LANDSCAPE CONDITIONS AND TRENDS IN AND AROUND Delaware Water Gap and Upper Delaware National Recreation Areas: Initial 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
NPS I&M Program

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8 June 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: 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 the Delaware Water Gap and Upper Delaware parks. 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. Among the conclusions are that the Delaware Water Gap and Upper Delaware park centered ecosystem is changing as a result of increasing population and land use modification that influences the ecological processes within the park boundaries. The park centered ecosystem has undergone substantial change in the past, relative to presettlement times and particularly with respect to conversion of forest to agriculture, but the more recent changes are primarily associated with increasing population pressure and associated residential development. These types of longer-term changes, which will have legacy effects well into the future, not only impact the water resources central to the parks amenity value, but also the connectivity of the park to the landscape and the region, thus the terrestrial diversity that relies at least partly on the parks resources. These types of land use changes are projected to intensify in the future, but their impacts can be mitigated by land management decisions (e.g. low impact development and best management practices). The park centered ecosystem, and the greater region, will also be increasingly influenced by climate change, thus management options for coping with climate change and interactions between land use and climate change need to be considered.

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1 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 Delaware Water Gap / Upper Delaware National Recreation Areas. 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 Delaware Water Gap / Upper Delaware National Recreation Areas.

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
		Future Scenarios of Impervious Cover	2010-2030	Jantz et al. 2010	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
	Biological Integrity	Pattern of natural landscapes	270 m; time period	Theobald 2009 Theobald et al. 2010	Completed
		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
Air and Climate	Weather and Climate	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)
		Climate gridded	1 km; 2000-	TOPS SOP?	

		daily	2008		
		Climate scenarios (monthly)	12 km; 2010-20??	TOPS SOP?	
Water	Hydrology	Surface Water Dynamics	2005, 2030	Goetz et al. in prep. Melton et al. SOP?	Completed
	Water Quality	Aquatic Macroinvertebrates (Biological IBI, sensitive taxa)	Predicted circa 2005, 2030	Goetz et al. 2008; Goetz et al. submitted. SOP	Completed

2 Overview of Trends and Predictions of Park Condition

2.1 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 DEWA/UPDE PACE outside the park was 32 times larger than the park area, with at total area of 14,046 km^2. The DEWA/UPDE PACE was smaller than 8 of the 9 other park units evaluated (Hansen et al in review) but the ratio of PACE to park area was larger than for most of the other units, indicating that the park lands protect a lesser proportion of the ecosystem than most other park units, but this was typical for parks centered on rivers / watersheds. The areas mapped for each criteria did not overlap substantially in the DEWA/UPDE PACE, with just xx% of the PACE covered by two or more criteria, a proportion lower than for the other park units evaluated

Figure xx. Gradations in color in the PACES outside of the parks indicate the number of overlapping classification criteria. Criteria 1 watershed = thin blue line; Criteria 3 crucial habitat = light tan; Criteria 4 contiguous habitat = tan; Criteria 5 edge effects = yellow. Places with many overlapping criterion may be considered more important for monitoring and management.

Table 2. Spatial characteristics of area covered by each criterion used to define the DEWA/UPDE PACE (km^2).

Metric	Total	Criterion				
		Contiguous habitat	Water-shed	Disturbance	Crucial Habitats	Edge Effects
Area outside park (km^2)	14,046	7,597	10,826	-	725	9,282
% of PACE uniquely covered		2.25	21.75	--	0.01	9.75

2.2 Landscape Dynamics / Ecosystem Productivity: Gross Primary Production

What: Estimates Ecosystem Productivity: 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: This indicator has been calculated for DEWA-UPDE, and will include measures of GPP trends and anomalies 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 (Wang et al. 2009). Production of the data set will continue under the NASA Earth Exchange (NEX) project for the foreseeable future.

