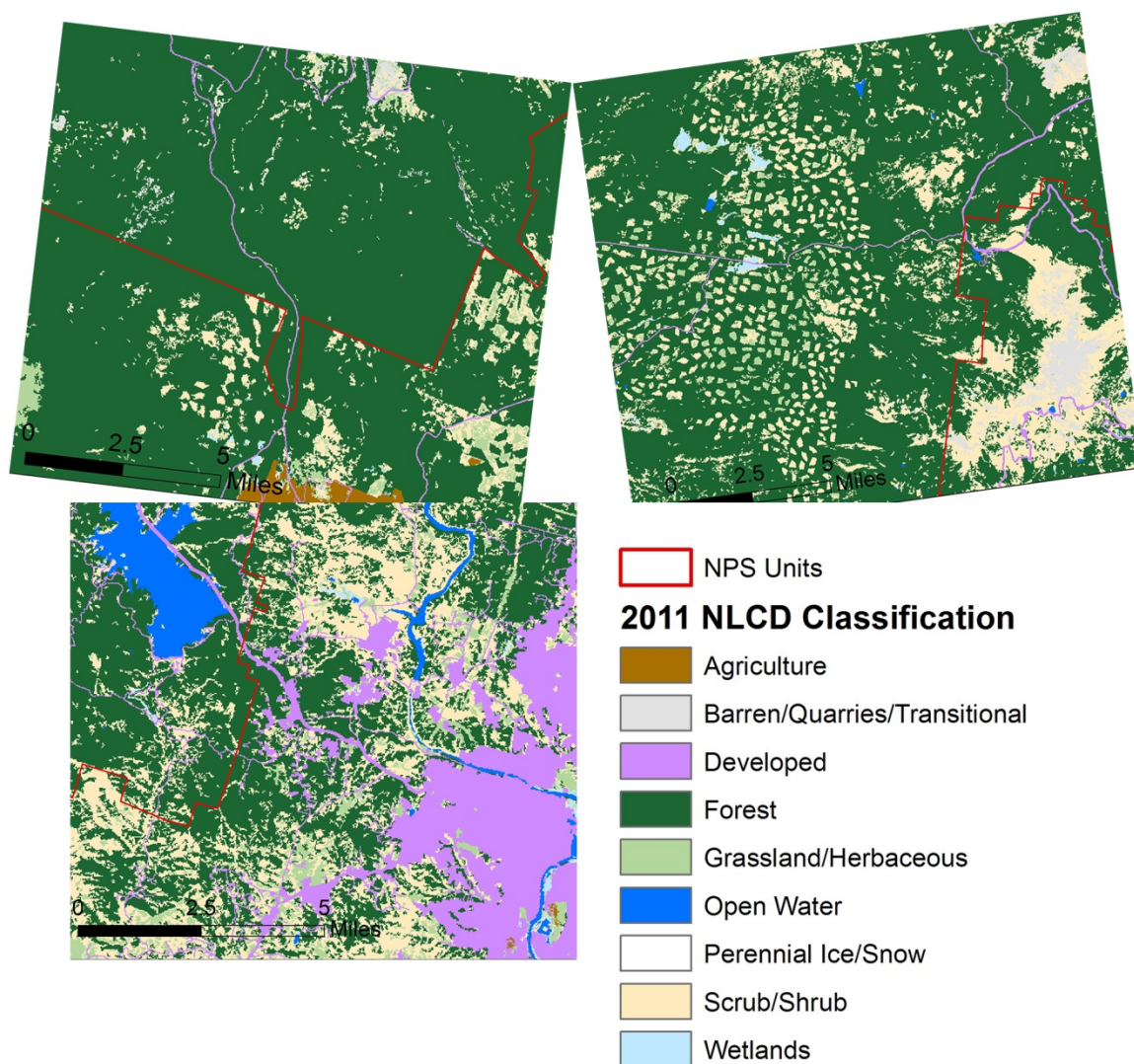




Land Cover and Land Use Monitoring Protocol for the Klamath Network

Narrative

Natural Resource Report NPS/KLMN/NRR—2016/1342



ON THE COVER

National Land Cover Database imagery for: southeastern Crater Lake National Park (top, left), eastern Whiskeytown National Recreation Area (bottom), and northwestern Lassen Volcanic National Park (top, right), showing probable human impacts in the form of development near the boundaries of these parks.

Map image design by: Lorin Groshong, Southern Oregon University

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information. Standard operating procedures associated with this protocol received the same level of review as the protocol narrative but are stored as self-published documents on the National Park Service Integrated Resources Management Applications web portal.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Klamath Network website (<http://science.nature.nps.gov/im/units/klmn/monitor/landcover.cfm>) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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List of Standard Operating Procedures (SOPs)

Standard Operating Procedures associated with this protocol are available as a collection in a separate document not published in the Natural Resource Report series. The document is available from the NPS Integrated Resource Management Applications portal (IRMA) using this clickable link:

[Mohren, S. R., L. C. Groshong, D. A. Sarr, A. Snyder, and A. Chung-MacCoubrey. 2016. Land cover and land use monitoring protocol for the Klamath Network: Standard operating procedures. National Park Service, Klamath Inventory and Monitoring Network, Ashland, Oregon.](#)

SOP 1: Preparation and Data Acquisition

SOP 2: Conservation Status Metrics

SOP 3: Land Cover Metrics

SOP 4: Pattern Metrics

SOP 5: Housing Metrics

SOP 6: Population Metrics

SOP 7: Road Metrics

SOP 8: Disturbance Metrics

SOP 9: Data Management

SOP 10: Analysis and Reporting

SOP 11: Revising the Protocol

Protocol Narrative Revision History

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Executive Summary

The overall purpose of natural resource monitoring in national parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems to help park managers and resource specialists better understand the ecosystem they are managing.

The Klamath Network vital signs selection process defined important questions regarding potential trends in ecosystem structure, function, and composition in the parks (Odion et al. 2005). Ten vital signs were selected by National Park Service (NPS) management staff and resource specialists and included: Exotic and Invasive Plant Species, Terrestrial Vegetation, Landbird Communities, Intertidal Communities, Water Quality (streams and lakes), Aquatic Communities (streams and lakes), Whitebark Pine, Land Cover and Land Use, Cave Entrance Communities, and Cave Environments. With the exception of the Land Cover and Land Use vital sign, the nine other vital signs give the Klamath Network parks a fine-scale, on-the-ground, look at specific focal communities and their change over time. Monitoring land cover and land use will complement these other monitoring projects by adding a different scale of analysis that provides a comprehensive view of park-wide and region-wide ecosystems. The monitoring strategy for all of the vital signs has been planned in a way that will allow the Network to synthesize data from multiple projects and thus provide a diverse array of information needed to answer questions about the structure, function, and composition of our ecosystems.

This protocol documents the purpose and need related to monitoring land cover and land use within six national park units in the Klamath region. The protocol tests the hypothesis that landscape features do not change over time by examining potential natural and anthropogenic changes to the environment. This protocol focuses on four monitoring objectives:

1. Determine the status and trends in the composition of land cover classes within all the Network parks and directly adjacent lands.
2. Determine the status and trends in the configuration and connectivity of the land cover classifications.
3. Determine the status and trends in human populations near the parks.
4. Determine long-term trends in distribution and extent of disturbances in and around the parks.

Understanding the status and trends in natural and anthropogenic features on the landscapes of the parks will help support NPS management of natural resources by providing relevant landscape-scale information that can be utilized as part of the parks' decision making process.

