LANDSCAPE CONDITIONS AND TRENDS IN AND AROUND Rocky Mountain National Park: 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: The Delaware Water Gap and Upper Delaware National Recreation Areas, Sequoia Kings Canyon and Yosemite National Parks, Yellowstone and Grand Teton National Parks, and Rocky Mountain National Park. This document reports initial findings on landscape trends and conditions in and around Rocky Mountain National Park. After a short introduction, the report highlights initial results for each of the 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.

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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 Water Gap / Upper Delaware National Recreation Areas.

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 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 Rocky Mountain National Park 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.

Indicators being developed for the Rocky Mountain National Park.

Level	Category	Indicator	Resolution	SOP[1] and Reference	Status
Landscape dynamics	Monitoring area	Protected area centered ecosystem boundaries	30 m	Piekielek et al. 2010 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	Initial results currently being reviewed (available at: TOPS web site)
	Disturbance Events	Rapid change in Vegetation index	1 km; monthly anomalies.	TOPS SOP Nemani et al. 2008	Initial results currently being reviewed (available at: TOPS web site)
	Land Cover	Impervious Cover Change	30m; 1984-2005	PALMS SOP Brown de Coulston	Completed
		Population Density (decadal)	1 km; 1900-2007	Davis et al. In prep	Completed
		Agricultural Area (decadal)	1 km; 1900-2007	Davis et al. In prep	Completed
		Rural Housing Density (decadal)	1 km; 1860-2007; 2000-2030	Piekielek et al. In prep. Hernandez et al. 2007	Completed through 1999, being updated to 2008
		Pattern of natural landscapes	270 m; time period	Theobald 2009 Theobald et al. 2010	Completed
	Biological Integrity	Landscape connectivity	30 m, 270 m, 1km; circa 2005	Goetz et al,. 2009 Jantz et al. 2008 Theobald in prep	Completed
		Ecosystem type composition	30 m Presettlement - present	Piekielek et al. 2010	Completed
		Phenology (NDVI, annual anomaly)	1 km (all); 8 & 16 day; 2000-2008	TOPS SOP Nemani et al. 2008	Initial results currently being reviewed (available at: tops web site)
Air and Climate	Weather and Climate	Climate gridded daily	1 km; 2000-2008	TOPS SOP?	
		Climate scenarios (monthly)	12 km; 2010-20??	TOPS SOP?	

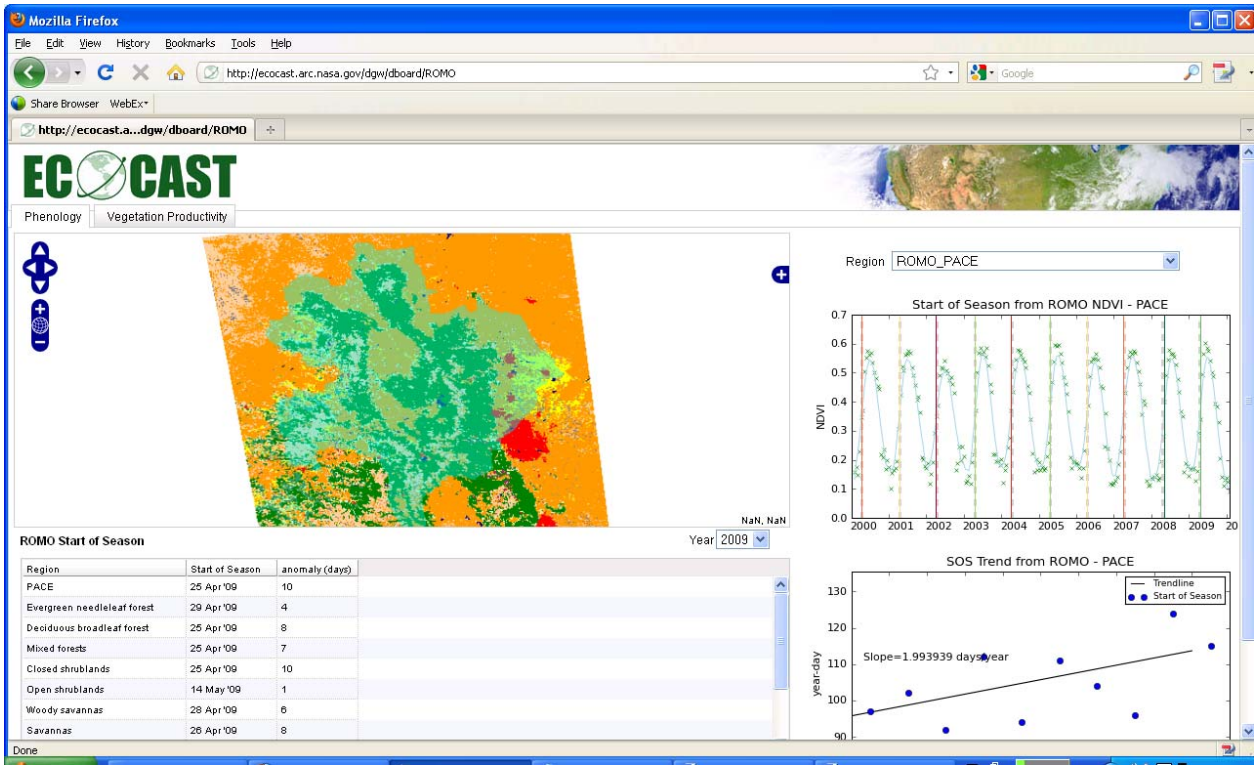
Weather and Climate: Landscape Phenology

