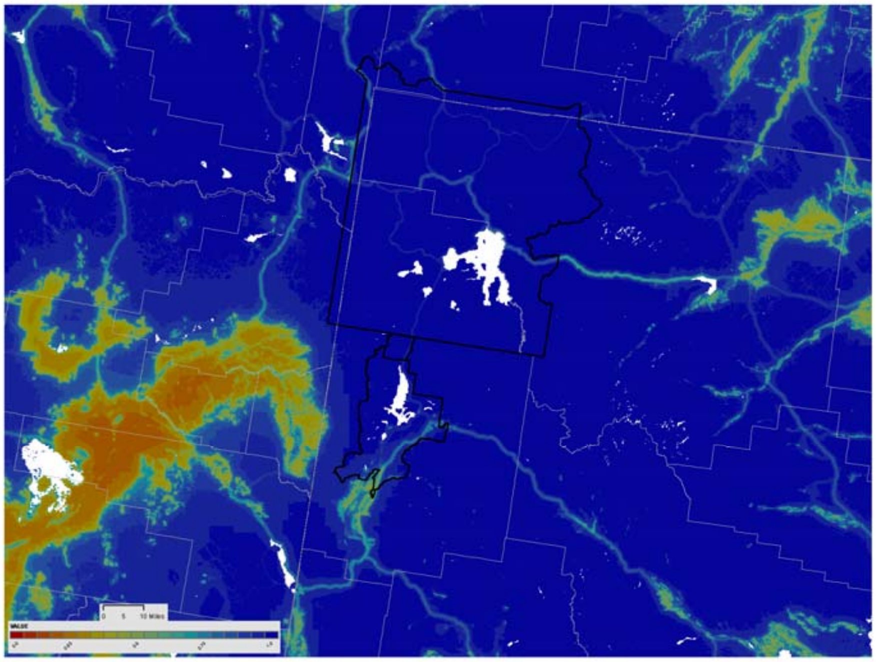


Fig 11. Pattern of Natural Landscapes in 1992, 2001, and 2030 (top, middle, bottom) using the multi-scale proportion metric. High NL values are shown in blue, areas dominated by urban and/or cropland agriculture appear as highly modified areas, shown in red. From Theobald, DM. 2010.



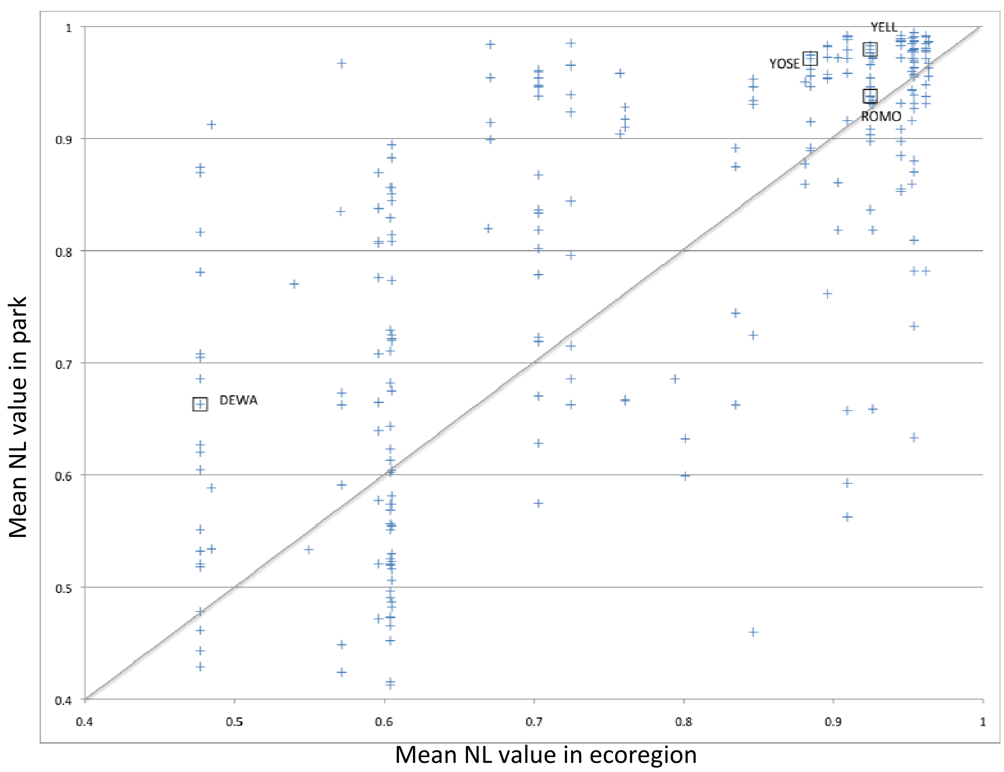


Fig 12. The mean natural landscape metric value for current (2001) landscape. From Theobald et al. 2010.