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List of Terms

AOA	Area of Analysis
BLM	Bureau of Land Management
CRI	Conservation Risk Index
CRLA	Crater Lake National Park
C-CAP	Coastal Change Analysis Program
DOI	United States Department of Interior
ESRI	Environmental Systems Research Institute
FIA	Forest Inventory and Analysis
FMA	Fire Management Area
GAP/ReGAP	Gap Analysis Program/updates to initial maps
GIS	Geographic Information System
I&M	Inventory and Monitoring
IRMA	Integrated Resource Management Applications
IUCN	International Union for Conservation of Nature
KLMN	Klamath Inventory and Monitoring Network
LABE	Lava Beds National Monument
LANDFIRE	Landscape Fire and Resource Management Planning Tools Project
LAVO	Lassen Volcanic National Park
LiDAR	Light Detection and Ranging
LCLU	Land Cover / Land Use
MRLC	Multi-Resolution Land Characteristics
NAIP	National Agriculture Imagery Program
NDVI	Normalized Difference Vegetation Index
NLCD	National Land Cover Data (Database, Dataset)
NPS	National Park Service
NOAA	National Oceanographic and Atmospheric Association
NPScape	National Park Service Landscape Dynamics Monitoring
ORCA	Oregon Caves National Monument and Preserve
PAD-US	Protected Areas Database for the United States
RNSP	Redwood National and State Parks
SERGoM	Spatially Explicit Regional Growth Model
SOP	Standard Operating Procedure
TIGER	Topologically Integrated Geographic Encoding and Referencing
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WHIS	Whiskeytown National Recreation Area

1 Background and Objectives

This protocol narrative outlines the rationale and methods for monitoring land cover and land use in the Klamath Inventory and Monitoring Network (KLMN or the Network) of the National Park Service (NPS). It has been prepared in accordance with NPS guidance and standards (Oakley et al. 2003, Mohren 2007, Sarr et al. 2007). The KLMN includes Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Lava Beds National Monument (LBE), Oregon Caves National Monument and Preserve (ORCA), Redwood National and State Parks (RNSP), and Whiskeytown National Recreation Area (WHIS), hereafter referred to collectively as the parks. The parks, located in southern Oregon and northern California, extend across a broad range of climate, geology, and topography, with a corresponding variety in flora, fauna, and land use history.

1.1 Rationale for Monitoring Land Cover / Land Use

The overall purpose of natural resource monitoring in national parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems. Use of monitoring information will increase confidence in managers' decisions, improving their ability to manage park resources. This increased knowledge will allow managers to confront and mitigate threats to the park and operate more effectively in legal and political arenas (Stephens et al. 2010).

The Klamath Network vital signs selection process defined important questions regarding potential trends in ecosystem composition, structure, and function in the parks (Odion et al. 2005). Land cover, use, and pattern, combined, were selected as one of the top ten vital signs to monitor in the Network. The other nine vital signs are: Exotic and Invasive Plant Species, Terrestrial Vegetation, Landbird Communities, Intertidal Communities, Whitebark pine, Water Quality (streams and lakes), Aquatic Communities (streams and lakes), Cave Environments, and Cave Entrance Communities. The monitoring of these other nine vital signs, in which sampling is done more frequently, give the Klamath Network parks a fine-scale, on-the-ground, look at specific focal communities and their change over time. Monitoring land cover and land use will complement these other monitoring projects by adding a different scale of analysis that provides a comprehensive view of park-wide and region-wide ecosystems. The monitoring strategy for all of the vital signs has been planned in a way that will allow the Network to synthesize data from multiple projects and thus provide a diverse array of information needed to answer questions about the composition, structure, and function of our ecosystems.

As described in the Klamath Network Monitoring Plan (Sarr et al. 2007), the Land Cover and Land Use vital sign was chosen by KLMN park managers as a key vital sign to monitor because of its potential to address the following questions:

1. How are connectivity, fragmentation, and level of park “insularity” changing with land use change in and around the parks?
2. What are the status and trends in disturbances?

3. What are the status and trends in structure and composition of the major land cover types?
4. What are the long-term trends in the predominant habitat types?

The goal of monitoring land cover and land use is to support NPS management of natural resources by providing relevant landscape-scale information to each of the NPS units that make up the Klamath Network. This protocol will test the null hypothesis that landscapes in and around the park do not change over time. Landscape spatial structure results from natural and anthropogenic processes, which vary over time, and underlies the diversity and integrity of ecosystems (Figure 1). The composition (types and amounts of different land-cover), configuration (spatial arrangement of land-cover types), and connectivity determine habitat availability, the movements of organisms, and energy and material flows on a landscape (Turner et al. 2001).

Substantive changes in landscape structure occur in response to natural and anthropogenic processes (Sarr et al. 2007). The latter are of particular concern and relevance for vital signs monitoring. For example, the landscape immediately east of WHIS is experiencing rapid suburban and rural development. Less severe, but potentially significant development pressure also affects some areas adjacent to RNSP. In addition, RNSP, CRLA, LAVO, ORCA, and WHIS all adjoin lands managed for timber production. Existing imagery shows intensive forest cutting adjacent to LAVO's west and CRLA's southeastern borders that has greatly altered landscape patterns and habitat connectivity. Following recent fires, burned forest habitat near WHIS was clearcut logged and further denuded by subsequent erosion. In both cases, adjacent habitat was fragmented and degraded in a way that has the potential to affect park wildlife and visual resources within the park.