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

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: This indicator include measures of the annual Start-of-Season anomaly, and graphs and plots to summarize spatial and temporal patterns in SOS by land cover type, as shown below. The indicator is intended to provide a relative measure of landscape phenology for use in detecting temporary and sustained shifts in SOS dates, as opposed to an absolute measure for specific plant species. A draft 'dashboard' summarizing patterns from this indicator is posted at http://ecocast.arc.nasa.gov/dgw/dboard/ROMO Results shown are preliminary.



Weather and Climate: Gridded Climate

Under development.

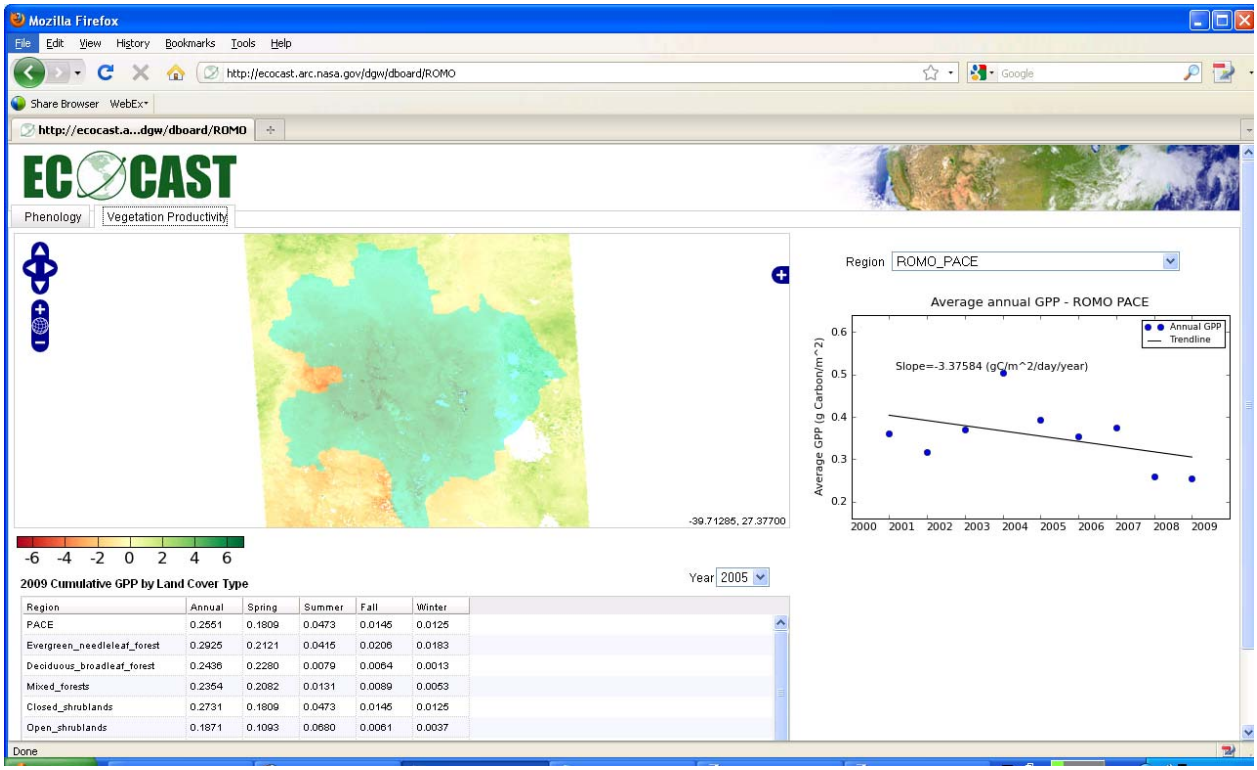
Ecosystem Productivity: Gross Primary Production

What: Estimates Ecosystem Productivity: Gross Primary Production Gross primary production (GPP) and measures spatial and temporal patterns 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: Summary measures for this indicator include annual GPP anomaly maps, and graphs and tables of cumulative GPP summarized by season and land cover type. This indicator relies on the use of MODIS data, and the TOPS implementation of the Biome-BGC model. Production of the dataset will continue under the NASA Earth Exchange (NEX) project for the foreseeable future. A draft 'dashboard' summarizing patterns from this indicator is posted at http://ecocast.arc.nasa.gov/dgw/dboard/ROMO Results shown are preliminary.



Disturbance Events: NDVI Anomalies

Under development

Biodiversity: Patterns of Natural Landscapes

What: Measures the natural landscape context
Why: Movement of plants & animals and ecological processes connect to adjacent landscapes beyond the park boundary
Summary: ROMO scores slightly higher (0.02-0.03) above the Southern Rockies ecoregion, but is declining from 0.940 in 1992 to 0.937 in 2001 to 0.928 in 2030. However, the ecoregion as a whole is declining at a rate 3x of ROMO.