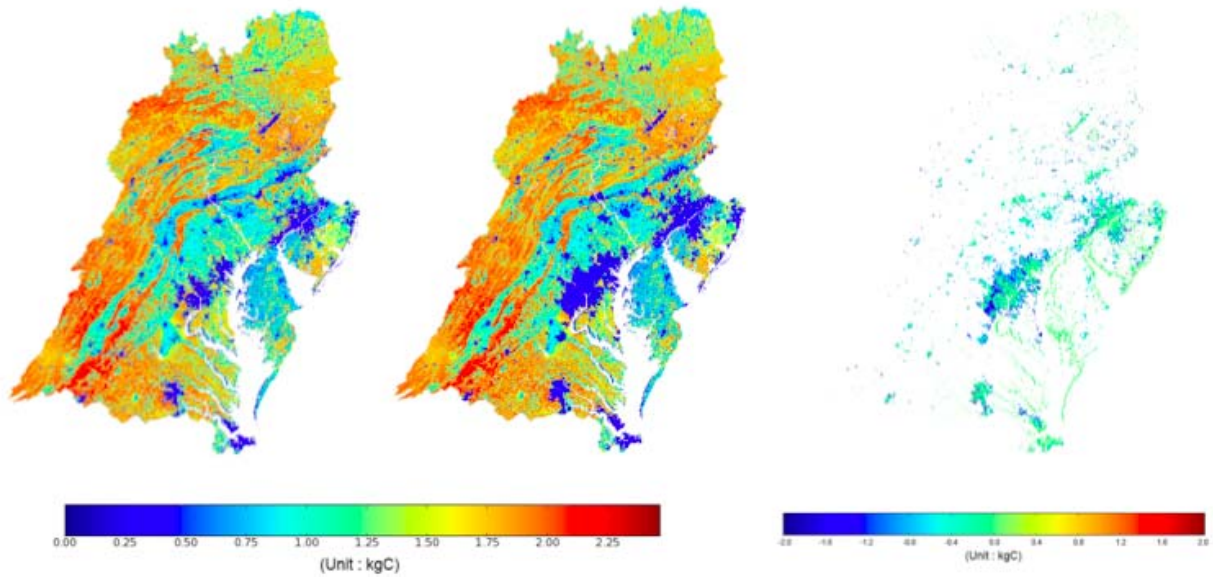


Figure xx. Year 2000 Gross Primary Productivity (GPP) simulated from the TOPS / Biome-BGC model (left image) and the same for year 2030 under future land use change predictions (center image). The spatial pattern of differences (all decreases) is also shown (right image). The land use change predictions are from the SLEUTH model (section x.x).

2.3 Landscape Dynamics / Disturbance Events: Vegetation Index Anomalies

[To be added - TOPS]

2.4 Landscape Dynamics: Impervious Cover Change

What: Estimates of past change in impervious cover, reflecting residential and commercial development (broadly "urbanization").

Why: Impervious cover change provides an indicator of ecosystem condition that includes impacts on the physical environment, both terrestrial (forests, agriculture) and aquatic (streams, rivers, lakes).

Summary: Impervious cover change in the DEWA/UPDE PACE has been substantial, impacting resources in a number of ways. The extent of this urbanization process has been documented using Landsat imagery augmented with higher resolution satellite and aircraft image data (e.g. digital orthophotos).

