LANDSCAPE CONDITIONS AND TRENDS IN AND AROUND Delaware Water Gap and Upper Delaware National Recreation Areas: Summary of Findings

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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 was 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 focused 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 our findings on landscape trends and conditions in and around the Delaware Water Gap and Upper Delaware National Recreation Areas. After a short introduction, the report highlights results for each of the indicators evaluated, and 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 pre-settlement 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 values, 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.

Table of Contents

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, the 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 was 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 were to:

1. (a) Identify NASA and other products useful as indicators for NPS I&M monitoring
   (b) Delineate the boundaries of the surrounding park-centered ecosystems (PACE) 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 framework for supporting management decisions.

The project focused on four sets of national parks to develop and demonstrate the approach: Delaware Water Gap and Upper Delaware National Recreation Areas, Rocky Mountain National Park, Sequoia Kings Canyon and Yosemite National Parks, and Yellowstone and Grand Teton National Parks.

As part of this project we reviewed and interpreted study results with NPS collaborators through a series of on site meetings, workshops and conference calls. These included review of the initial results with core NPS I&M collaborators, and interpretation and synthesis of a fuller set of results to identify key trends and management challenges. The final results are available to the fuller NPS staff associated with each park, as well as others within the NPS and the general public at this web site: *http://science.nature.nps.gov/im/monitor/lulc/palms*.

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 developed by the project and status is listed in Table 1. We first present patterns of change in key indicators from past to present, and potential future change. In section 2 we summarize these trends, in direction and magnitude, their links with one another, and highlight some of the indicators that appear to have the largest potential implications for park management.

Table 1. Indicators for the Delaware Water Gap / Upper Delaware National Recreation Areas. All indicator products are available at the PALMS web site and where otherwise indicated (science.nature.nps.gov/im/monitor/lulc/palms).

Level	Category	Indicator	Size/Period	SOP[1] and Reference
Landscape dynamics	Monitoring area	Protected area centered ecosystem boundaries	30 m	Hansen et al. 2011 Piekielek et al. 2010a,b SOPs
	Primary Production	TOPS Gross & Net Primary Productivity (GPP/NPP)	1 km daily and/or monthly summaries; 2000-2008	Melton et al. SOP Nemani et al. 2008
	Disturbance Events	Rapid change in Vegetation Index	1 km Monthly anomalies	Nemani et al. 2008
	Land Cover	Impervious Cover Change	30m 1984-2005	Goetz et al. SOP Jantz et al. 2009
		Future Scenarios of Impervious Cover	1km 2010-2030	Jantz et al. 2007 Jantz et al. 2010
		Population Density (decadal)	1 km 1900-2007	Davis and Hansen *submitted*
		Agricultural Area (decadal)	1 km 1900-2007	Davis and Hansen *submitted*
		Rural Housing Density (decadal)	1 km 1992-2030	NPScape SOP Theobald forthcoming
	Biological Integrity	Pattern of natural landscapes	270 m circa 2000	Theobald SOP Theobald 2010
		Landscape connectivity	30 m, 270 m, 1km; circa 2000	Goetz et al. 2009 Jantz & Goetz 2008 Theobald 2010
		Ecosystem type composition	30 m Presettlement - present	Piekielek et al. 2010c SOP
Air and Climate	Weather and Climate	Phenology (NDVI, annual anomaly)	1 km 8 & 16 day; 2000-2008	Melton et al. SOP Nemani et al. 2008
		Climate gridded daily	1 km 2000-2008	Jolly et al., 2004
Water	Hydrology	Surface Water Dynamics	Catchment 2005, 2030	Goetz et al. *in prep*.
	Water Quality	Aquatic Macroinvertebrates (Biological IBI, sensitive taxa)	Catchment 2005, 2030	Goetz et al. 2008; Goetz et al. *in press*; Goetz and Fiske, SOP

2 Overview of Findings: Trends and Predictions of Park Condition

The PALMS project set of observations, hindcasts and forecasts of ecosystem condition, as summarized by the indicators in Table 1, are diverse and dynamic (see Table 2). Overall the combination of near-term observations and reconstructions document historical transitions in land use across the greater DEWA – UPDE park area centered ecosystem (PACE). These include well-documented historical increases in population density and agricultural area, associated with changes in ecosystem type composition and the spatial patterns of land use. Moreover, statistical analyses of the historical climate data from meteorological stations indicate that the UPDE – DEWA PACE has experienced a 2 degree (celsius) rise in mean annual temperature, which is third highest among the 56 US Natonal Parks analyzed (Haas 2011). These historical changes were accompanied by more recent increases in rural housing density and impervious cover that, in turn, were associated with declines in landscape (habitat) connectivity and changes in the pattern of the natural landscape. They were also associated with changes in surface water dynamics and related indicators of water quality (e.g. aquatic macroinvertebrate richness and sensitive taxa), documented primarily through calibrated model simulations.

Moreover, our simulations of future land use change, primarily rural residential and commercial development (and associated impervious cover change), developed extensively through consultations with many local stakeholders (Jantz et al. 2009), provide further insights into how various indicators of ecological processes (i.e. landscape connectivity, patterns of natural landscapes, surface water dynamics, aquatic biota, ecosystem type composition) may be influenced by different future land management decisions. When coupled with TOPS, the changes in land use are translated into changes in surface water dynamics, phenology, disturbance anomalies and landscape productivity (primarily via forest replacement with a matrix of more residential land use). The trends towards declining landscape connectivity, increased population and housing density will likely lead to greater impervious cover. The ecological consequences of these changes will likely be 'flashier' runoff patterns, increased variation in stream and river flows, and a loss of native aquatic macrointertebrates (see Goetz references).

Together these coupled observations and model simulations provide a powerful set of tools for assessing potential future impacts of land use change in the unique protected area centered ecosystem of the UPDE and DEWA natural recreation areas, and so informing management decisions. A range of additional indicator variables that we have compiled as part of the current activity, including historical meteorological and gridded climate data, are available to inform and facilitate these efforts.