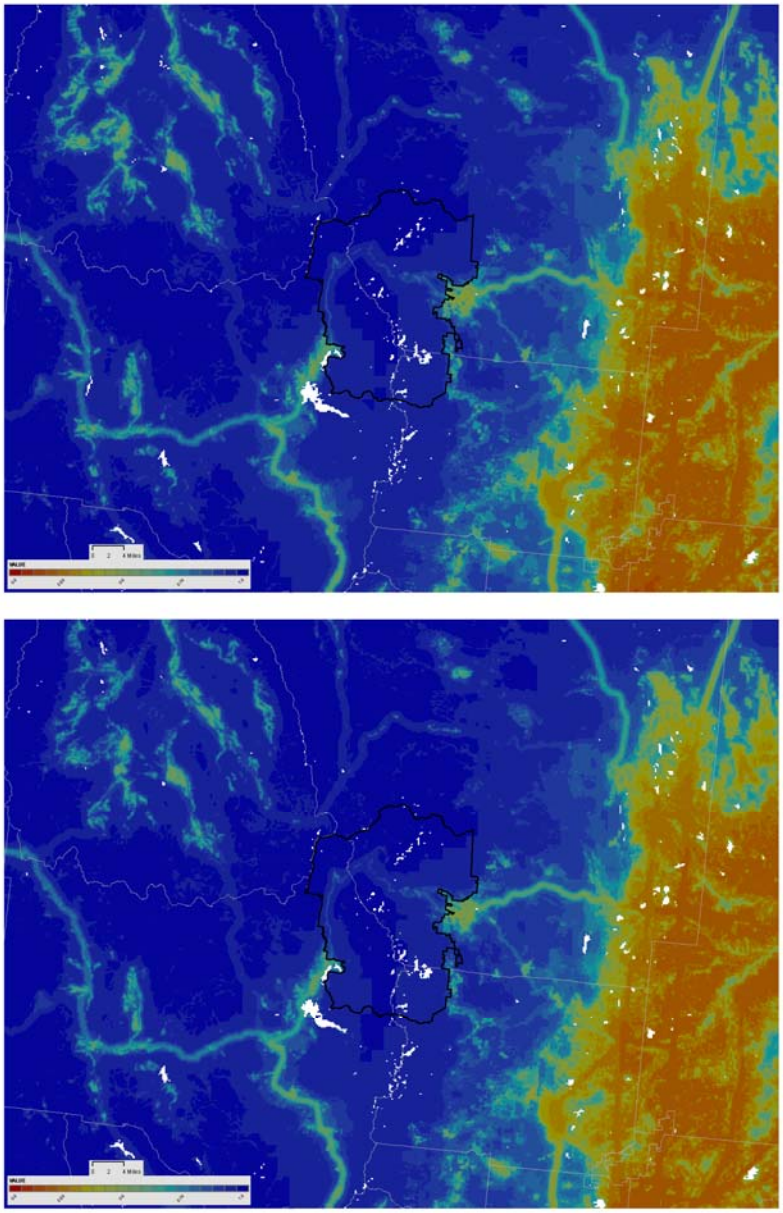
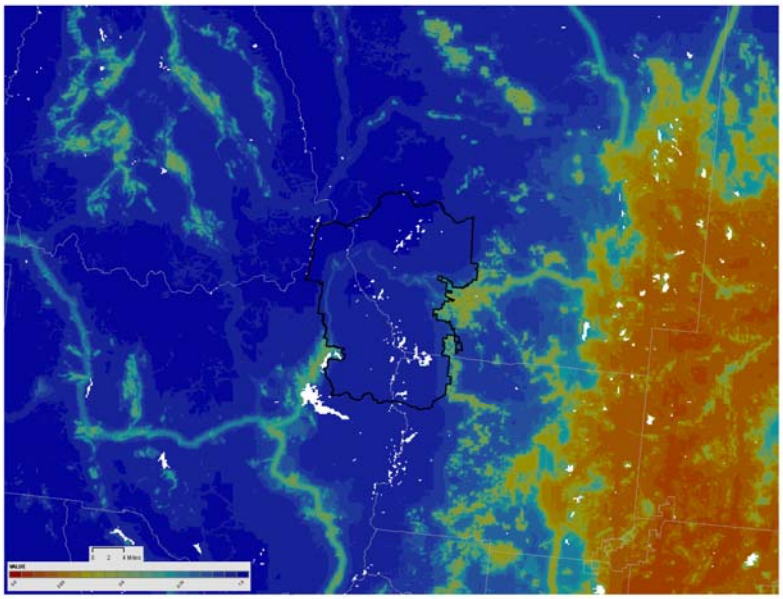


Fig 14. Pattern of Natural Landscapes in 1992, 2001, and 2030 (top, middle, bottom) using the multi-scale proportion metric. High NL values are shown in blue, areas dominated by urban and/or cropland agriculture appear as highly modified areas, shown in red. From Theobald, DM. 2010. Estimating natural landscape changes from 1992 to 2030 in the conterminous US. *Landscape Ecology*.