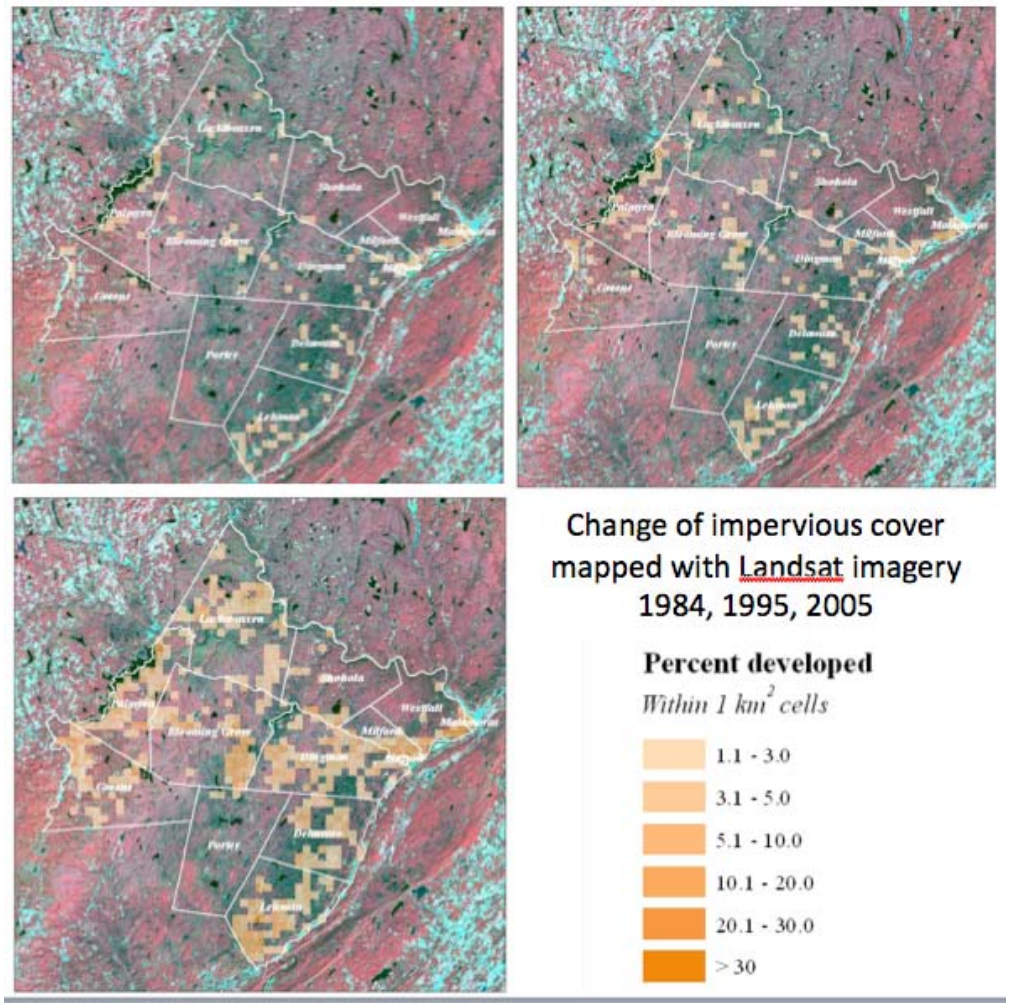


Figure xx. Impervious cover change between 1984 (upper left), 1995 (upper right) and 2005 (lower left) based on Landsat image analysis and interpretation (see SOP and Brown de Coulston et al. REF).

2.5 Landscape Dynamics: Future Scenarios of Impervious Cover

What: Estimates of past change in impervious cover, reflecting residential and commercial development (broadly "urbanization"), predicted into the future using the SLEUTH urban growth model.

Why: Impervious cover change provides an indicator of ecosystem condition that includes impacts on the physical environment, both terrestrial (forests, agriculture) and aquatic (streams, rivers, lakes). Future predictions are useful for assessing what additional changes might take place, under different scenarios, and the impacts those changes could have on park resources.

Summary: Predicted impervious cover change in the DEWA/UPDE region varies substantially depending upon the type of future scenario (business as usual / current trends, versus conservation or accelerated growth).