In the sections that follow we document the various indicators in more detail. The intent here is not to provide a detailed description or background of the indicators or their derivation – that information can be found in the cited references, the standard operating procedures (SOPs) and, to a lesser extent, the resource briefs the project has produced (all available at the PALMS website: *http://science.nature.nps.gov/im/monitor/lulc/palms*). Whereas these various indicators and the online resources supporting them have utility for informing management decisions, e.g. by portraying past and potential changes and their ecological implications, they can only do so in the context of larger management objectives and local policy realities that require compromise from the many stakeholders involved in ensuring the continued viability of this protected area centered ecosystem.

Table 2. Past and predicted trends of indicators: Delaware Water Gap / Upper Delaware National Recreation Areas. Indicators with substantial trend directions and magnitudes are highlighted.

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

Individual Indicator Summaries

2.1 Delineating Protected Area Centered Ecosystems

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 condition.

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 criterion tended to overlap moderately in the DEWA/UPDE PACE, with 63% of the PACE covered by two or more criteria.

Figure: Gradations in color in the PACE outside of the parks indicate the number of overlapping classification criteria. Criteria 1 watershed = boundary; 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. Spatial characteristics of area covered by each criterion used to define the DEWA/UPDE PACE (km^2), and the proportion of the PACE uniquely covered by each criteria.

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: Gross primary production (GPP) and measures patterns and trends in annual 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: Results for the DEWA-UPDE parks and PACE indicate an overall decline in annual GPP since 2001 for both the area contained by the DEWA park boundary and the PACE, though the time series is relatively short. UPDE shows fewer regions with significant trends. The observed pattern is likely the results of recent infestations in the region by Hemlock woolly adelgid (*Adelges tsugae*), though climate and land use change may also be potential drivers. This indicator relies on the use of MODIS data, and the TOPS implementation of the Biome-BGC model (Wang et al., 2009). Summaries of the patterns and trends by land cover type are available at http://ecocast.arc.nasa.gov/dgw/dboard/ERMN. Production of the data set will continue under the NASA Earth Exchange (NEX) project for the foreseeable future.

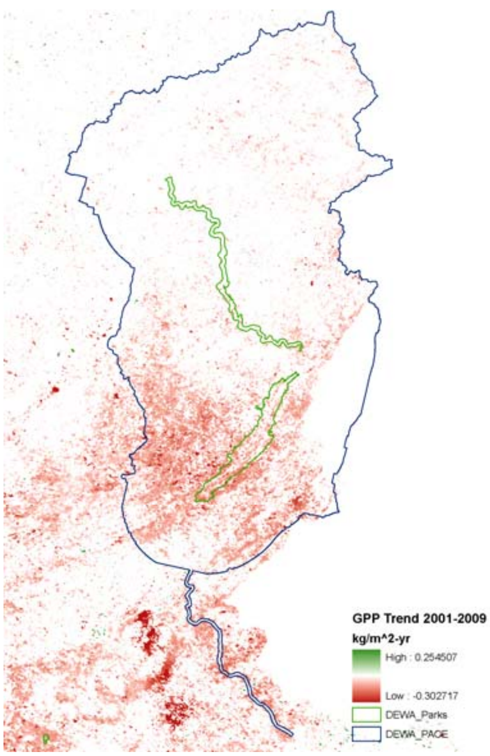


Figure a: Trend in annual GPP between 2001-2009.

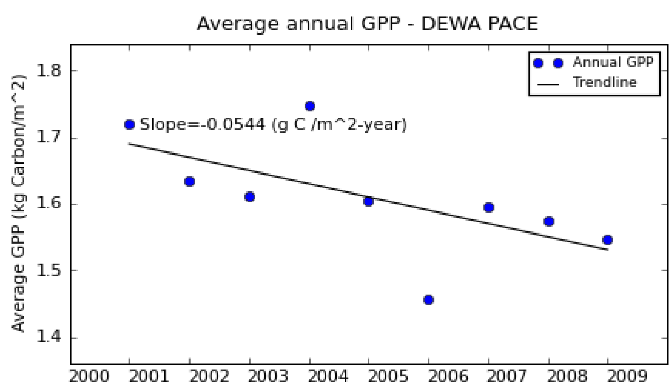


Figure b: Average annual GPP for the DEWA PACE region for 2001-2009. A linear trend line is provided for reference.

Figure: Observed trends in Gross Primary Productivity (GPP) simulated from the TOPS / Biome-BGC model (Fig a) for the region including the DEWA and UPDE parks, and the DEWA PACE. Since the time series is short, trends have been filtered for statistical significance. The average annual GPP for the DEWA PACE has also been calculated for 2001-2009 (Fig b), with a linear trend line fitted for reference.

2.3 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 DEWA. 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 widespread anomalies in NDVI for the period from 2001-2009, with generally less than 5% of the park experiencing a monthly anomaly that departs from historical normals by more than 2.0 standard deviations (Figure a). A recent anomaly map from July, 2010, shows relatively few anomalies within the DEWA-UPDE park boundaries relative to the 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).

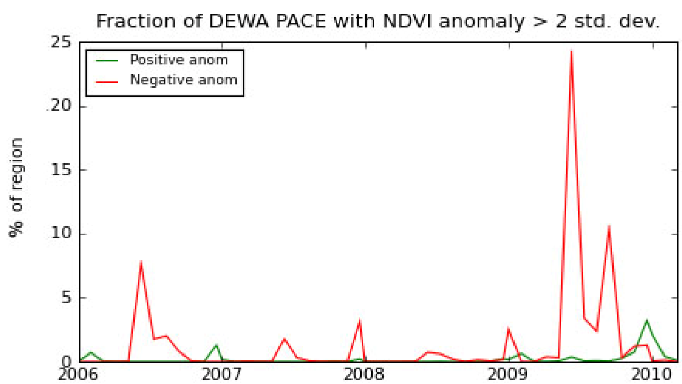


Figure a: The fraction of the DEWA PACE exhibiting an NDVI anomaly departing from historical normals (calculated from 2001-2008) by more than two standard deviations (a), and a normalized NDVI anomaly map for July, 2010, showing anomalies greater than 2.0 standard deviations for DEWA-UPDE PACE (b).