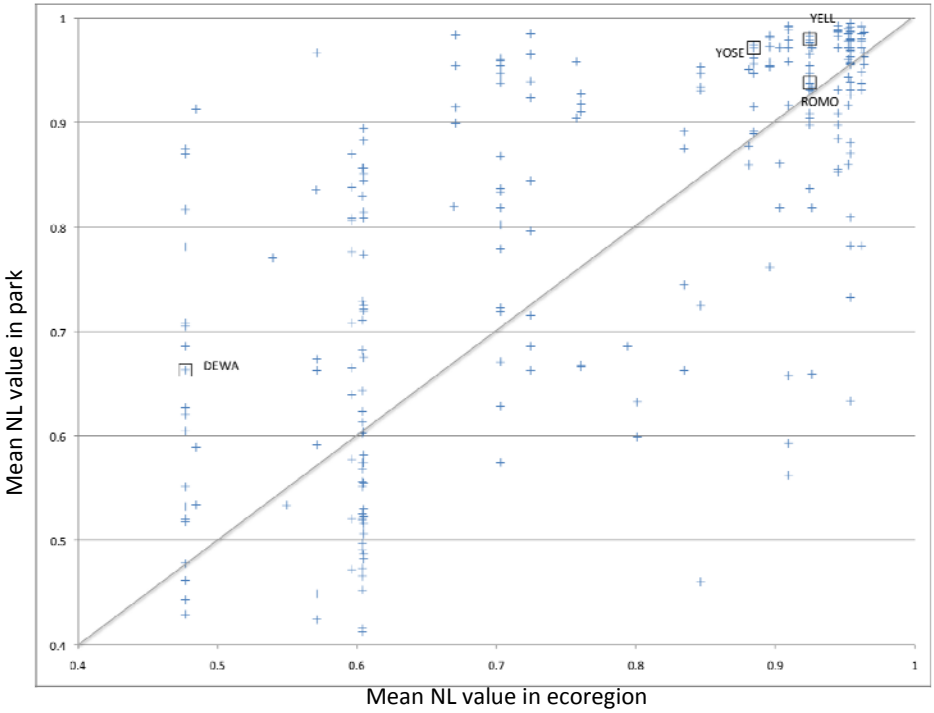


Fig xx. The mean natural landscape metric value for current (2001) landscape.

Biodiversity: Landscape Connectivity

What: Measures the connectivity of natural landscapes
Why: Movement of plants and animals and ecological processes connect to adjacent landscapes and beyond the park boundaries.
Summary: ROMO is situated on a pathway that provides much grater than average connectivity and serves as a key location of connectivity along the Southern Rockies.

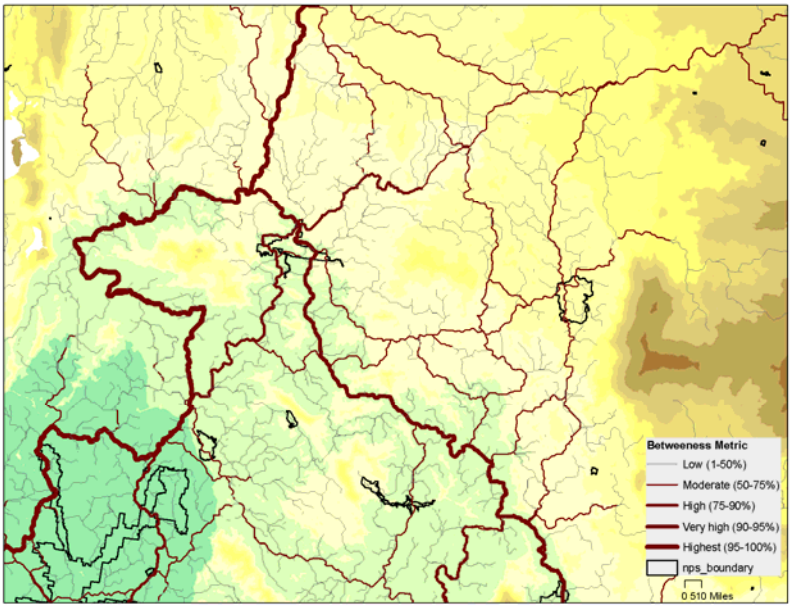
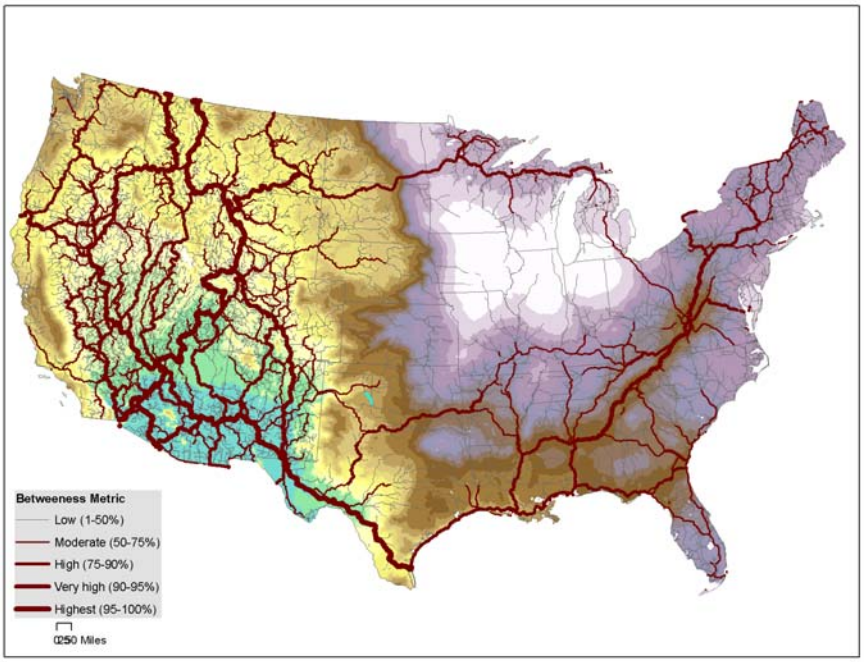