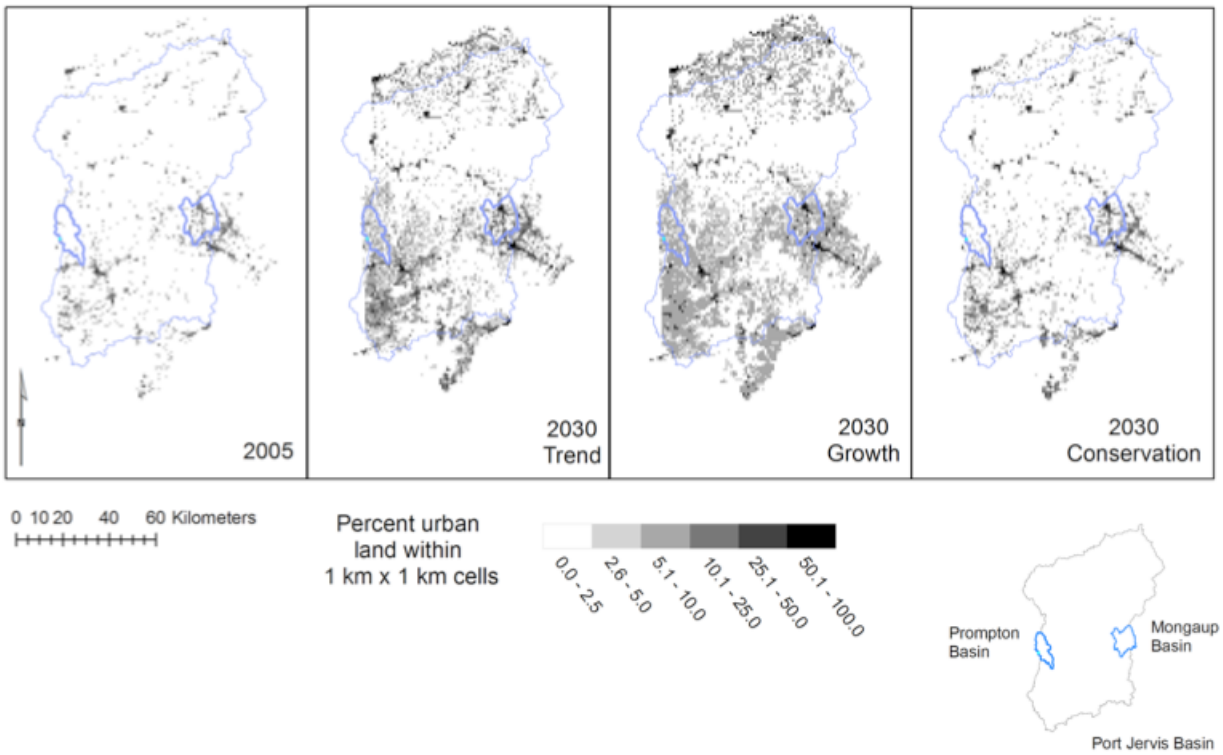


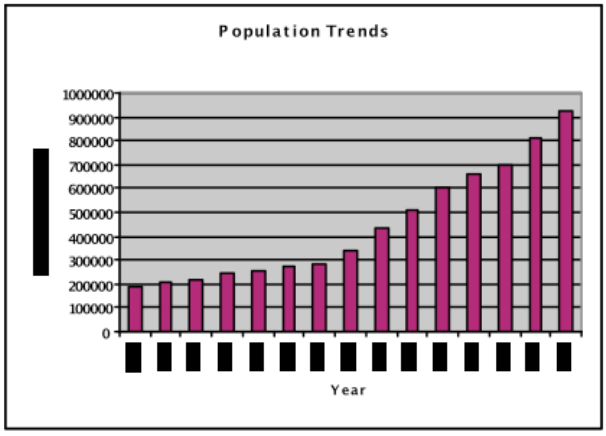
Figure xx. Change in impervious cover from year 2005 (left), as mapped with Landsat imagery (section 2.4), to year 2030 under a current trends scenario (2nd frame), an accelerated growth scenario (3rd frame) and a conservation scenario (right frame). Watersheds where hydrology modeling was calibrated and tested are outlined in light blue (see section 2.13).

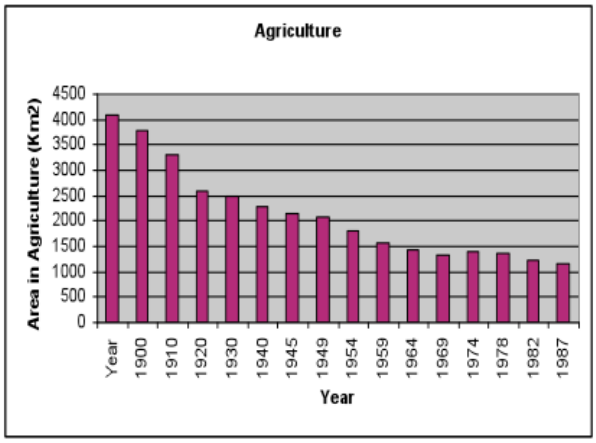
2.6 Landscape Dynamics: Land use within protected-area centered ecosystem

What: Metrics of land allocation and change in PACEs, including areas outside of the park boundaries. Developed lands included buffers of 1 km adjacent to agriculture or home densities>0.031 units/ha, 500 m from primary roads and railroads, and 100 m from secondary roads.

Why: These data provide indications of the requirements for maintaining park condition given the characteristics of the surrounding PACE.

Summary: Of the 9 parks analyzed nationally, DEWA / UPDE has the greatest proportion of developed and private lands, as well as high home densities, some portion of which was already established between 1940 and 2000. Some 84% of the PACE outside of the park is private land, a larger amount than for other PACEs. Nearly 98% of those private lands are in agriculture, roads, homes or other land uses termed "developed" or are with the buffers around development.





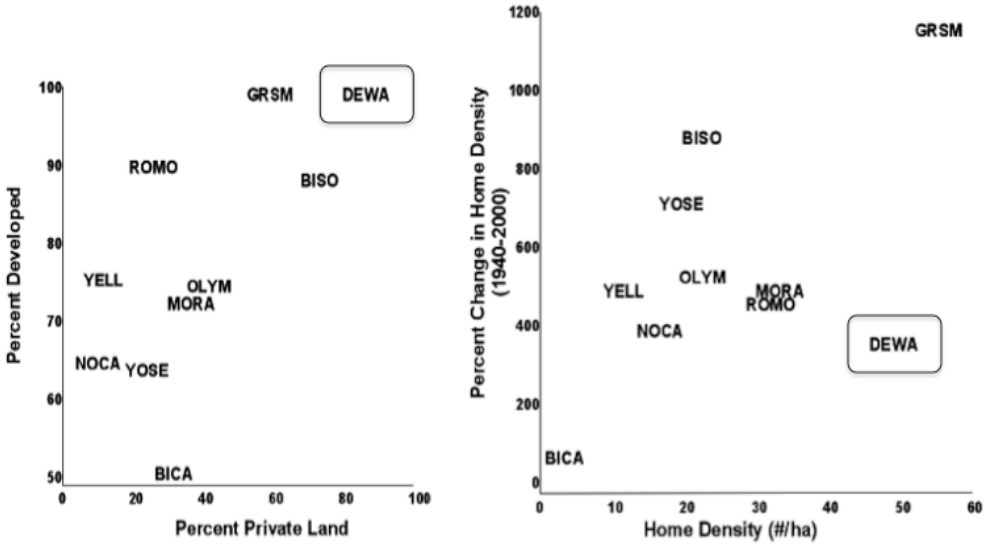


Figure xx. Location of the protected area centered ecosystems along (left) gradients in land ownership and land development (home densities of >0.031 units/ha, roads, or agriculture lands) and (right) home density (units/ha) and percent change in home density from 1940 to 2000.