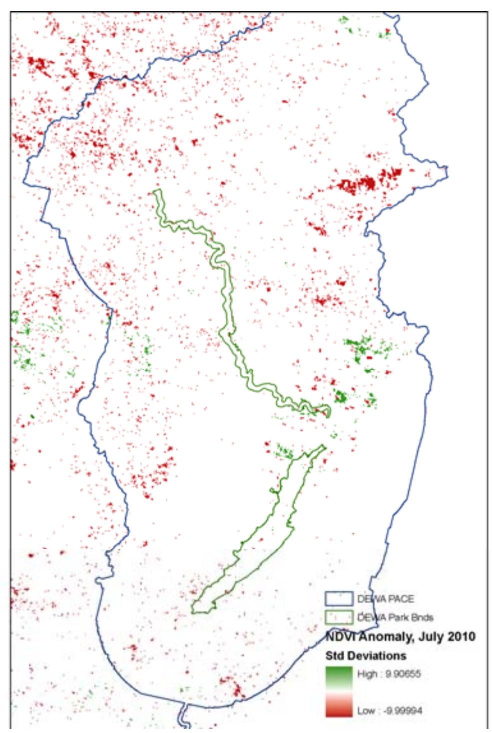


Figure b: Normalized NDVI Anomaly for July, 2010 (units are in standard deviations).

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). Stream life is impacted when impervious cover exceeds 10% across the watershed that drains into it (see Goetz references).

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). Increases in urbanization of this magnitude impact stream life, water quality, bank erosion, sedimentation and the risk of flooding events.

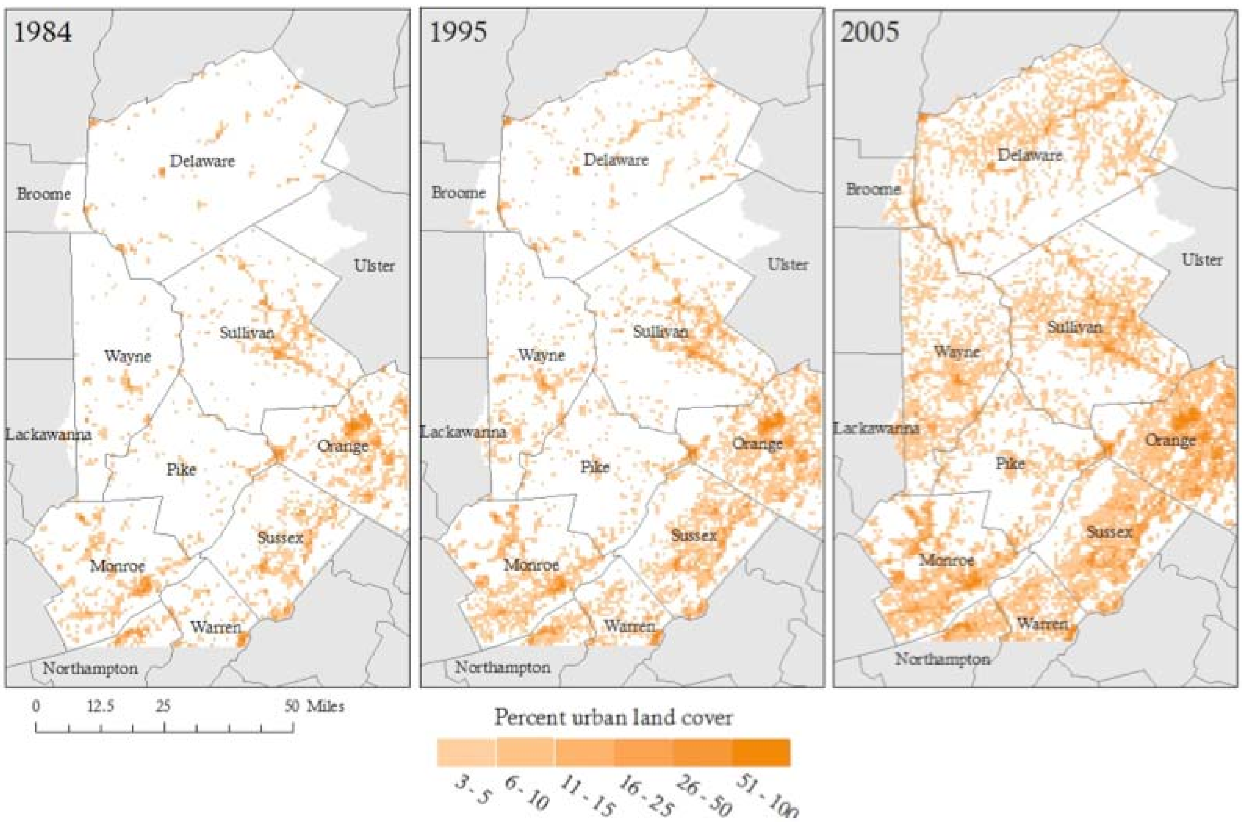


Figure: Impervious cover change between 1984 (left), 1995 (center) and 2005 (right) based on Landsat satellite image analysis and interpretation (see SOP and Jantz et al. 2008).

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. Values presented in the figure are aggregated to 1km cells because model predictions are inaccurate at fine resolution, such as those derived from satellite imagery (shown in section 3.4).

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). If urbanization continues the current trend or otherwise fails to incorporate some land conservation, impacts on streams and waterways are very likely. This is true even with mitigation from retention ponds and stream buffers since communities are directly connected to streams via storm drains.