Fig xx. Thicker red lines show more cumulative movement assuming animals are moving across the landscape avoiding human-modified areas, for Yellowstone region (above) and US (below). From Theobald & Reed (in prep).



Delineating Protected Area Centered Ecosystems (PACE)

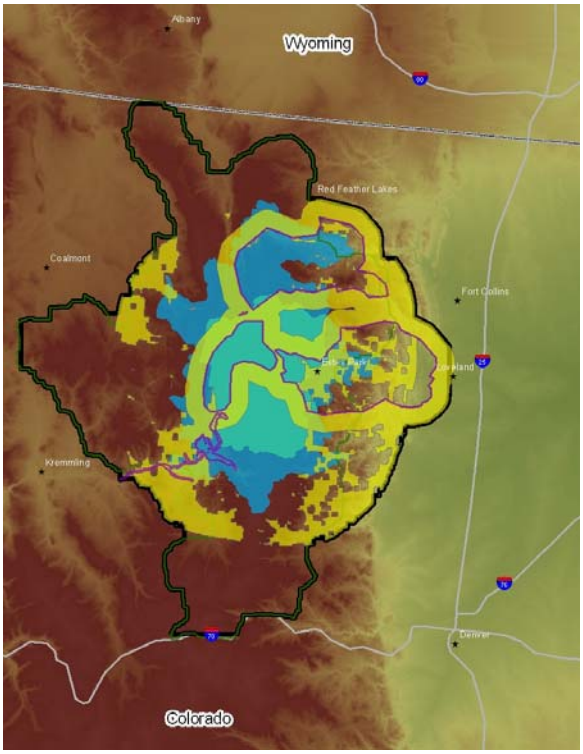
What: Area surrounding park with strong ecological connections to the park..

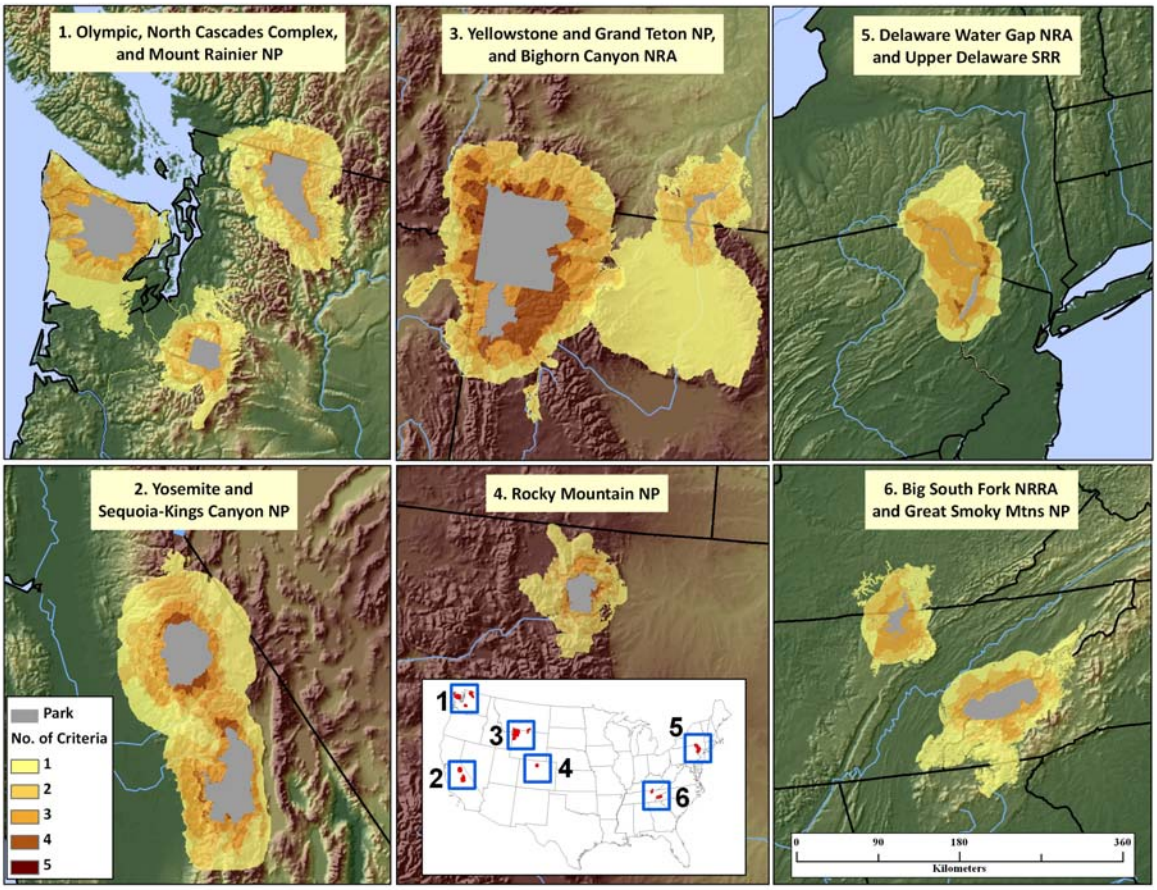
Why: This area may be important for monitoring, research, and cooperative management to maintain park