2.7 Biological Integrity: Patterns of Natural Landscapes

What: Measures the natural landscape context developed using information on land cover modifications including presence of roads, human activities associated with developed land use, housing density and road use (traffic), as well as incorporating how the broader landscape context modifies local conditions.

Why: Landscape context is important for the movement of plants and animals, as well as for ecological processes that connect to adjacent landscapes beyond the park boundary.

Stressors: Land use change, climate change.

Summary: DEWA/UPDE lands score higher than the ecoregion in which they lie, meaning that they have more natural landscape than their surroundings, but this ratio has declined from 0.68 in 1992 to 0.66 in 2001, and is projected to decline to 0.61 by 2030.

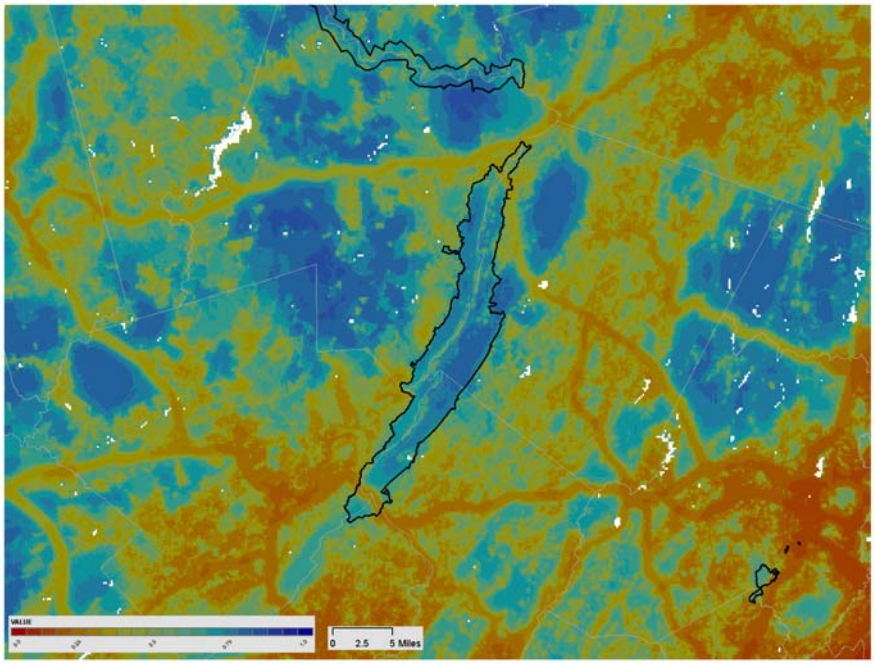


Figure xx. Metric of natural landscape (blue colors) relative to more human modified areas (red colors). Theobald et al (2010) provide more detail on the approach and assumptions.

2.8 Biological Integrity: Landscape Connectivity

What: Measures of the connectivity of habitat in natural landscapes.

Why: Habitat connectivity is relevant to the movement of plants and animals, as well as for ecological processes that connect to landscapes that may extend well beyond park boundaries.

Stressors: Land use change, climate change.

Summary: Core habitat areas identified in the DEWA/UPDE region were derived using various satellite image data products, the distance from roads and developed areas, and the natural landscapes maps (section 2.10). The connectedness of core habitat areas is high running through the center of the region, indicating a moderately high density of connectivity between high-value habitat areas along the Appalachian mountain chain.