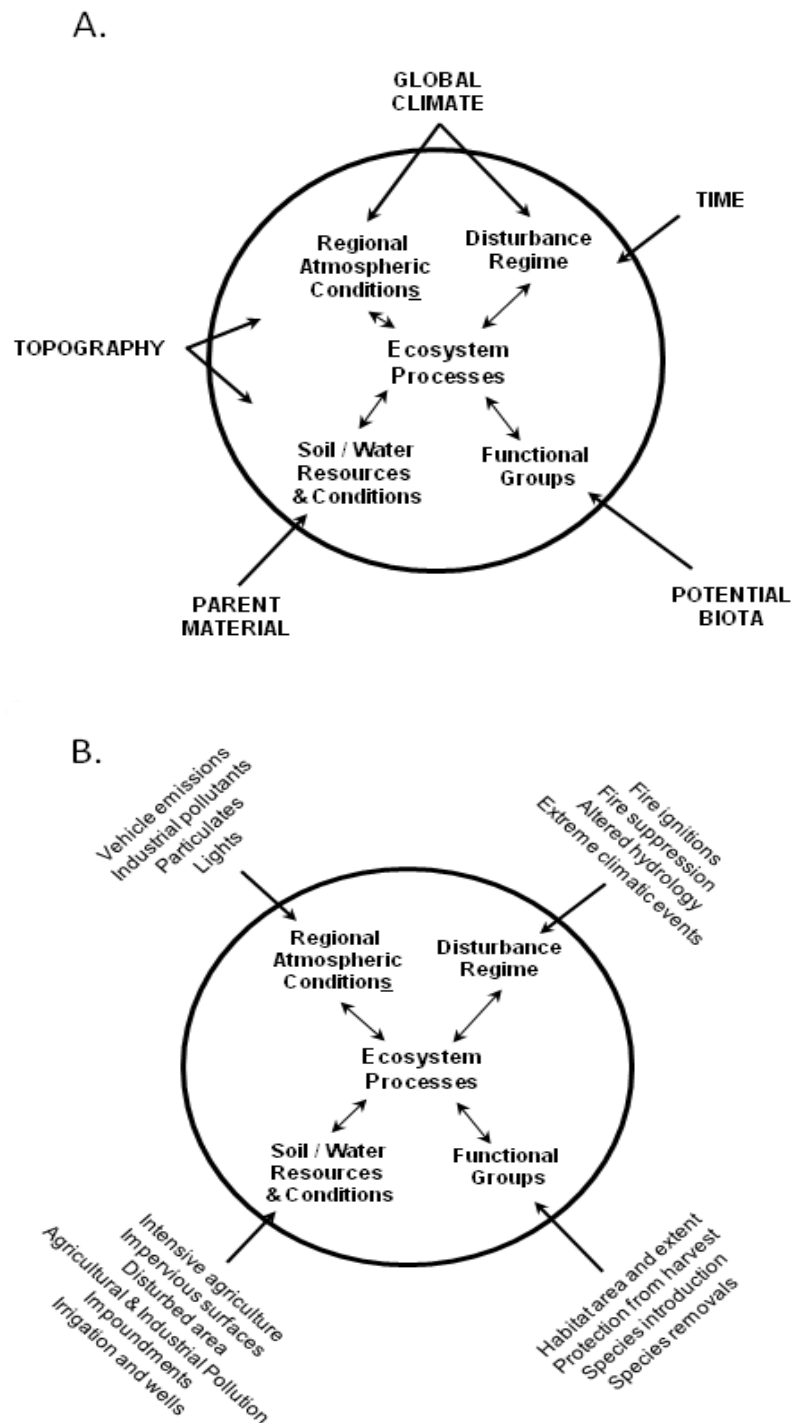


Figure 1. Landscape spatial structure underlies the diversity and integrity of ecosystems and results from natural and anthropogenic processes, which vary over time. (A) General ecosystem model showing primary constraints (upper case) and ecosystem attributes or 'interactive controls'. (B) Factors that commonly alter ecosystems at local to landscape-scale. Modified from Chapin et al. (1996) and Miller (2005).

1.2 Inventory, Monitoring, and Land Use History

The parks within the KLMN have been implementing a variety of management actions (e.g., prescribed burning, road decommissioning, and habitat restoration) that can have a direct effect on some of the indicators that will be monitored as part of this project. Park managers contribute to online data systems that help make data and information available at regional or national scales (e.g., Landscape Fire and Resource Management Planning Tools [LANDFIRE]). Some of the landscape-scale inventories and monitoring projects that have been implemented in each park are briefly described below.

1.2.1 All Parks and the I&M Program

As part of the Inventory and Monitoring (I&M) Program's 12 basic inventories, a vegetation map depicting habitat types at the association scale is expected to be completed for all parks by 2017. Vegetation maps have been completed for LABE (DiPaolo et al. 2015), ORCA (Odion et al. 2013), and WHIS (HSU 2006), and the remaining parks' maps are near completion. Geologic inventories have been completed for CRLA (KellerLynn 2013), LABE (KellerLynn 2014), LAVO (KellerLynn 2014), ORCA (KellerLynn 2011), and WHIS (Thornberry- Ehrlich 2007). In addition to the geologic and vegetation maps, soils maps have been completed for CRLA (Weinheimer 2002), RNSP (USDA 2008), and WHIS (USDA 2013).

1.2.2 Lava Beds National Monument

Beginning in 2009, the park began mapping populations of invasive weeds and has begun control efforts throughout the park. The park has also made efforts to survey and document social trails around some of their front-country areas and has mapped all known borrow pits as part of a borrow pit restoration project.

1.2.3 Oregon Caves National Monument and Preserve

Oregon Caves National Monument and Preserve is completely surrounded by the Rogue River-Siskiyou National Forest. Anthropogenic activities affecting land cover / land use in the region include logging and, to a lesser extent, road and building development, fuels treatments and prescribed burning, grazing, mining, and illegal plantations.

Natural disturbances that affect landscape changes in and around the park, often triggered or aggravated by human activity, include tree diseases, insect pests, wildfire or lack thereof, slope failure, and climate change. Port-Orford cedar (*Chamaecyparis lawsoniana*) in the park are currently unaffected by the root disease caused by the pathogen *Phytophthora lateralis*, but infections have been documented downstream in the Cave Creek watershed at Cave Creek Campground and along Caves Highway as close as 1.6 km from the park. In the park, the forest above the cave is heavily affected by dwarf mistletoe and fire suppression. A 1990 study by Agee, Potash, and Gracz defined the park's fire history. The last significant wildfire in the park occurred in 1921 and mainly burned the understory. Slope failure has occurred along Caves Highway and has a high potential along some U.S. Forest Service (USFS) roads in the region. Debris flows have occurred on the steep slopes and drainages in the region—notably, a 1964 debris flow in the upper Cave Creek drainage that flooded the historic Chateau and caused extensive damage.

While there are a variety of natural and anthropogenic factors that can affect the results of the analyses described in this protocol, the park has implemented few landscape-scale studies. However, the park does have a variety of data that are available to assist with this effort (e.g., fuels prescription data, fire ignition points, invasive plant management locations, and surrounding timber management activities).

1.2.4 Redwood National and State Parks

In addition to work being completed by the inventory and monitoring program, the park has also collected LANDFIRE data to support fire and fuels management planning. This information includes fire behavior fuel models, canopy bulk density, canopy base height, canopy cover, canopy height, fuel loading models, Fire Regime Condition Class, and a Fuel Characteristic Classification System.

The park is also currently working on a collection of historical summer Landsat satellite images with significant fog cover for a fog distribution study that extends from RNSP down to San Francisco, California. Reclassification and summary information is expected to be completed soon. The park is also collating imagery for marijuana monitoring efforts. These data are being collected more regularly/intensively for the other parks in the Network where there might be more convenient access and greater marijuana-growing activity (e.g., WHIS).

Some limited work with the Normalized Difference Vegetation Index (NDVI) on 1 m color infrared National Agriculture Imagery Program (NAIP) imagery has been completed. This work was done in 2010 to help evaluate regrowth after watershed restoration. This work is being completed in conjunction with remotely sensed Light Detection and Ranging (LiDAR) data to develop canopy height models.

Other related work in progress includes updating spotted owl (*Strix occidentalis*) and marbled murrelet (*Brachyramphus marmoratus*) habitat modelling based on 1 m LiDAR canopy height data for old-growth forest habitat by the park.

1.2.5 Whiskeytown National Recreation Area

Whiskeytown National Recreation Area partnered with the University of Washington to develop some basic forest structure layers using Light Detection and Radar (LiDAR) imagery that may be used for some of our analyses once it is complete. In addition, the park has a variety of geospatial datasets that can be used to help interpret our results, including park vegetation maps, locations of exotic plant infestations, prescribed burn locations, illegal marijuana cultivation sites, Forest Inventory Analysis (FIA) and Fire Management Area (FMA) data, and fire severity maps.

1.3 Link to National Strategy (NPScape)

Most NPS I&M networks identified landscape dynamics and adjacent land use change as vital signs for their parks (Monahan et al. 2012). As a result, the NPS Inventory and Monitoring Division decided to implement the NPScape project to support NPS management of natural resources by providing relevant landscape-scale information to each of the NPS units with significant natural resources (Gross et al. 2009).

The NPScape project was designed to provide information on the status and trends of park natural resources at broad regional and ecosystem scales. Resulting NPScape data, products, analyses, tools, and procedures cumulatively identify, evaluate, and report a suite of information-rich measures for park units served by the I&M Program. Broad landscape dynamics measures and their respective calculated metrics focus on environmental drivers, ecosystem-level attributes, and the conservation context of NPS units. Together, these measures can inform park decisions, help to identify potential threats to park resources, and provide opportunities for conservation (Monahan et al. 2012).