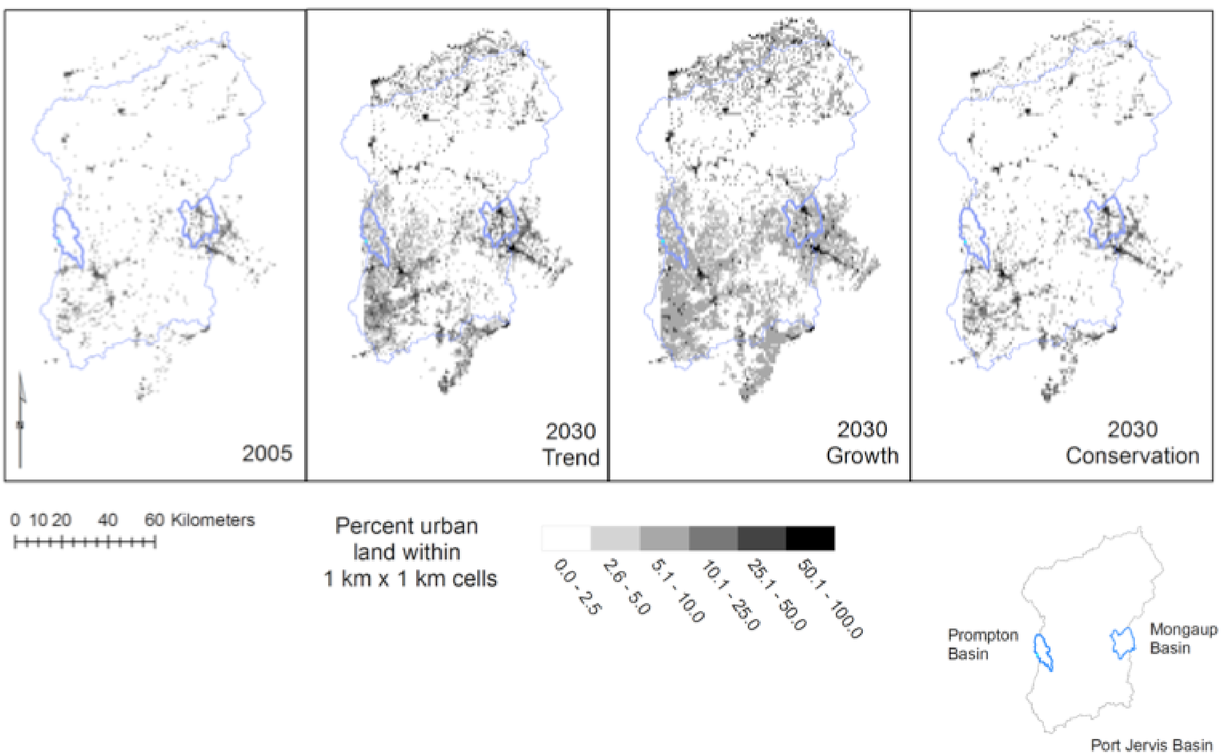


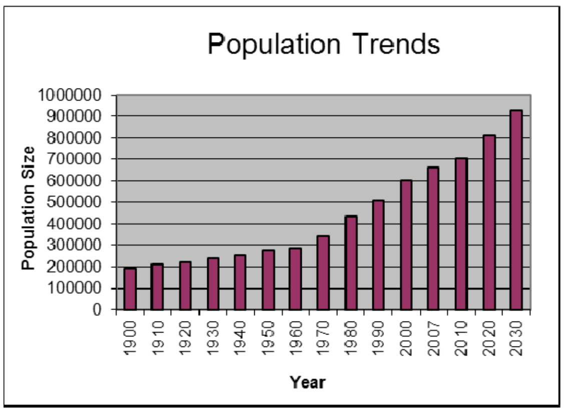
Figure: Change in impervious cover from year 2005 (left), as mapped with Landsat imagery (section 2.4), to year 2030 under a current trends scenario (2nd frame), an accelerated growth scenario (3rd frame) and a conservation scenario (right frame). Watersheds where hydrology modeling was calibrated and tested are outlined in light blue (see section 3.12).

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.



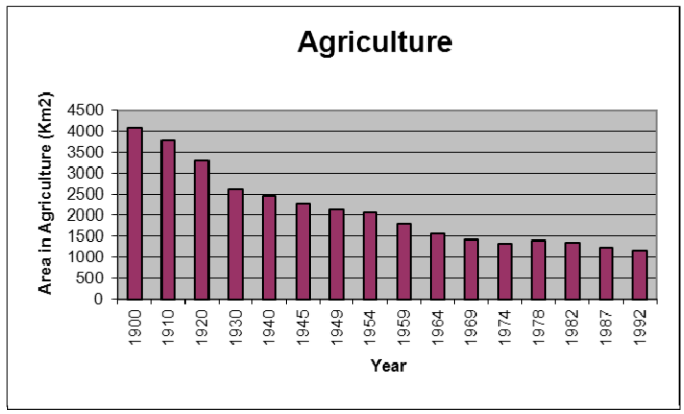
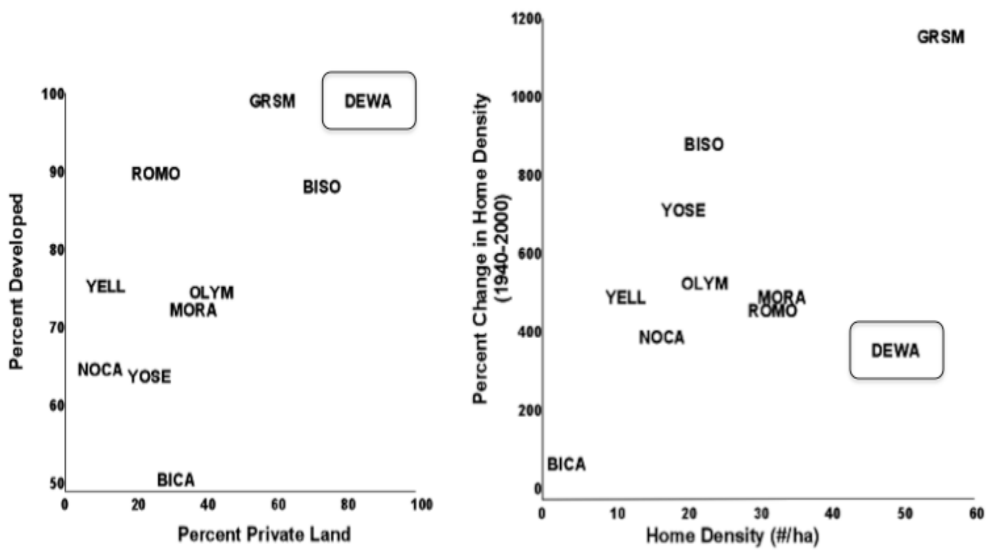


Figure: Location of the PACE along (left) gradients in land ownership and land development (home densities of >0.031 units/ha, roads, or agriculture lands) and (right) home density (units/ha) and percent change in home density from 1940 to 2000.



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.