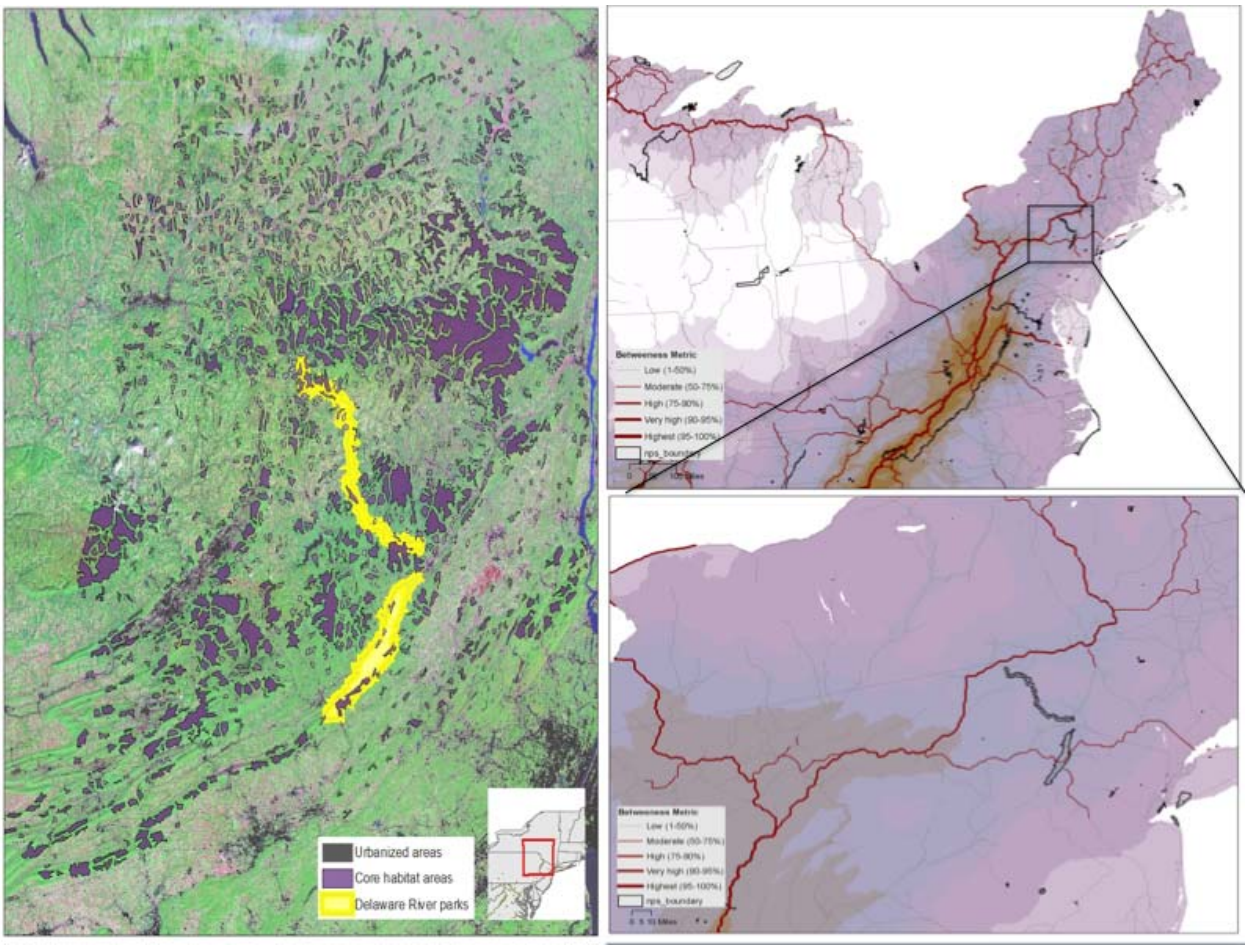


Figure xx. Connectivity of core habitat areas around DEWA/UPDE (left image) relative to connectivity of natural landscapes derived at the national scale (images on the right). Thicker red lines in the images at right show more cumulative movement assuming a theoretical terrestrial animal is moving across the landscape avoiding human-modified areas.

2.9 Biological Integrity: 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.

Summary: Most forest types have experienced dramatic net decreases relative to their presettlement state, including hemlock (–74%), oak (-71%) and riparian floodplain (-68%), wetland (-59%) and other forest ecosystem types. Losses on public lands have been substantially less than on private lands. Mean patch size has decreased substantially (>60%) in all of the ecosystem types. Mean distance to the next nearest patch of the same ecosystem type has decreased from 35% to 61% across ecosystem type classes.

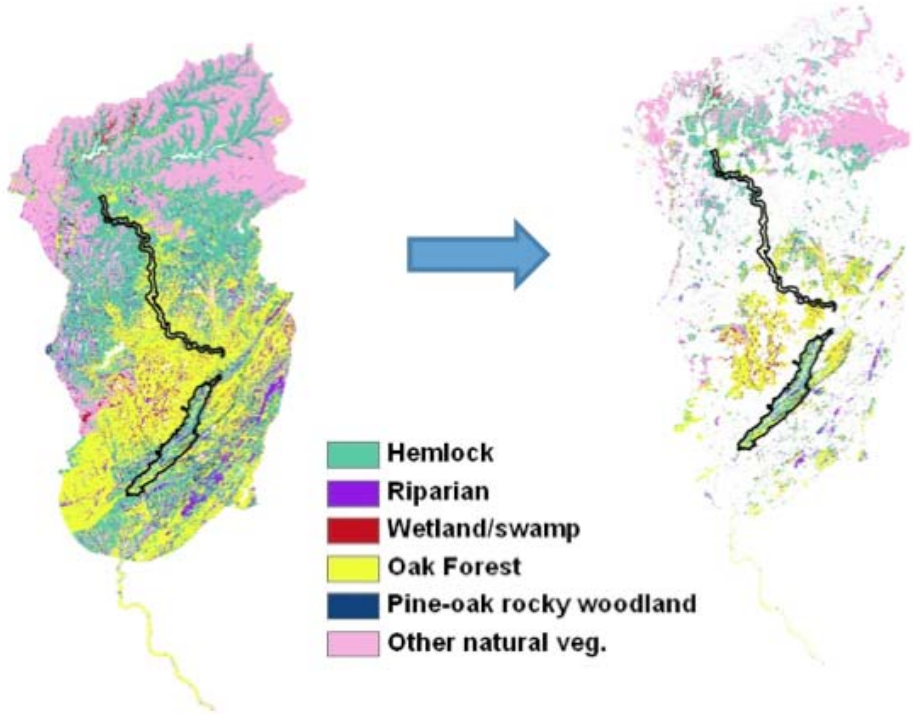


Figure xx. The loss of ecosystem type area due to current land uses including residential and agricultural development and transportation networks. Note on methods: the distribution of pre-settlement ecosystem types were mapped by the LANDFIRE program based on biophysical factors and modeled disturbance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

2.10 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.