Biodiversity: Landscape Connectivity

What: Measures the connectivity (Fig 13) of natural landscapes.
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 ecoregion.

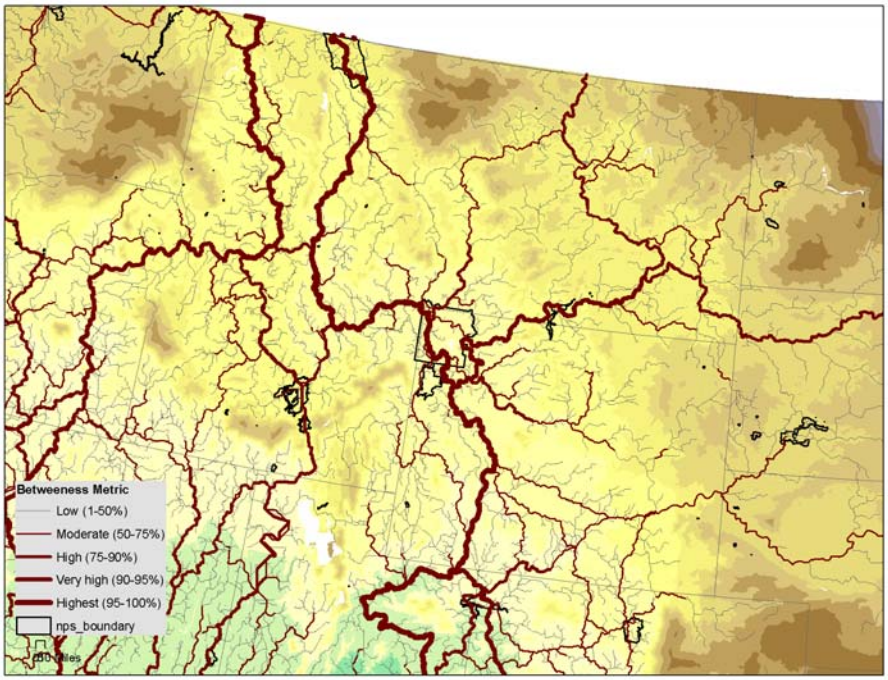
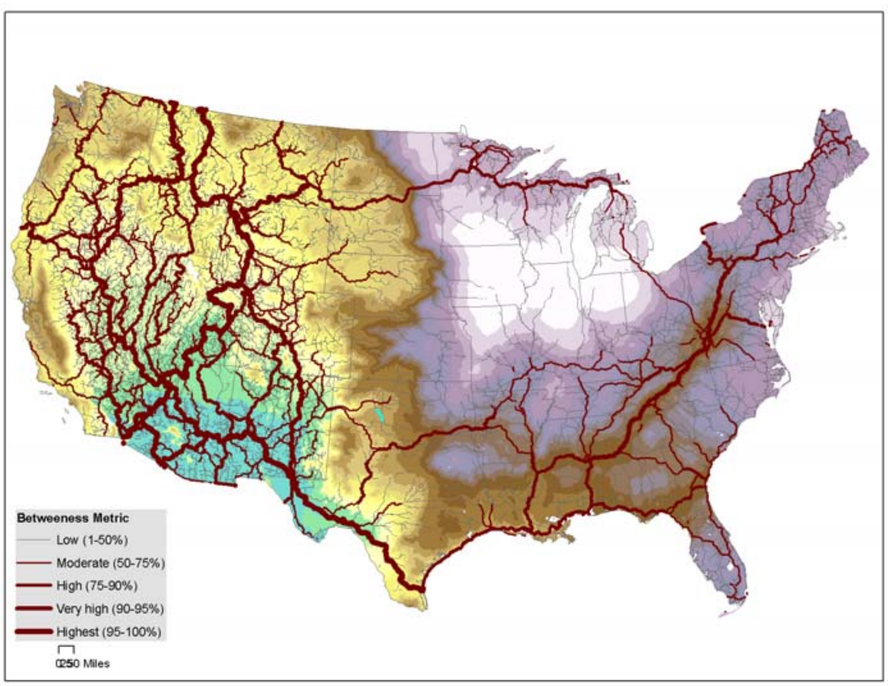