In order to avoid duplicate efforts, the Klamath Network waited for the completion of the first phase of the NPScape project before starting the development of this protocol. The degree to which the resulting NPScape tools and procedures were utilized was a decision left to individual parks and networks. After reviewing the results of the national NPScape project and considering the limited funding available to implement the KLMN landscape protocol, we decided to base our protocol on NPScape methods as closely as possible. NPScape tools are designed in a manner that allows us to utilize localized datasets to develop more detailed and accurate results. In addition, the indicators analyzed as part of the NPScape project directly relate to the KLMN land cover and land use goals and objectives addressed during the vital signs selection process. As an added benefit, the NPScape team continues to develop products that can be utilized by the Network to help us better meet the park managers' needs.

Given that landscape dynamics is a common vital sign to many networks, the I&M Central Office has initiated a project to fully develop NPScape methods and tools into a national-level landscape dynamics protocol that will be implemented by the Central Office. Because the national and KLMN protocols are NPScape-based and therefore closely aligned, KLMN will eventually transfer responsibility for protocol implementation to the national office and amend the KLMN protocol according to national I&M guidance.

1.4 Network Monitoring Plan

The Network's monitoring plan was developed using conceptual models (Sarr et al. 2007) that provide the foundation for the Network's approach to monitoring the composition, structure, and function of ecosystems (Figure 2). Composition is the array of ecosystem components (genes, species, populations, special habitats, etc.). Structure refers to the spatial arrangement of physical components, such as canopy structure or habitat corridors for species movement. Ecosystem function refers to the many processes that ecosystems require and provide through time, including nutrient cycling, carbon cycling, and hydrologic cycling, which interact with disturbance processes, biological interactions (e.g., interspecific competition), and demographic and reproductive processes (Figure 2). As described in the Network's monitoring plan, it is not the intent of the KLMN to develop protocols that are designed to be stand-alone projects. It is our intent to show that relationships between status and trend patterns can be examined between protocols, providing us with a better understanding of the dynamic nature and condition of our park ecosystems (Sarr et al. 2007).

This land cover and land use protocol will generate products and information at the landscape-scale that can be used to improve our understanding of changes in the structure and composition of park

ecosystems. In addition, when these data are analyzed in conjunction with data from other vital signs monitoring projects (e.g., vegetation, landbird, streams, lakes) and/or inventory projects (soils, vegetation mapping, geology) that involve sampling at finer spatial scales, we will be able to develop interrelated datasets of invaluable information. Such integrated datasets will help park managers gain a more holistic understanding about the resources in their parks.

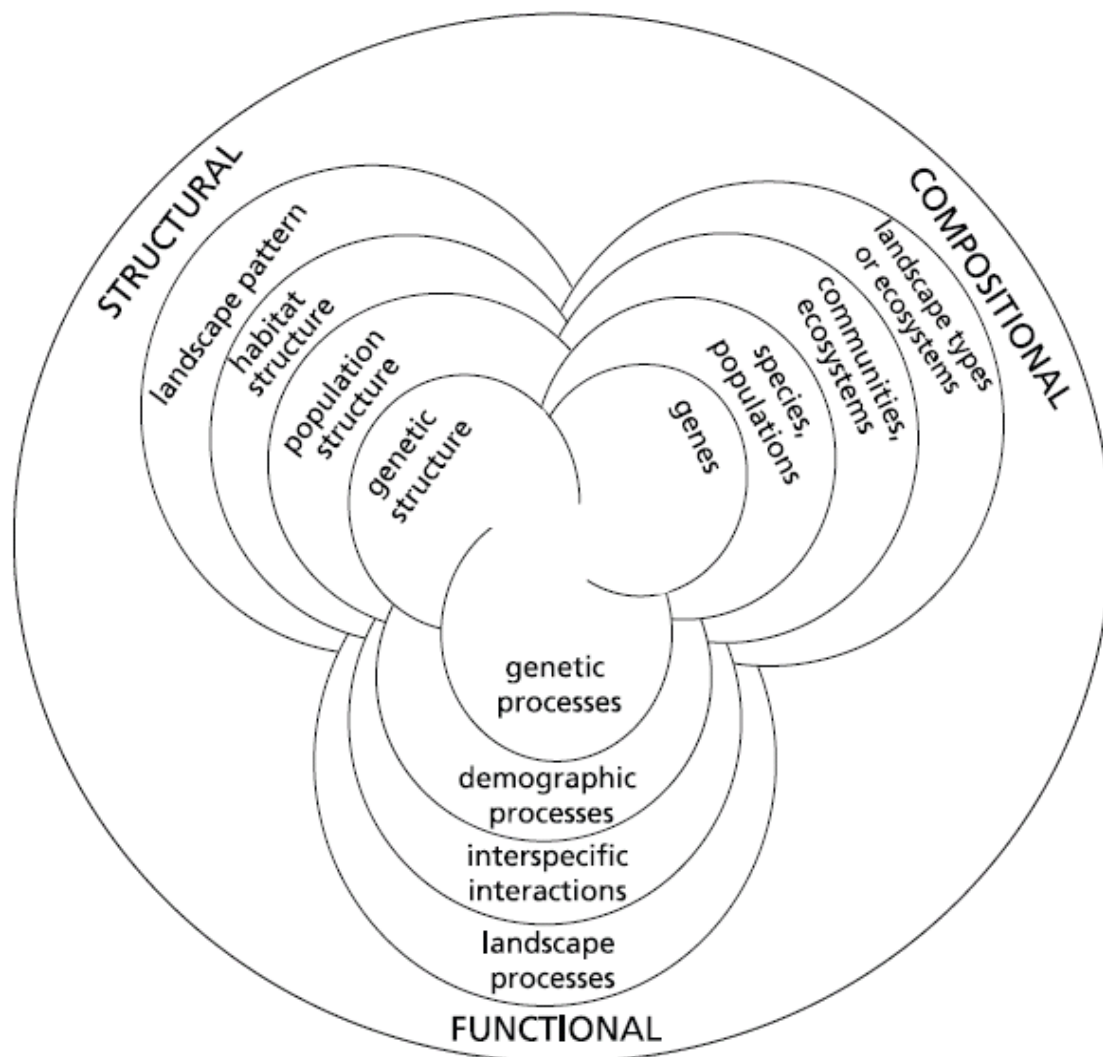


Figure 2. Conceptual model showing composition, structure, and function across various levels of scale and biological organization (from Noss 1990).

1.5 Monitoring Objectives and Potential Monitoring Questions

To test the null hypothesis that environments are not changing over time, the park and network staff worked together to develop the four monitoring objectives listed in Table 1. Multiple scoping meetings were held with park managers and resource specialists to formulate the objectives and monitoring questions for this project. For each objective listed in Table 1, we provide monitoring questions that can be answered as part of this protocol. Park managers should be able to use the results of this protocol to better manage park resources.

Table 1. Monitoring objectives, monitoring questions, and measureable objectives that are addressed by the KLMN Land Cover and Land Use protocol.