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 has been calculated for DEWA-UPDE, and will include measures of the annual Start-of-Season anomaly, and graphs and plots to summarize trends in SOS by land cover type. 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.

2.11 Weather and Climate: Gridded Climate

(to be added - TOPS)

2.12 Weather and Climate: Climate Scenarios

(to be added - TOPS)

2.13 Water / Hydrology: Surface Water Dynamics

What: River gauge calibrated simulations of the hydrological dynamics of streams integrating small catchments, including overload flow (runoff) and baseflow.

Why: Hydrological dynamics are important not only for flood events, thus community planning and human safely, but also for stream bank erosion and aquatic life (biota).

Stressors: Land use change, climate change.

Summary: Small watersheds of the UPDE watershed have been influenced by exurban development and thus impact park resources and water quality. Increased impervious cover increases the flashiness of streams, i.e. producing greater runoff over shorter time periods and with shorter lag times while also decreasing the baseflow of streams, including during the periods between precipitation events. The former causes greater stream velocity, thus erosion and in-bank incision, while the latter impacts the aquatic life that streams can support.

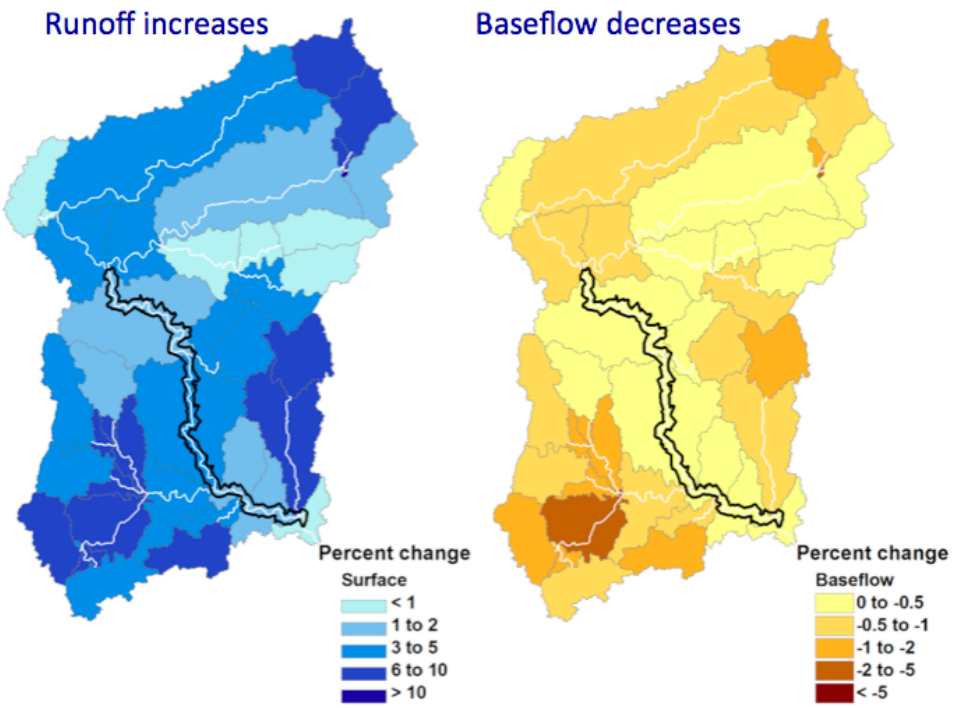


Figure xx. Predicted change (increase) in impervious cover from exurban development to year 2030 under a growth scenario (see section 2.5) impacts average monthly runoff (right image), and baseflow (right image) by sub-basin of the Upper Delaware watershed. The runoff and baseflow images are differences based on current conditions relative to a future scenario based on current growth trends. The predictions are based on use of the SWAT model, which was calibrated for a 25 year period using precipitation and river gauge data from 1981-2006.

2.14 Water / Water Quality: Aquatic Macroinvertebrates

What: Predicted indices of biological index of biotic integrity (B-IBI) and sensitive taxa (*Ephemeroptera*, *Plecoptera*, and *Tricoptera*).

Why: Stream biota, particularly sensitive taxa, provide good indicators of water quality and aquatic ecosystem integrity.