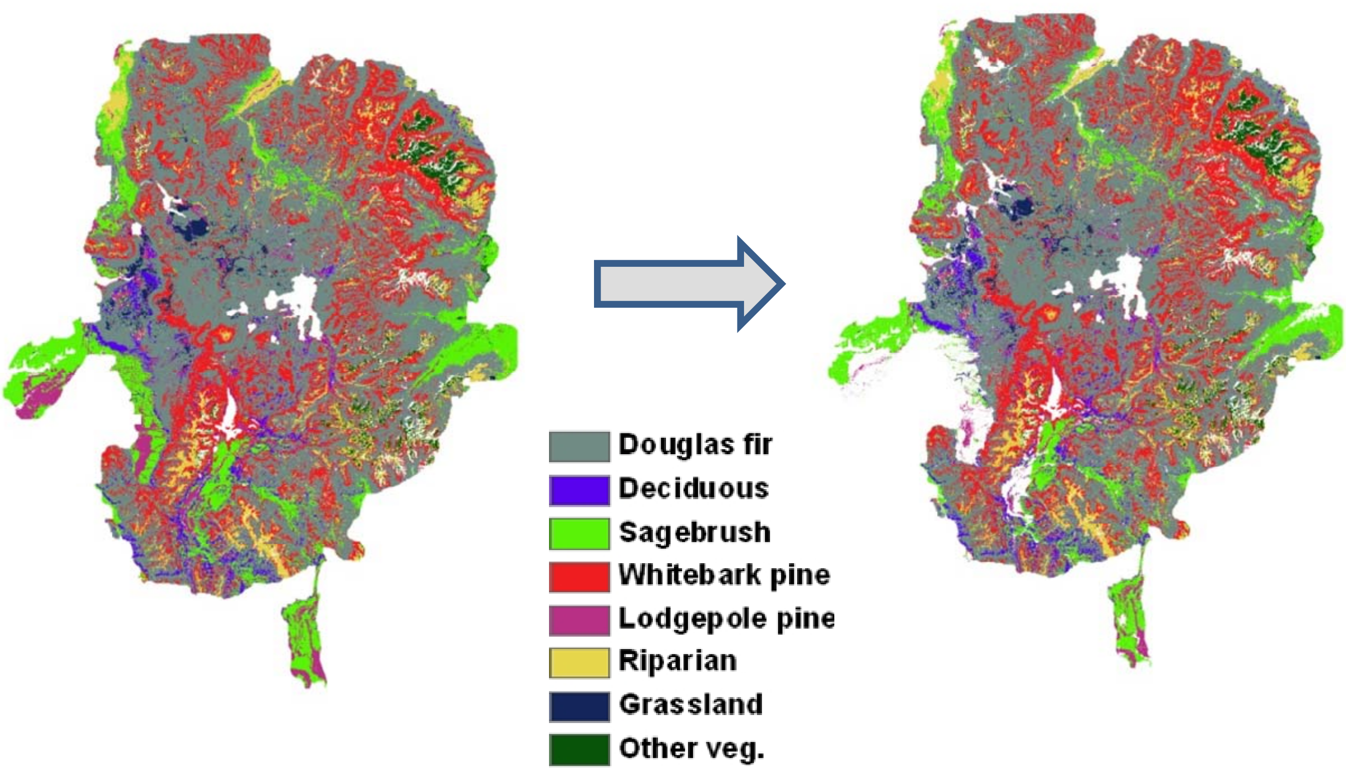
Fig 13. Thicker red lines show more cumulative movement assuming animals are moving across the landscape avoiding human-modified areas, for Yellowstone region (above) and US (below). From Theobald & Reed (in prep).



Biodiversity: Ecosystem Type Composition

What: Estimates reduction in area of potential pre-settlement ecosystem types due to current land use (Fig 14).
Why: Ecosystem types of greatest proportional loss are candidates for focused conservation, management and restoration.
Summary: The sagebrush ecosystem type has experienced the greatest proportional loss across the YELL/GRTE PACE boundary (Table 4). Total losses of ecosystem types to human land uses have been minimal. When compared by ownership categories, losses on public lands have been minimal and on private lands moderate. 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 only as an artifact of there being more but smaller patches on the landscape. This result suggests that fragmentation of ecosystem types by human land uses used in this analysis does not appear to be a major problem at present.

Fig 15. Locations of ecosystem types within the YELL and GRTE PACE boundary from Pre-European settlement to present day. From Piekielek et al. 2010b.



Pre-European settlement **Present Day**

Discussion:
This analysis takes an approach to quantifying changes in ecosystem types by interpreting NPS areas as reference conditions and changes as having occurred only where there has been human development, both within and outside of parks. This approach is justified in that both historical and present day ecosystem types are observed under similar climate conditions so that range shifts of ecosystem types due to climate changes are not represented in these data. Where local vegetation datasets of known accuracy are available, they have been compared to modeled pre-European conditions to look for logical consistency of modeled data. With the exception of a NPS vegetation mapping program dataset for GRTE, local data for the YELL/GRTE PACE area were generally unavailable. However, experience in other areas where local data is more broadly available suggests that this approach works well for ecosystem types which occur over large areas and are aggregated on the landscape. In other areas this approach has yielded agreement within parks ranging from 66% agreement for the ‘Douglas fir/Ponderosa pine’ ecosystem type at ROMO (the ROMO NPS vegetation map reports overall 71% accuracy), down to only 12% agreement between historically mapped ‘shrublands’ in ROMO and actual shrubland locations. In the case of the YELL/GRTE PACE boundary these results suggests that modeled data for the ‘Riparian’ ecosystem type may not be as reliable as those presented for other ecosystem types. What’s more, although we know the ‘Lodgepole pine’ ecosystem type is prevalent on today’s landscape it was not modeled over large or aggregated areas in pre-European settlement conditions and therefore these results should also be interpreted with caution. The results for the remainder of ecosystem types (excepting of riparian and lodgepole pine), should be interpreted as meaningful pending further validation.