Monitoring Objective	Monitoring Questions	Measurable Objectives
Objective #1 Determine the status and trends in the composition of land cover classes within all the Network parks and directly adjacent lands.	What is the areal extent of land cover types within and adjacent to parks?	Total area (km ²) of each Anderson level 2 land cover type within each of the designated Areas of Analysis (AOA). In addition, proportion of each AOA occupied by each land cover class in percent. Total area (km ²) of anthropogenic impervious surfaces.
	What proportion of adjacent land contains natural cover types and how much has been converted to urban or agricultural uses?	Determine the total area (km ²) of each Anderson level 2 land cover type that has changed into a different cover classification. Determine what percent of the land in each AOA has been converted from natural to urban or agriculture. Examine trends in total area and percent of area changing over time.
	Which parks are most isolated and which are potentially most at risk as evaluated by habitat conversion?	Examine trends in habitat conversion outside of the park measured in hectares of growth and kilometers of distance from the park
	What percent of lands surrounding the parks are protected and what does this say about future risks to resources?	Examination of the area of lands in the regional and watershed scales that are listed as GAP status 1 and 2 versus 3 and 4. Total area is measured in km ² and portion of area for each AOA is measured in percent. Trend analysis to compare how this area is changing over time.
	Which areas of the park units are potentially most at risk?	Examine trend in land cover types measured as km ² and note cover types that are disappearing or being converted to nonnatural cover types.
	How is land cover connectivity changing?	Determine density of area classes as defined in Table 7 and examine trends in how this density has changed over time.
Objective #2 Determine the status and trends in the configuration and connectivity of the land cover classifications.	What are the patterns of relevant land cover types within and adjacent to parks?	Examine the trend in the changing pattern of each land cover type. Look at trends in changing pattern classifications as described in Table 8.
	How has distance from roads and size of roadless areas changed?	Examine Euclidian distance (m) from any pixel on the landscape and the nearest road and patch size distribution of roadless areas in the three AOAs.
	How have the size and number of forest and nonforest patches of natural habitats changed on the lands surrounding parks? For large parks, how have the sizes of patches within the park changed?	Within each Area of Analysis, examine patch size of each land cover type and look at changes in patch size measured over time in km ² .
	How has road density changed in parks and adjacent areas?	Examine the total km of road by road type in the three AOAs and look at how trends in these roads have changed over time. Also examine the road density and distance to roads for each AOA.
	What is the land ownership adjacent to the park unit?	Summarize the ownership status in total area and percent of area for each AOA that is in and around the park.

Table 1 (continued). Monitoring objectives, monitoring questions, and measureable objectives that are addressed by the KLMN Land Cover and Land Use protocol.

Monitoring Objective	Monitoring Questions	Measurable Objectives
Objective #3 Determine the status and trends in human populations near the parks.	What is the population within and adjacent to parks and how has it changed over time?	Summarize and analyze trends in the overall population growth of each town or city with the landscape and regional AOA scale. Measured as total number of individuals.
	How has population density changed in lands adjacent to parks?	For each census block determine the population density and examine how the density for each block is changing over time. Measured in number of individuals per housing block.
	What is the spatial relationship of park boundaries with areas of high housing density? Which areas are most impacted by population growth?	For each census block that is adjacent to the park boundary, summarize changes in density over time. Measured in number of individuals per housing block.
Objective #4 Determine long-term trends in distribution and extent of disturbances.	How are fires distributed within and adjacent to the parks?	Examine the total area (km ²) and percentage of area for each AOA that are affected by fires that occur each year within the three AOAs. Look at trends over time.
	How are anthropogenic disturbance associated with vegetation management distributed within and adjacent to the park?	Examine trends in total area (km ²) and percentage of area for each AOA that is affected by non-fire related activities (harvest, seeding, reforestation, etc.) as described in Table 10.

1.6 Management Implications

The success of this protocol will depend on how useful the information from this protocol is to park management staff and resource specialists. A monitoring system that meets the needs of managers will also facilitate continuity across generations of managers, help avoid reinventing tools, and provide a basis for comparable analyses amongst the six parks in the Klamath Network.

KLMN park managers and resource specialists played a key role in selecting network vital signs. Once vital signs were selected, the KLMN held several scoping meetings with park staff throughout the development of this protocol to make certain the objectives and goals would be useful. Upon completion of analysis, results will be provided to park staff, and park managers will provide feedback to ensure that the protocol is meeting their needs. While a monitoring project cannot provide every piece of information needed to understand the ecosystems of a park and influences on those ecosystems, this project provides a good balance between the needs of park managers and resource specialists, utilizing data that are currently available, and accounting for monitoring of the other nine vital signs selected by the park staff.

Ultimately this protocol should provide a wealth of information that will help the park staff understand how various aspects of the ecosystems, both natural and anthropogenic, are changing over time. This information can then be used to help understand the consequences of park management actions and increase knowledge about how the areas surrounding the parks are changing.

2 Sampling Design and Rationale

2.1 Rationale for Selecting this Sampling Design

As described in chapter 1, the rationale for monitoring land cover and land use as a vital sign is to address key questions about changes in landscape composition, fragmentation, and disturbance surrounding parks in the Network. The NPScape team chose Conservation Status, Housing and Population, Land Cover, Landscape Pattern, and Roads as key measures of status and trends at park- and region-wide ecosystem scales. We also chose to look at Disturbance as a key measure. These measures focus on broad-scale factors that link landscape attributes to resources within the parks. The ecological relationships and processes articulated in Figure 3 are common to many parks, and provide a sound basis for evaluating the potential effects of landscape-scale measures on park resources. These landscape-scale measures include natural disturbances (e.g., fire), critical habitats, ecological flows (e.g., pollutants, nutrients), and both direct and indirect effects of humans (e.g., poaching, noise, behavioral disturbance) (Monahan et al. 2012).

Understanding the spatial context of park resources is important to identifying and evaluating opportunities to prevent resource damage or loss, assessing actions for restoration, and identifying key threats to park resources. A clear understanding of the relationships between park natural resources, nearby protected areas, and the corridors linking them presents an opportunity to better preserve these resources. While many of the measures are, by themselves, insufficient to determine the status of an individual resource, the sum of this information provides a picture of the history, status, risks, and opportunities for conservation decisions that can substantially alter the future condition of park ecosystems (Monahan et al. 2012).

We plan on using many of the tools and methods from the NPScape program to implement our sampling design due to the fact that 1) the NPScape tools are designed in a manner that allows us to utilize localized datasets to develop more detailed and accurate results, and 2) the indicators selected by the NPScape team help us address the monitoring questions proposed by the park managers and resource specialists.

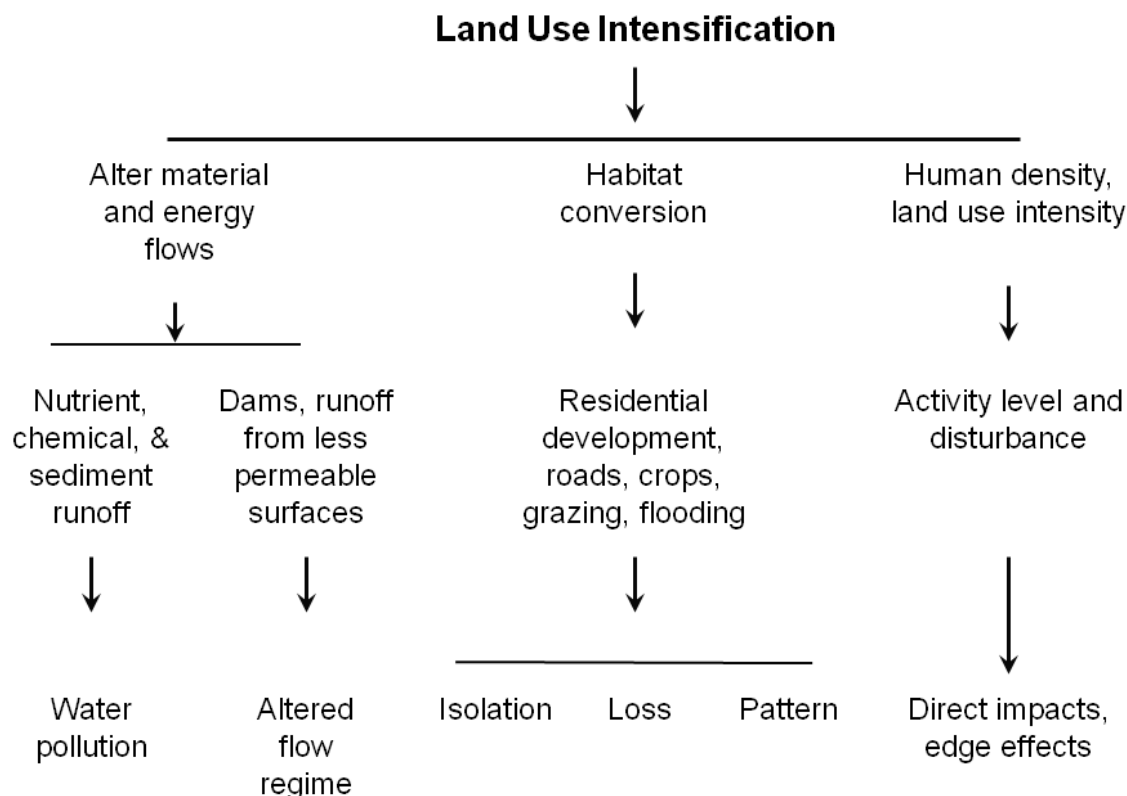


Figure 3. Mechanistic links between attributes of land use intensification and natural resources, depicting the relationships described by Hansen and DeFries (2007).