Summary: The ROMO pace outside the park was 8.8 times larger than the park area. The contiguous habitat layer covered the largest unique portion of the PACE, followed by the human edge effects layer. Some 34.5% of the PACE was covered by two or more criteria. Only 24% of the PACE outside of the park is private land, a smaller amount than for many other PACEs.

Metric	Total	Criterion				
		Contiguous habitat	Water-shed	Disturbance	Crucial Habitats	Human Edge Effects
Area outside park (km^2	9450	6768	1690	---	1398	1986
% of PACE uniquely covered		42.75	0.0	---	0.25	10.25

Solid blue = watershed, Purple line = crucial hab., Green line = contiguous hab., Solid yellow = edge effects, Black line = draft PCE boundary





Maps of protected-area centered ecosystems for Rocky Mountain and 12US National Park units. Gradations in color in the PACES outside of the parks indicate the number of overlapping classification criteria. Places with many overlapping criterion may be considered more important for monitoring and management.

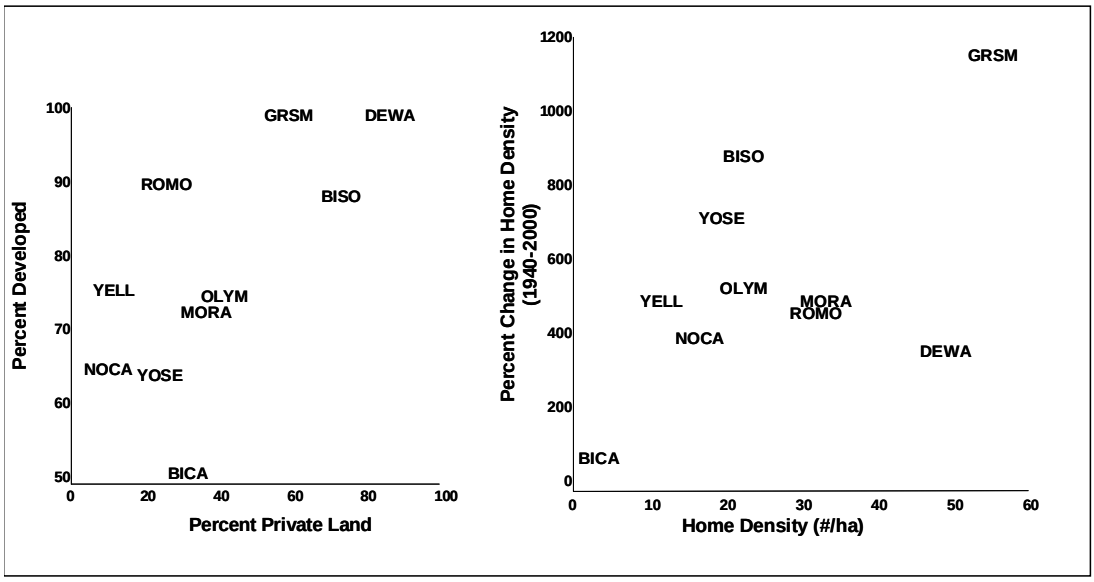
Land use within protected-area centered ecosystems (PACEs)

What: Metrics of land allocation and change in PACES outside of parks.

Why: These data provided indication of the challenges in maintaining park condition given the characteristics

Summary: Only 24% of the PACE outside of the park is private land, a smaller amount than for many other PACEs. Nearly 90% of those private lands are in agriculture, roads, homes or other land uses termed "developed". Home density in these private lands and growth in home density since 1940 are medial relative to the PACES examined thus far.

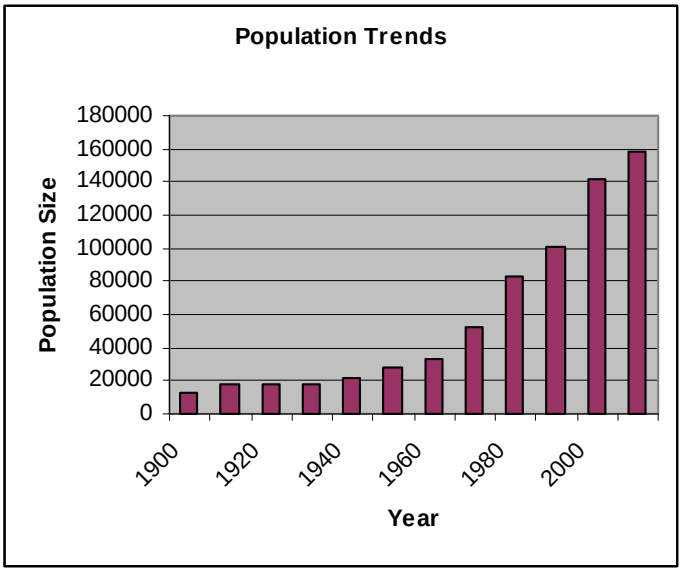
Percent of land that is private	Percent of private land developed in 2000	Home density on private lands in 2000 (#/km^2)	Change in home density on private lands during 1940-2000 (%)
24.0	89.3	0.323	455.2