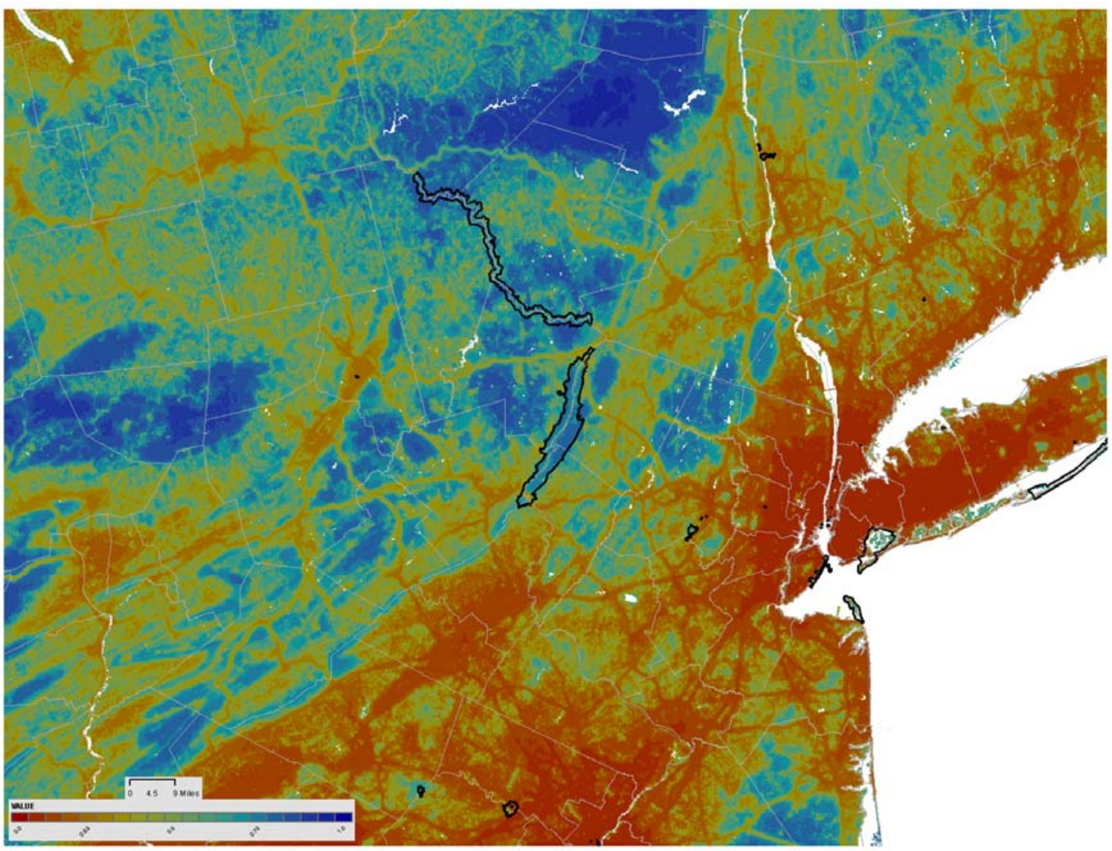


Figure: Metric of natural landscape (blue colors) relative to more human modified areas (red colors). Theobald et al (2010) provide more detail on the approach and assumptions.

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.

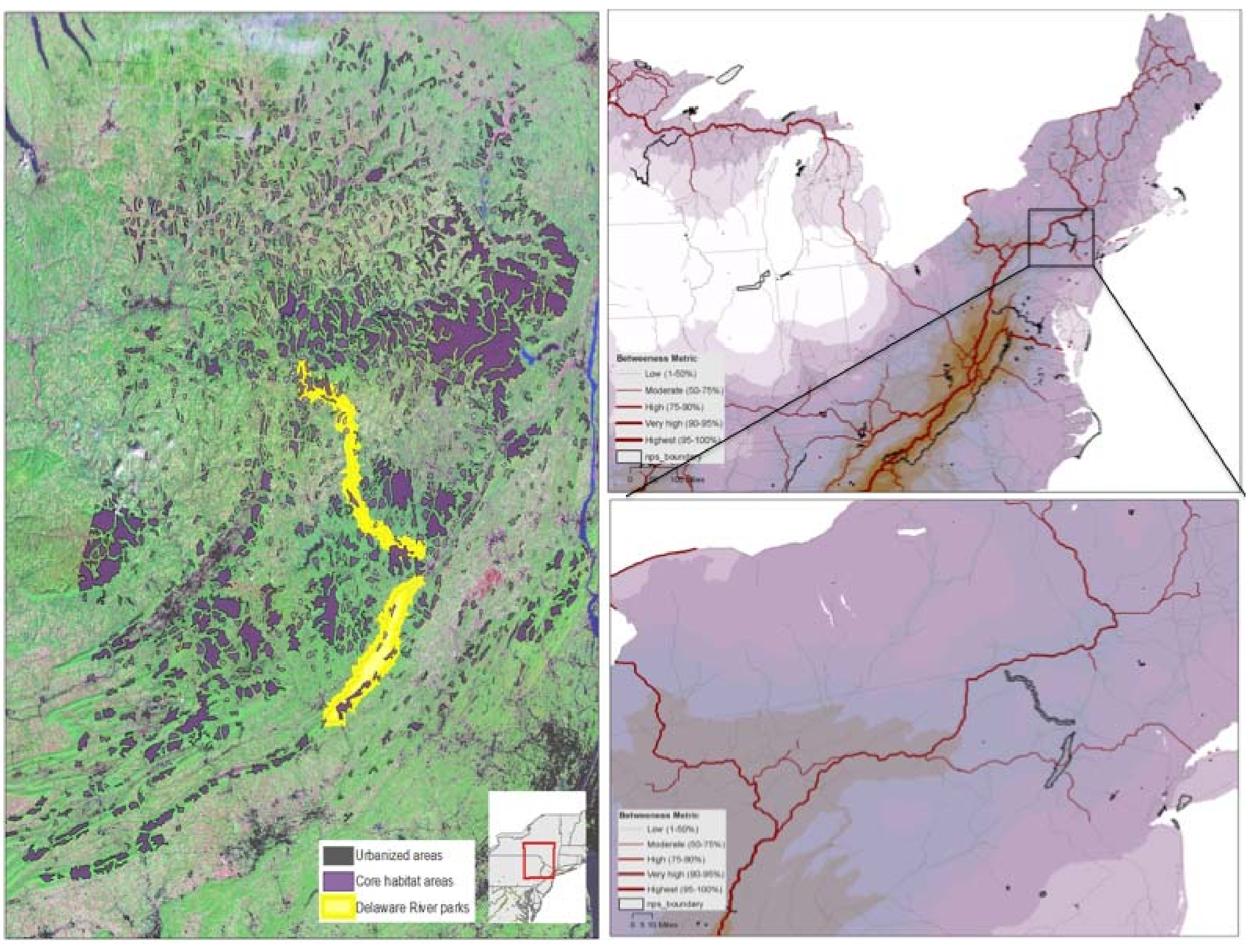


Figure: Connectivity of core habitat areas around DEWA/UPDE (left image) relative to connectivity of natural landscapes derived at the national scale (images on the right). Thicker red lines in the images at right show more cumulative movement assuming a theoretical terrestrial animal is moving across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