2.2 Sampling Frames / Areas of Analysis

Taking into account multiple scales of time and space over which data can be analyzed strongly influenced our evaluation of most measures. In general, management decisions about park resources are influenced by factors across all scales, but most decisions involve short time scales and small spatial scales. “Big decisions,” where big refers to the spatial domain affected and the consequences, are relatively rare, but they can be very important. We recognized that resources and drivers of change need to be evaluated at multiple scales, and that no single scale or set of scales will meet all needs (Gross et al. 2009). The Klamath Network plans on implementing this protocol at three types of spatial scales, or Areas of Analysis (AOA): Park, Park-Manager-Selected, and Regional (Table 2).

Table 2. Area (km²) covered for each "Area of Analysis" that will be analyzed as part of this monitoring protocol.

	Park Scale (km²)	Park-Manager- Selected Scale (km²)	Regional Scale (km²)
Crater Lake National Park	738.26	5353.67	6910.35
Lava Beds National Monument	189.44	21.841, 2259.192	4999.16
Lassen Volcanic National Park	434.22	3866.20	5891.84
Oregon Caves National Monument and Preserve	18.44	248.94	3392.41
Redwood National and State Parks	573.12	2441.79	9363.69
Whiskeytown National Recreation Area	170.53	2027.34	4586.78

¹Jack Fire extent, ²HUC10 watershed extent

2.2.1 Park Scale

The "Park Scale" focuses on an area that NPS park managers have the most influence over and which they can directly alter through management actions. These areas will provide the most detailed datasets with the best information to describe landscape-scale changes that are occurring in the parks. Analysis at this scale will give park managers the best possible picture of changes that are occurring in the park. For Oregon Caves NMP and Lassen Volcanic NP, small administrative areas outside the main park area were removed from the AOA. The boundary for Redwood NSP includes the state parks.

2.2.2 Park-Manager-Selected Scale

While many of the ecological processes we are examining occur at each of the parks, the varying size of the parks, activities surrounding the parks, and natural resources within the parks means we need to examine these ecological processes at a scale that meets park staff-specific concerns. Each park has ecologically important areas that may be missed if we only focus on the park and regional scales. Therefore, we have worked with the natural resource staff at each park to define an AOA for their park that best meets their needs. The AOA for each Park-Manager-Selected Scale contains all or portions of several Hydrologic Unit Code (HUC) 10 watersheds and are described below. LABE has selected an additional AOA, which is a fire boundary.

Crater Lake National Park

At least some portion of nine HUC 10 watersheds are within the boundaries of CRLA, including Headwaters Rogue River, Diamond Lake, Beaver Marsh, Big Springs Creek-Klamath Marsh, Jack Creek-Williamson River, Crater Lake-Williamson River, Hog Creek-Williamson River, Wood River, and the South Fork Rogue River. These nine watersheds compose an area of approximately 5354 km² and range in size from 174 km² (Diamond Lake) to 1005 km² (Headwaters Rogue River).

Lava Beds National Monument

At least some portions of three HUC 10 watersheds are within the boundaries of LABE, including Copic Bay, Lower Klamath Lake, and Tule Lake. These three watersheds compose an area of approximately 2259 km² and range in size from 471 km² (Tule Lake) to 981 km² (Copic Bay). A second AOA was selected, which is the boundary for the Jack Fire that occurred in 2008 in the

northern section of the park; it covered 21.84 km². This is an area where analysis would reveal changes in the proportion of shrub/herbaceous cover over time.

Lassen Volcanic National Park

At least some portion of eight HUC10 watersheds are within the boundaries of LAVO, including Hat Creek, Butte Creek-Lost Creek, Upper Pine Creek, Upper North Fork Feather River, Headwaters North Fork Feather River, Mill Creek, South Fork Battle Creek, and North Fork Battle Creek. The eight watersheds compose an area of approximately 3866 km².

Oregon Caves National Monument and Preserve

Oregon Caves National Monument and Preserve is completely contained within the HUC 10 watershed known as Sucker Creek. This watershed covers approximately 249 km².

Redwood National and State Parks

At least some portion of seven HUC 10 watersheds are within the boundaries of RNSP, including Big Lagoon-Frontal Pacific Ocean, Point St. George-Frontal Pacific Ocean, Redwood Creek, Smith River-Frontal Pacific Ocean, South Fork Smith River, Tectah Creek-Klamath River, and Turwar Creek-Klamath River. While many of the ecological processes we are examining occur at each of the parks, the varying size of the parks, activities surrounding the parks, and the content of the parks means we need to examine these ecological processes at a scale that meets the needs of specific parks. While the regional scale will cover many of the same areas as this AOA, there may also be ecologically important areas that are missed. RNSP staff determined that the AOA that best meets their needs includes only HUC 10 watersheds for the southern end of the park, including the Big Lagoon-Frontal Pacific Ocean, Redwood Creek, Lower Mad River, and Humboldt Bay-Frontal Pacific Ocean watersheds which covers approximately 2442 km².

Whiskeytown National Recreation Area

At least some portions of four HUC 10 watersheds are within the boundaries of WHIS, including Churn Creek-Sacramento River, Clear Creek, North Fork Cottonwood Creek, and Weaver Creek-Trinity River. These four watersheds compose an area of approximately 2027 km² and range from 352 km² (North Fork Cottonwood Creek) to 756 km² (Clear Creek).

2.2.3 Regional Scale

One of the objectives of this protocol is to examine landscape-scale change within the park and compare it to changes that are occurring outside the park. The effective domain of many local ecological processes is thought to be on the order of 15 to 40 km, but few studies have demonstrated effects at distances greater than 25 km. Examples of processes that operate on this scale are daily to weekly animal movements, initiation and propagation of large fires, and dispersal of local pollutants (Gross et al. 2009). Therefore, we define a regional scale of analysis as including all adjacent areas within 30 km of the park boundaries that are described in section 2.2.1. These regional analyses will utilize datasets that are consistent both inside and outside the park boundaries to ensure consistency in inference. This scale will not only allow us to compare changes at the regional scale inside and outside of each park, it will also allow us to compare changes among the parks, since standardized

datasets and Areas of Analysis are being utilized for all parks. Figures 4 to 9 show the areas of analysis for each park unit.