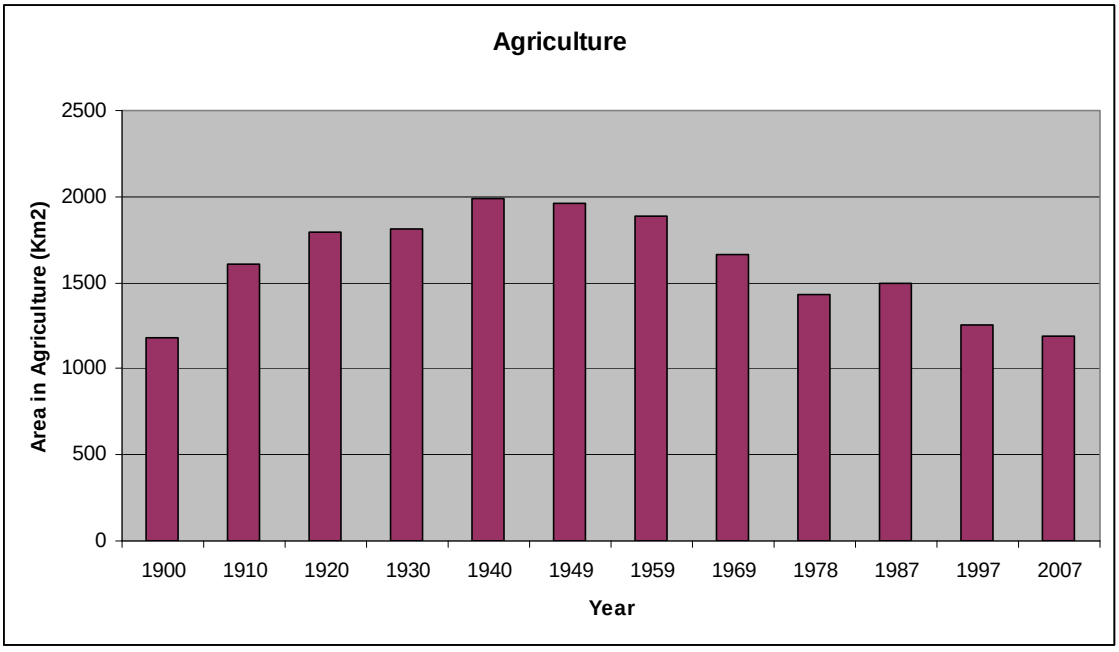


Location of the protected area centered ecosystems along gradients in land ownership and land development (home densities of >0.031 units/ha, roads, or agriculture lands) (left) and home density (units/ha) and percent change in home density from 1940 to 2000 (right).

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.

ROMO PACE: 1900 - 2007





Population distributed was distributed within PACE based on housing density. Ag data are for counties that cover >=10% of PACE or >=40% of the county is covered by the PACE.

Climate and Precipitation.

100-year climate trends for 6 National Parks (PACEs) by region based on PRISM data. Non-zero values are significant trends and represent the average annual increase or decrease across the time period of 1895 - 2007. Those highlighted in yellow are the three fastest changing in temperature of the 60 parks in the study. From Hass et al. in prep.

Region	National Park	Precip. (mm)	Temp. (C)
Desert Southwest	Organ Pipe Cactus	0	2.615
Northeast	Delaware Water Gap	0	2.031
Northern Rockies	Grand Teton	0	0.982
	Yellowstone	0	0.856
Pacific Southwest	Sequoia	0	0.585
	Yosemite	0	0.522
Southern Rockies/Colorado Plateau	Rocky Mountain	0	1.928

Landscape dynamics: Ecosystem type composition

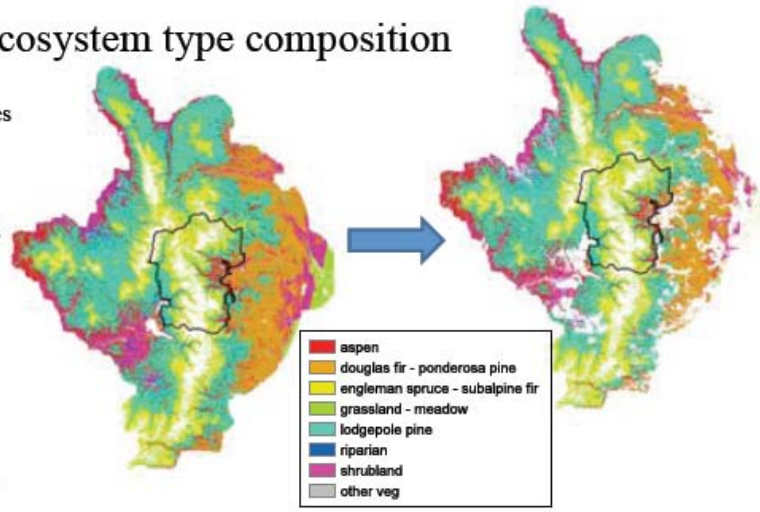
Landscape dynamics: Ecosystem type composition

What: Estimates reduction in area of potential pre-settlement ecosystem types due to current land use.