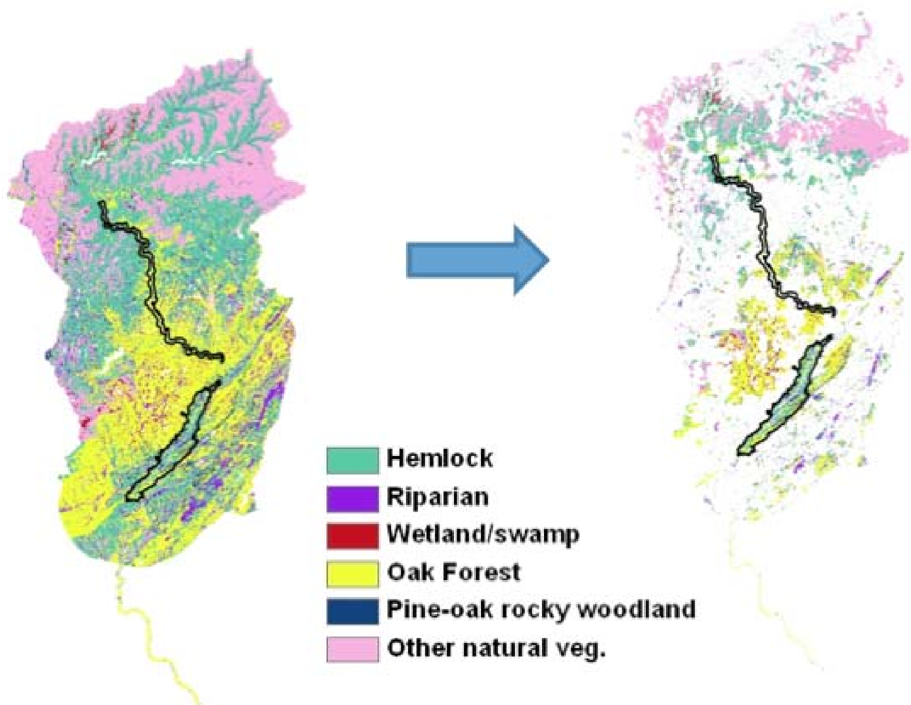


Figure: The loss of ecosystem type area due to current land uses including residential and agricultural development and transportation networks. Note on methods: the distribution of pre-settlement ecosystem types were mapped by the LANDFIRE program based on biophysical factors and modeled disturbance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

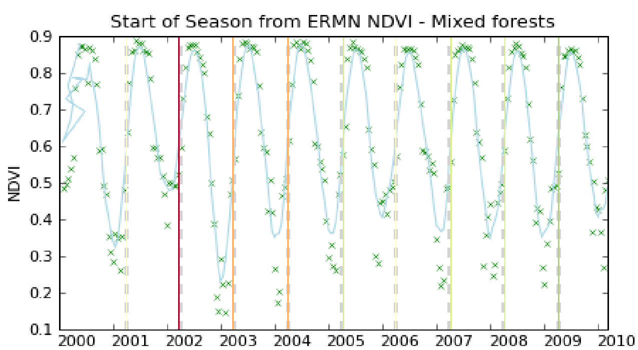
2.10 Weather and Climate: Landscape Phenology

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

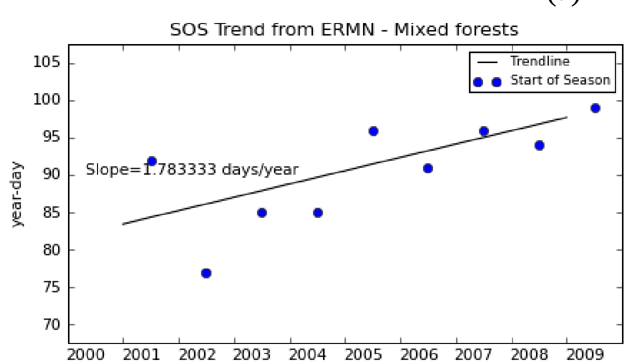
Why: Sustained shifts in vegetation phenology are a predicted consequence of climate change. Satellite-derived phenology indicators provide a useful supplement to surface measures, which may track only a subset of plant species.

Stressors: Climate change, land use change, drought

Summary: This indicator has been calculated for DEWA-UPDE and the DEWA PACE region, and include measures of the annual Start-of-Season (SOS) relative to historical averages, and graphs and plots to summarize trends in SOS by land cover type (http://ecocast.arc.nasa.gov/dgw/dboard/ERMN). While the time series is relatively short, the indicator captures the internannual variability over the last ten years, providing a baseline for detection of future trends. The indicator provides 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)



(b)

Figure: The NDVI time series for the ERMN region is shown for 'mixed forest' land cover types (a), with dashed lines representing the historical average SOS date for the region. The average SOS date for mixed forests within the ERMN region is shown, with a linear trend line plotted for reference. Average SOS dates for mixed forests have ranged from March 16 (day 75) in 2002 to April 10 (day 100) in 2009 (b), with a series of later than average SOS dates since 2005 (b). Summaries for additional regions and land cover types are available at: http://ecocast.arc.nasa.gov/dgw/dboard/ERMN.

2.11 Weather and Climate: Gridded Climate

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

Summary: This indicator has been calculated for DEWA-UPDE and the DEWA PACE region for the 30-year period from 1980-2009, and as expected, indicates that patterns observed in the DEWA and UPDE parks are similar to patterns within the overall PACE. Trends in the annual average daily maximum temperature and cumulative precipitation indicate an increase for the region, while trends in minimum temperature indicate a decrease in minimum nighttime temperatures. The spatial patterns shown in Figure 10 also capture the variability in trends for the region surrounding the DEWA 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.