Stressors: Land use change, climate change, drought.

Summary: Small watersheds of the UPDE watershed, like anywhere else, are influenced by land cover and land use change, including residential development. Increased impervious cover tends to reduce water quality by increasing sediment and pollutant loads, as well as reducing baseflows, and each of these negatively impacts stream biotic indices. The predictions for the UPDE catchments were based on models developed in the mid-Atlantic region using Maryland's Biological Stream Survey (MBSS) and land cover data sets (see SOP). The model predictions need to be assessed using *in situ* measurements in the upper Delaware, and can be calibrated using those data sets, as they become available, if and as needed.

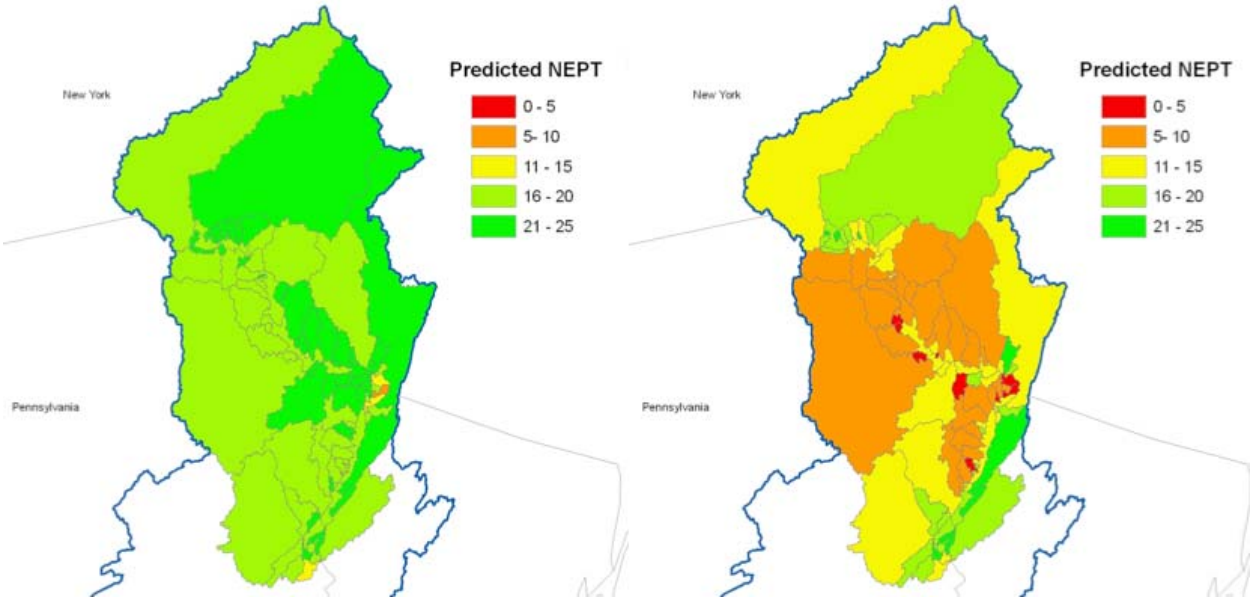


Figure xx. Predicted number of sensitive stream taxa (EPT) based on current (left) and future conditions (right). The latter incorporate changes in impervious cover from exurban development to year 2030 under an urban growth scenario (see section 2.5). Different sized catchments can be used for predictions at multiple scales, following the SOP.

3 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
  - Hydrofraking?
  - Powerlines?

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

Table 3. Trends in indicators developed for the Delaware Water Gap / Upper Delaware National Recreation Areas.

Level	**Category**	**Indicator**	**Trend Direction (recent past / future projected)**	**Trend magnitude (recent past / future projected)**
Landscape dynamics	Primary Production	TOPS GPP/NPP	?? / Decline	?? / Moderate
	Disturbance Events	Rapid change in Vegetation index	NA	NA
	Land Cover	Impervious Cover Change	Decline / NA	Moderate / NA
	Biological Integrity	Future Scenarios of Impervious Cover	NA / Decline	NA / Decline
		Population Density (decadal)	Increase / Increase	Moderate / Large
		Agricultural Area (decadal)	Increase / ??	Large / ??
		Rural Housing Density (decadal)	Increase / Increase	Moderate / Large
		Pattern of natural landscapes	NA	NA
	Weather and Climate	Landscape connectivity	Decline / Decline	Moderate / Large
		Ecosystem type composition	NA	NA
		Phenology (NDVI, annual anomaly)	NA	NA
Air and Climate	Hydrology	Climate gridded daily	NA	NA
		Climate scenarios (monthly)	NA	NA
		Surface Water Dynamics	NA / Variable	NA / Variable
Water	Water Quality	Aquatic Macroinvertebrates (Biological IBI, sensitive taxa)	NA / Decline	NA / Variable

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

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