Why: Ecosystem types of greatest proportional loss are candidates for focused conservation, management and restoration.

Stressors: land use change.

Grasslands and meadows have undergone greatest proportional loss followed by shrubland and douglas fir ecosystems. Most losses have occurred on private lands where an average of half of each ecosystem type has been lost to human activity. Engelmann spruce – subalpine fir communities do not appear to have been significantly affected by land use change in this analysis.



Ecosystem Type	Hectares (thousands)	% Loss total	% Loss pvt land	% Loss Pub. land
Aspen	111	12	35	0
Douglas fir – ponderosa pine	141	26	60	0
Engelmann spruce – subalpine fir	157	0	35	0
Grassland meadow	36	35	86	5
Lodgepole pine	280	9	45	2
Riparian	41	23	49	5
Shrubland	74	30	46	5
Other natural veg.	5	40	68	3
Mean		**22**	**53**	**3**

Note on methods: the distribution of pre-settlement ecosystem types were mapped by the LANDFIRE program based on biophysical factors and modeled disturbance conditions. This layer was validated within park boundaries using NPS Veg. Mapping program data with varying "accuracy". We evaluated the loss of ecosystem type area due to current land uses including residential and agricultural development and transportation networks.

Summary and Prospects

Story Lines Emerging from Trends (see table 3 below for reference)

- Spatial patterning of the natural component of the system
  - Climate, ecosystem / habitat types, productivity, hydrology
- Change in climate averages and spatial patterning over time

- Temporal and spatial patterns of human communities and use
  - Human population density
  - Change in land cover and use & agriculture
  - Exurban expansion & impervious cover
  - Spatial pattern of intensive land uses

- Interactions among biophysical patterns, productivity, human environment, habitat connectivity and climate.
  - Human transformation of the ecological system
  - Future prospects based on spatial predictive modeling

- Key current and emerging management challenges

Feedback & thoughts on refining / updating / delivering / using these analyses?

References

<additional reference material for this section is welcome / desired >

Goetz, S.J. and G. Fiske. 2009. PALMS SOP – GIS Methodology for mapping Biotic Integrity and Indicator Taxa across watersheds in the eastern USA. National Park Service, Fort Collins, CO.

Goetz, S.J. and G. Fiske. 2010. PALMS SOP – Estimating Impervious Cover Change. National Park Service, Fort Collins, CO.

Goetz, S. J., Fiske, G. & Jantz, C. A. (submitted). On the relationship between stream biotic diversity and urbanization, past and future, in New England USA. *GIS and Geospatial Techniques as applied to Urban Water issues* (ed. by L. Patrick). Springer Press.

Goetz, S. J., Sun, M. & Jantz, C. A. (in preparation). Changes in the hydrology of the Upper Delaware watershed with increasing urbanization. *Landscape and Urban Planning*.

Goetz, S. J. & Fiske, G. (2008) Linking the diversity of stream biota to landscapes in the mid-Atlantic USA. *Remote Sensing of Environment*, 112, 4075-4085.

Goetz, S. J., Jantz, P. & Jantz, C. A. (2009) Connectivity of core habitat in the northeastern United States: parks and protected areas in a landscape context. *Remote Sensing of Environment*, 113, 1421-1429.

Hansen, A., Davis, C., Piekielek, N., Gross, J., Theobald, D., Goetz, S., Melton, F. & Defries, R. (submitted) Delineating the Ecosystems Containing Protected Areas for Monitoring and Management. *Proceedings of the National Academy of Sciences*.

Jantz, C. A., Goetz, S. J., Donato, D. & Claggett, P. (2010) Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model. *Computers, Environment and Urban Systems*, 34, 1-16.

Jantz, P. & Goetz, S. J. (2008) Using widely available geospatial data sets to assess the influence of roads and buffers on habitat core areas and connectivity. *Natural Areas Journal*, 28, 261-274.

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.

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.

Piekielek, N.B., C. Davis and A. Hansen 2010. 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.

Piekielek, N.B., C. Davis and A. Hansen 2010. PALMS SOP - Analyzing Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. (3.3 MB)

Piekielek, N.B., C. Davis and A. Hansen 2010. PALMS SOP - Estimating Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. (10 MB)

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* (in press – preprint available online)

Theobald, D.M., S.J. Goetz, J. B. Norman, and P. Jantz. 2009. Watersheds at risk to increased impervious surface in the conterminous United States. Journal of Hydrologic Engineering 14(4): 362-368.

Wang, W., K. Ichii, H. Hashimoto, P. Thornton, and R. Nemani. 2009. A hierarchical analysis of the terrestrial ecosystem model BIOME-BGC: model calibration and equilibrium analysis. *Ecological Modeling* 220(17):2009-2023.