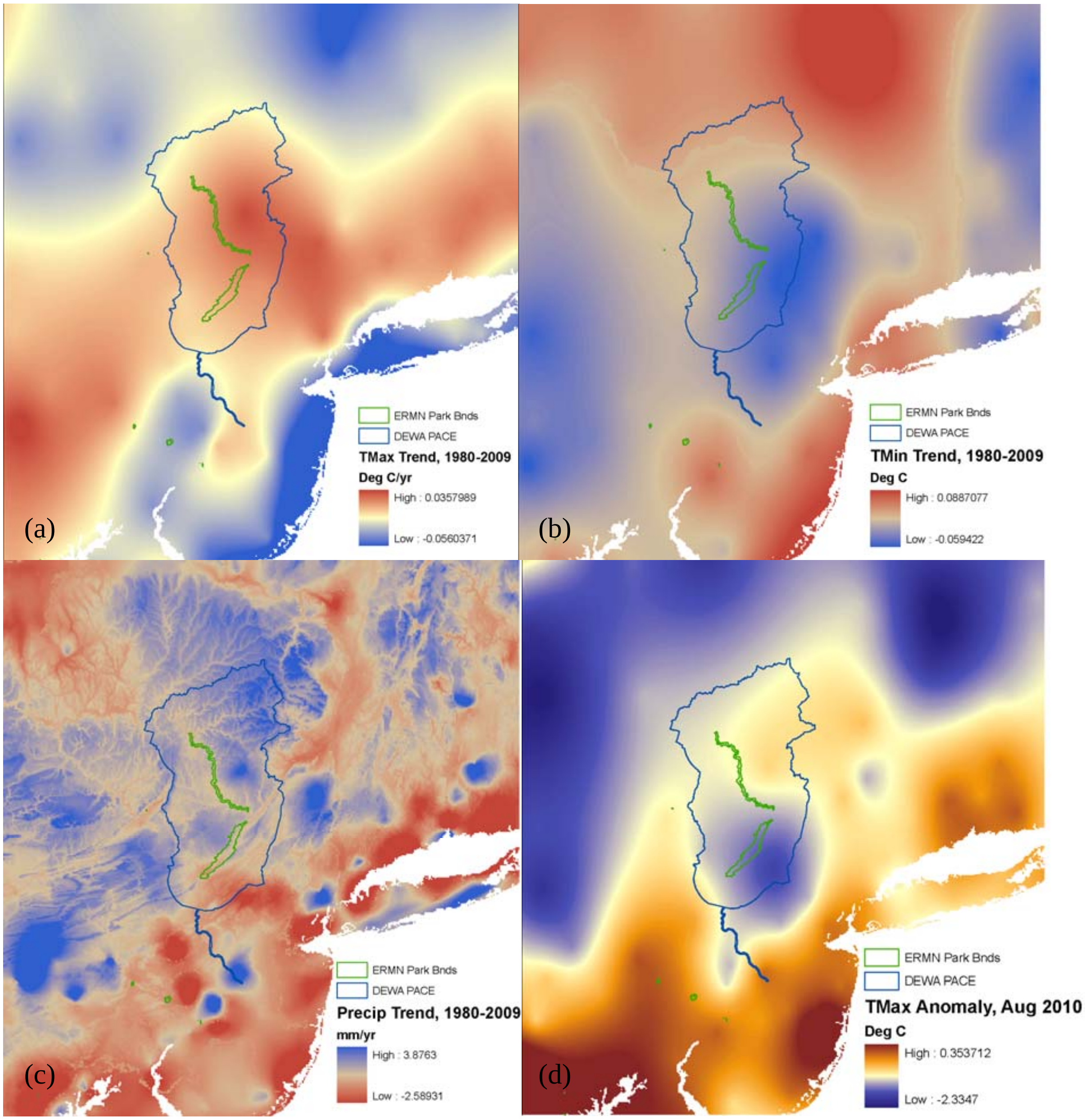


Figure a-d: Trends for the thirty-year period from January 1, 1980 through December 31, 2009 are shown for the annual average daily maximum temperature (a), annual average daily minimum temperature (b), and annual cumulative precipitation (c). In addition, an example of a monthly anomaly map (current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

2.12 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.

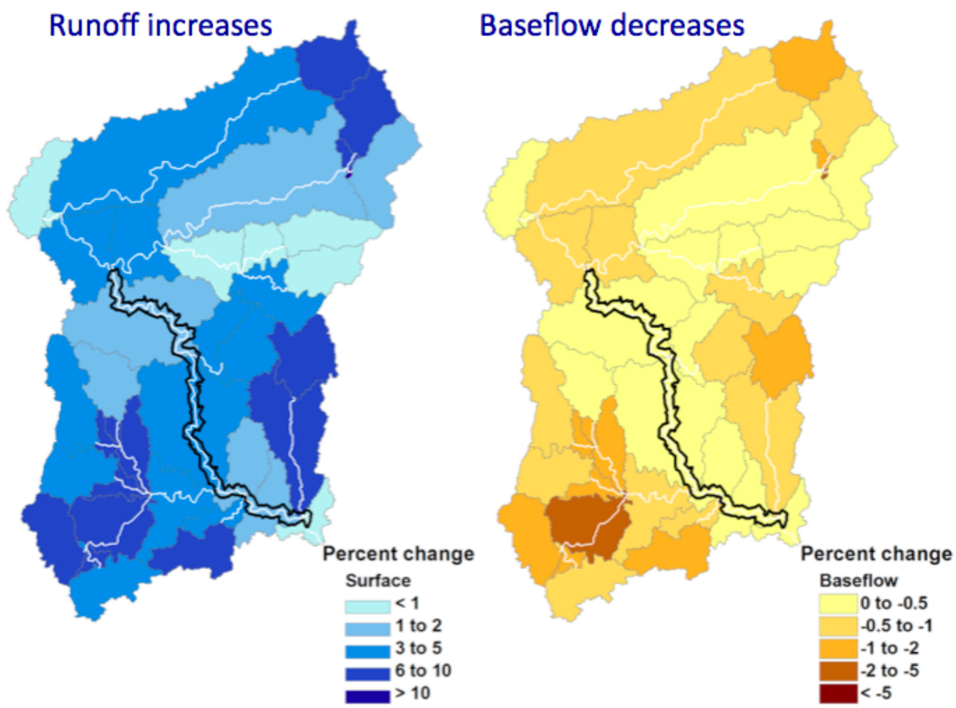


Figure: Predicted change (increase) in impervious cover from exurban development to year 2030 under a growth scenario (see section 2.5) impacts average monthly runoff (right image), and baseflow (right image) by sub-basin of the Upper Delaware watershed. The runoff and baseflow images are differences 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.