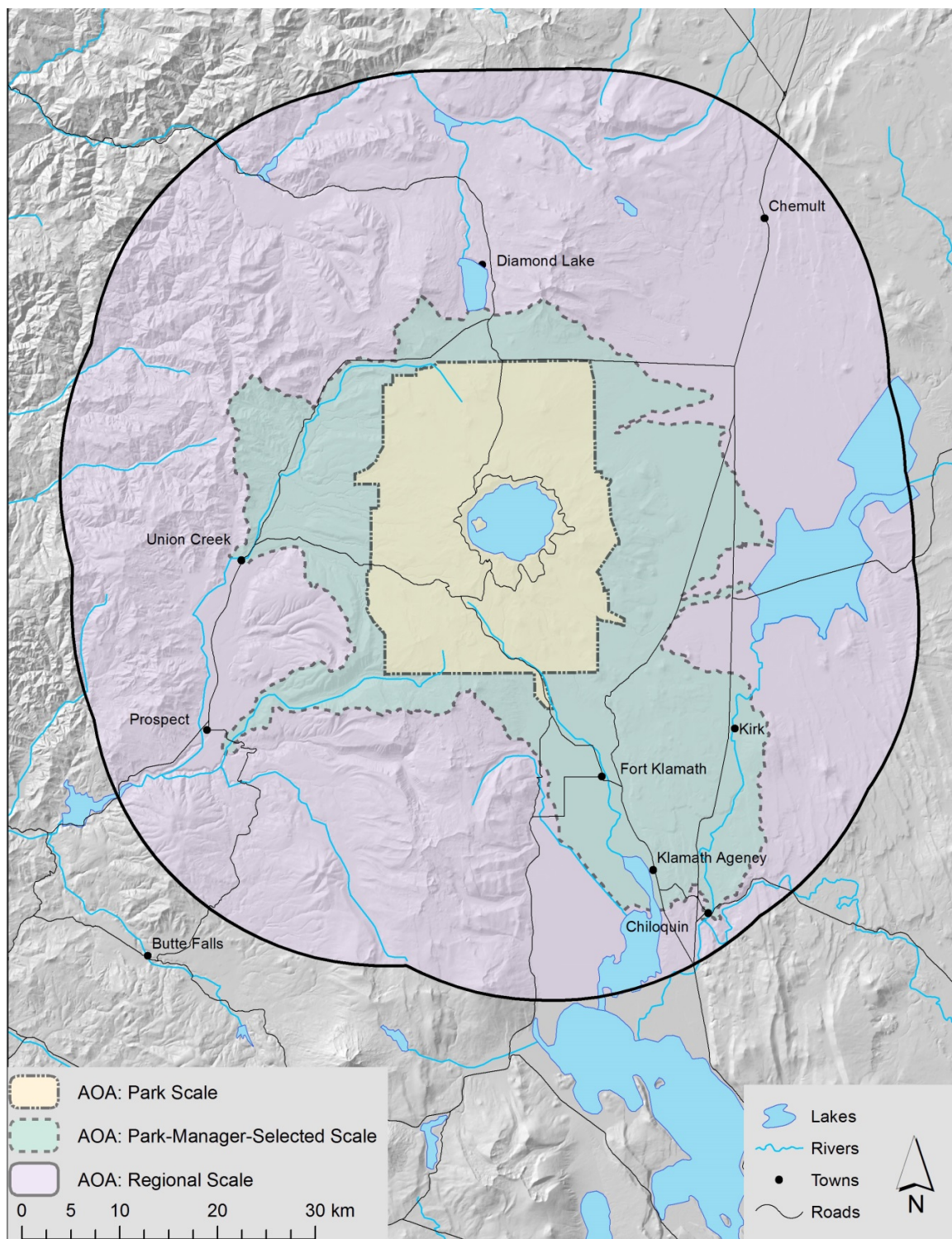


Figure 4. Reference map for Crater Lake National Park showing the three Areas of Analysis used in this monitoring protocol.

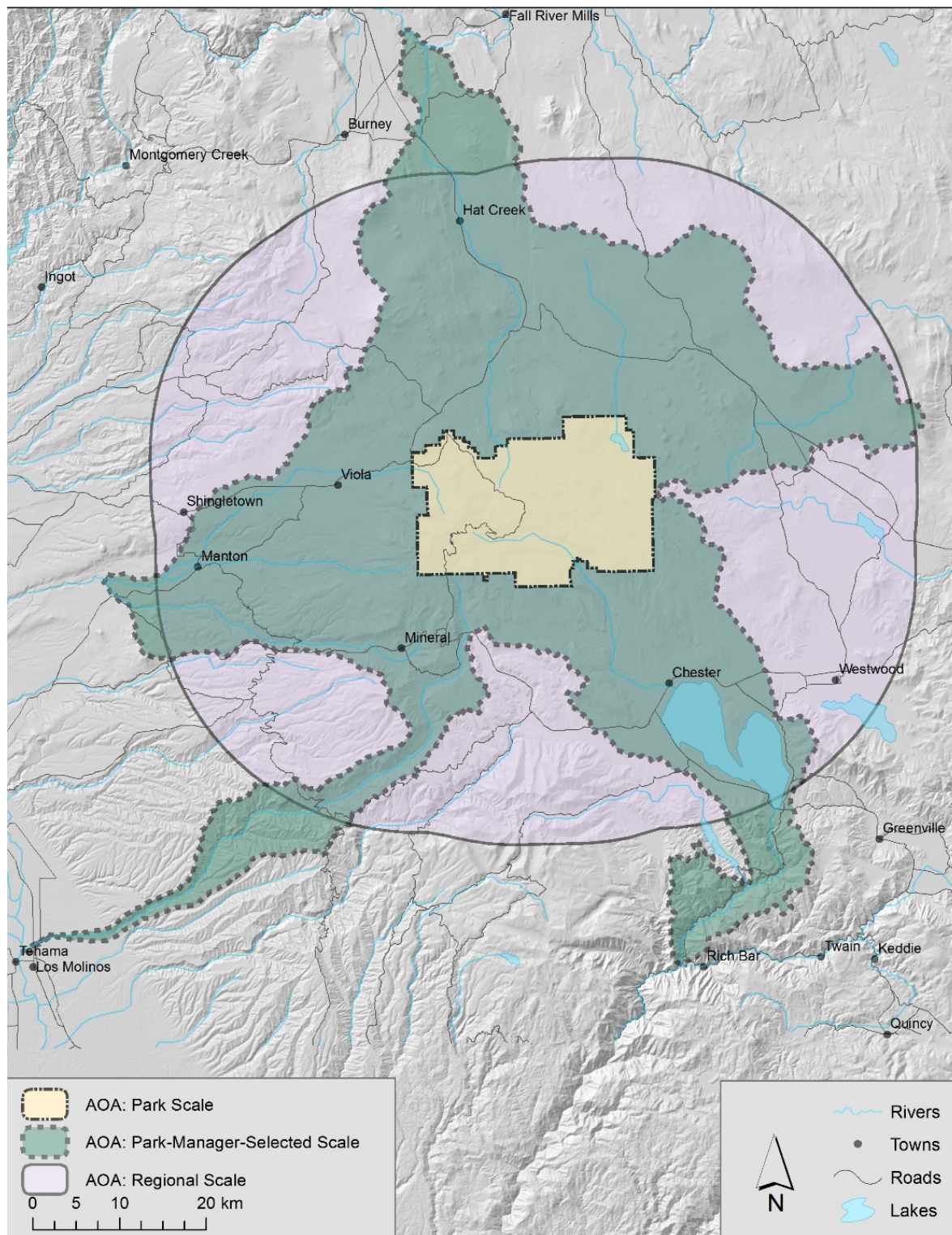


Figure 5. Reference map for Lassen Volcanic National Park showing the three Areas of Analysis used in this monitoring protocol.