Sagebrush
The ‘Sagebrush’ ecosystem type has incurred the largest proportional losses (19%) in this analysis. Of this 19% loss in total area, 33% of sagebrush communities on private lands have been lost whereas only 3% of sagebrush communities on public lands have been lost. This result is consistent with anecdotal evidence that much of the human land development on the YELL/GRTE landscape has occurred in valley bottoms and on mountain toe slopes where many sagebrush communities also occur. Historically, sagebrush communities occurred over very large areas and were highly aggregated. In present day conditions sagebrush communities have experienced a substantial 75% loss in patch size suggesting that large continuous sagebrush communities are becoming a rarity in this landscape. The reported decrease in mean distance to the next nearest sagebrush community is merely an artifact of there being more, smaller patches on the present day landscape. With the erosion of human land uses in present day conditions, in actuality we would expect further distances between large patches of sagebrush communities. Obscured from this analysis are the effects of ranching and fencing on sagebrush communities as this land use is not associated with large-scale land cover change and were not represented in our human land use data. Accounting for ranching, fencing and short-comings in calculating changes in mean patch distances, we expect that sagebrush communities are far more fragmented in today’s landscape than they were historically. Loss and fragmentation of sagebrush communities undoubtedly translates into consequences for species which specialize on this ecosystem type in the YELL/GRTE PACE, such as sage-grouse and pronghorn both of which are already species of concern. This analysis suggests that sagebrush communities are at the greatest risk of loss and degradation.

Deciduous

The ‘Deciduous’ ecosystem type largely occurs in wet and riparian areas across the YELL/GRTE PACE area. Deciduous communities are relatively small in their total area and are important due to the diversity of species that they often support. Deciduous communities have experienced 7% total losses with 36% of those occurring on private lands being lost. Similar to sagebrush communities, this is suggestive that deciduous communities on private lands are being lost to human development, although other studies have suggested drying and succession to mixed-conifer and conifer stands as a pathway of loss for deciduous communities (Parmenter et al. 2003). As is mentioned above, this analysis used only human development to account for loss of ecosystem type area, so it may be that deciduous communities are being lost to both human development and climate variability or change in addition to the 7% calculated here. Mean patch size of deciduous areas has decreased by 30% suggesting that this ecosystem type has been moderately fragmented by human development. Much of this fragmentation has likely occurred on private lands, meaning that patch size on private lands has likely decreased by somewhat more than 30%. Deciduous communities support species richness in the YELL/GRTE PACE area disproportionate to the area that they cover. As such, and given moderate losses of deciduous areas on private lands they should be the focus of conservation, management and restoration.

Grasslands

Because of the way that ecosystem types are named and mapped in this analysis the ‘Grassland’ ecosystem type is underrepresented. Within the YELL/GRTE PACE area sagebrush communities and grassland communities are in fact interwoven in many places. Many of the same results and conclusions for sagebrush communities can also be made for grassland communities. Grassland communities in this analysis have experienced 6% total losses, but strikingly 47% of grasslands on private lands have been lost. Similar to sagebrush communities, grasslands on private lands occur in areas that are the primary focus of human development. As such, grasslands and the species that rely on these ecosystem types should be the focus of conservation, management and restoration within the YELL/GRTE PACE area.

Table 4. Proportional changes in aerial extent of ecosystem types within the YELL and GRTE PACE boundary 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**

Notes on methods: the locations of pre-settlement ecosystem types were mapped by the USFS LANDFIRE program at the NVCS ecological systems scale based on biophysical factors, the location of existing ecological systems and modeled historical disturbance conditions. Ecological systems were cross-walked to ecosystem types used by the PALMs project. This layer was validated within park boundaries using NPS Veg. Mapping program data where available with varying degrees of agreement. For the YELL/GRTE PACE boundary NPS vegetation mapping data were only available for GRTE and published cross-walks from vegetation associations to ecological systems were unavailable. We evaluated the loss of ecosystem type area due to current land uses including residential and agricultural development and transportation networks.

Biodiversity: Habitat Type Composition

What: Estimates reduction in area of key habitats from presettlement 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 5). 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 5. 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 extrapated, 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.

Projected future climate…

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, lead 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 extripated 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.

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