2.13 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.

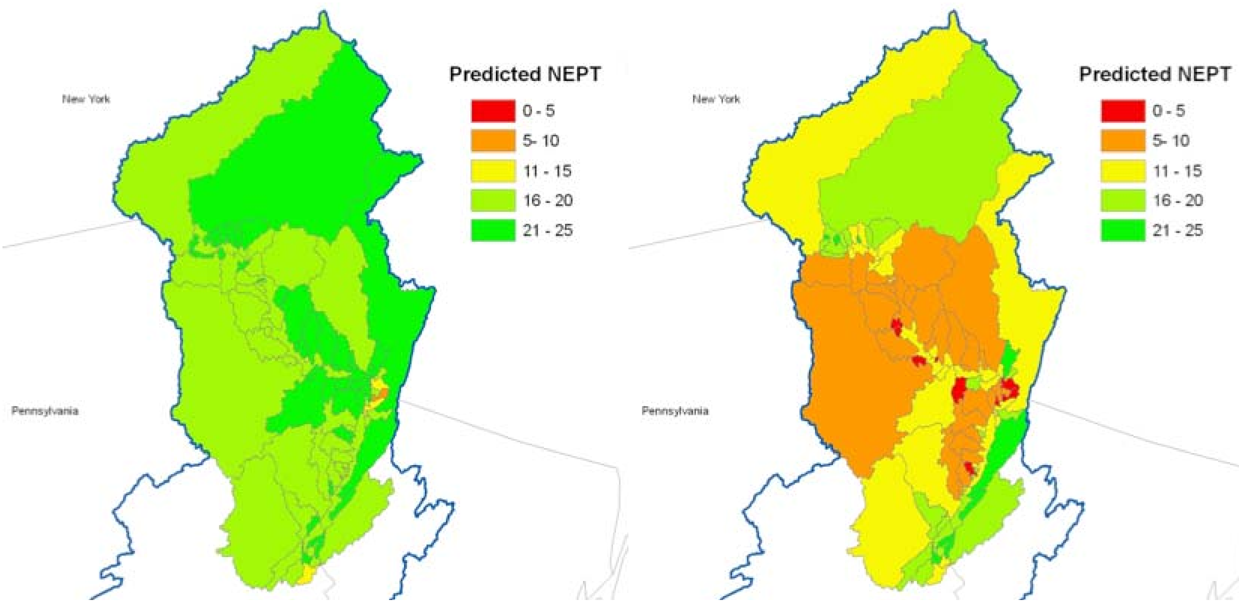


Figure: Predicted number of sensitive stream taxa (NEPT) based on current (left) and future conditions (right). The latter incorporate changes in impervious cover from exurban development to year 2030 under an urban growth scenario (see section 2.5). Different sized catchments can be used for predictions at multiple scales, following the SOP (Goetz and Fiske 2010).

3 Future Prospects

We have documented human transformation of the landscape and associated ecological systems of the UPDE – DEWA national recreation areas, including the larger protected area centered ecosystem (PACE). Future potential lines of applied research include exploring the coupled interactions of the human environment and climate system with changes in the patterns of productivity and other landscape-scale biophysical properties and processes – perhaps extending to and incorporating additional parks within the Eastern Rivers and Mountains Network. The TOPS framework, in particular, has the potential to allow one to take the land use scenarios a step further by incorporating the influences and impacts of various climate change scenarios. The latter is an avenue of research that was not a primary focus of the PALMS activity to date, but one we hope to investigate in future collaboration with the NPS I&M program across a broader range of NPS networks. This work, as well as other specific UPDE – DEWA concerns and emerging management challenges (such as hydro-fracture mining for natural gas, hemlock wooly adelgid infestations, and the impact of climate change on native trout populations) can be informed in real and meaningful ways by incorporating a range of NASA-supported Earth System Science data products and associated models.

4 References

Davis, C., & Hansen, A. (submitted). Land-use change around U.S. National Parks. *Ecological Applications.*

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. (in press). 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. (forthcoming). 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.

Haas, J. 2011. Quantifying change in our National Parks: An analysis of climate change and ecosystem productivity. M.S. Thesis. University of Montana, Missoula, MT.

Hansen, A., Davis, C., Piekielek, N., Gross, J., Theobald, D., Goetz, S., Melton, F. & Defries, R. (in press) Delineating the Ecosystems Containing Protected Areas for Monitoring and Management. *BioScience*.

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, C.A., M. Mrozinski and E. Coar (2009) Forecasting Land Use Change in Pike and Wayne Counties, Pennsylvania. 45 pages.

Jantz, C.A. and Goetz, S.J. (2007). Can Smart Growth Save the Chesapeake Bay? *Journal of Green Building* 2 (3): 41-51.

Jantz, P. and 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.

Jolly, W. M., J. M. Graham, A. Michaelis, R. Nemani, and S. W. Running. 2004. A flexible, integrated system for generating meteorological surfaces derived from point sources across multiple geographic scales. Environmental Modelling & Software 20:873-882.

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.

National Park Service. 2010. NPScape housing measure – phase 1 metrics processing SOP: Current housing density, historic housing density, and projected housing density metrics. National Park Service, Fort Collins, Colorado. Natural Resource Report NPS/NRPC/IMD/NRR—2010/251. 40 pages.

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. 2010a. PALMS SOP - Estimating 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. 2010b. PALMS SOP - Analyzing Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. (10 MB)

Piekielek, N.B., C. Davis and A. Hansen. 2010c. 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* 25:999-1011

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.

Theobald, D.M., S.E. Reed, K. Fields, and M. Soule (submitted). A map of natural landscape connectivity to prioritize conservation activities in the US. *Science*.

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.