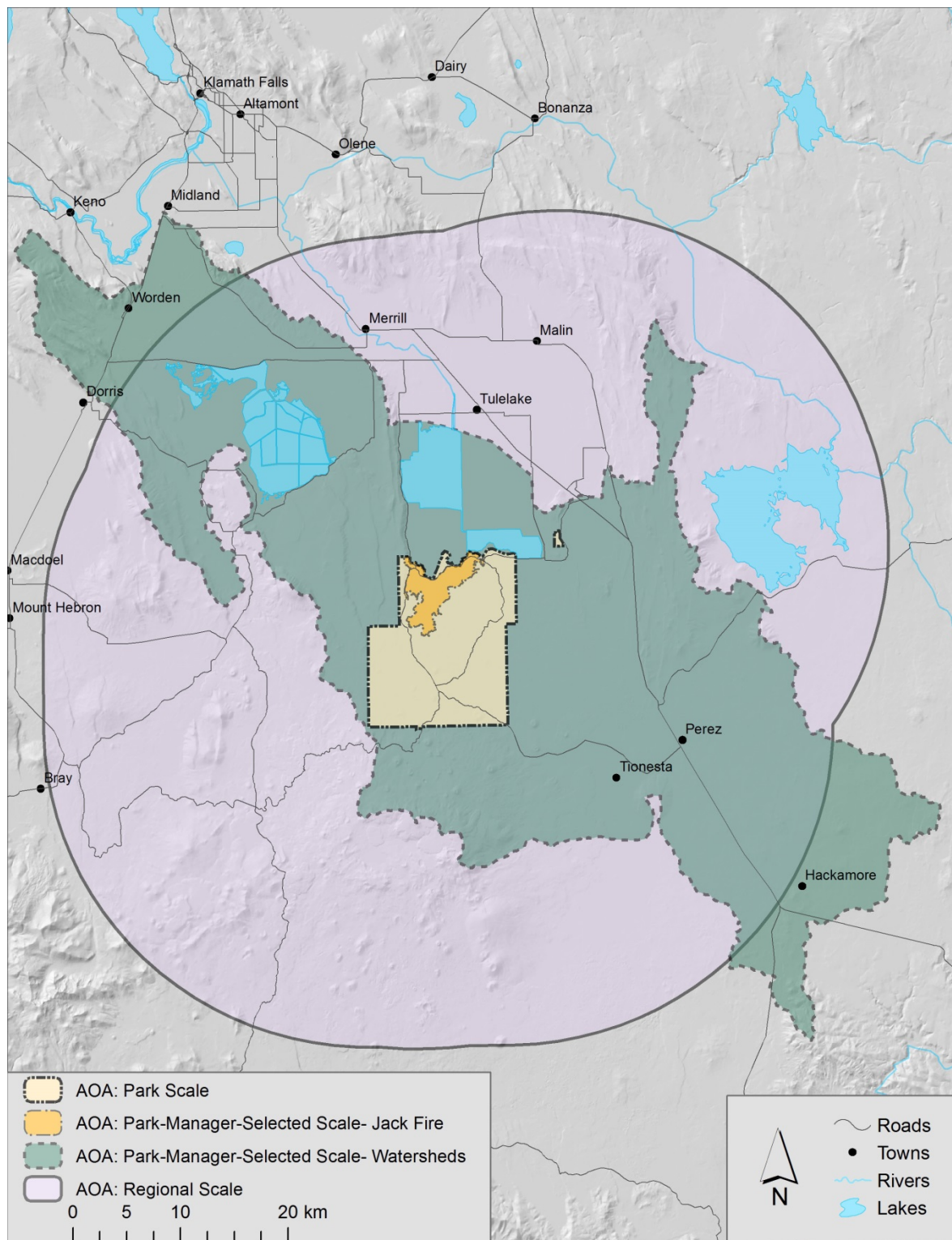


Figure 6. Reference map for Lava Beds National Monument showing the four Areas of Analysis used in this monitoring protocol.

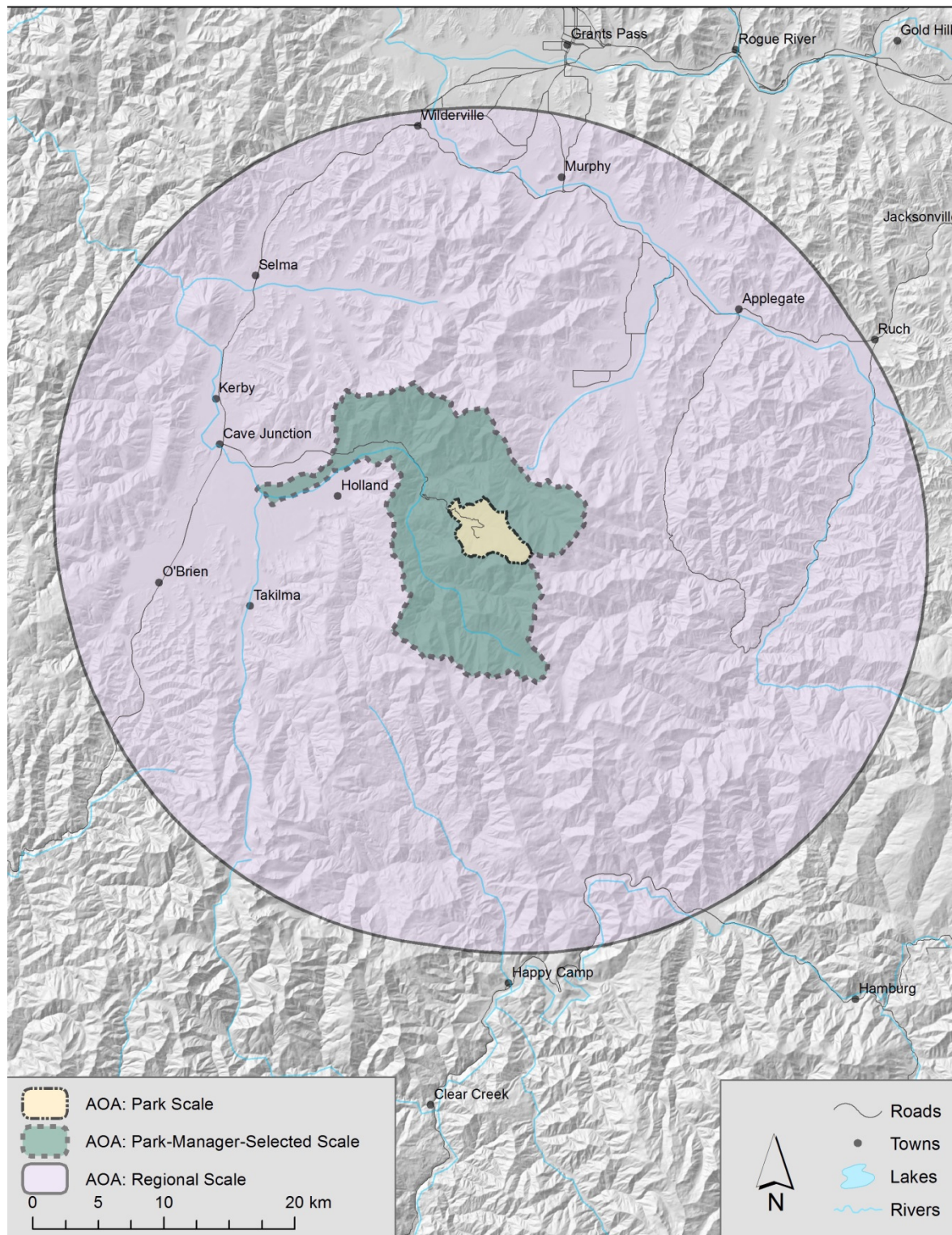


Figure 7. Reference map for Oregon Caves National Monument and Preserve showing the three Areas of Analysis used in this monitoring protocol.

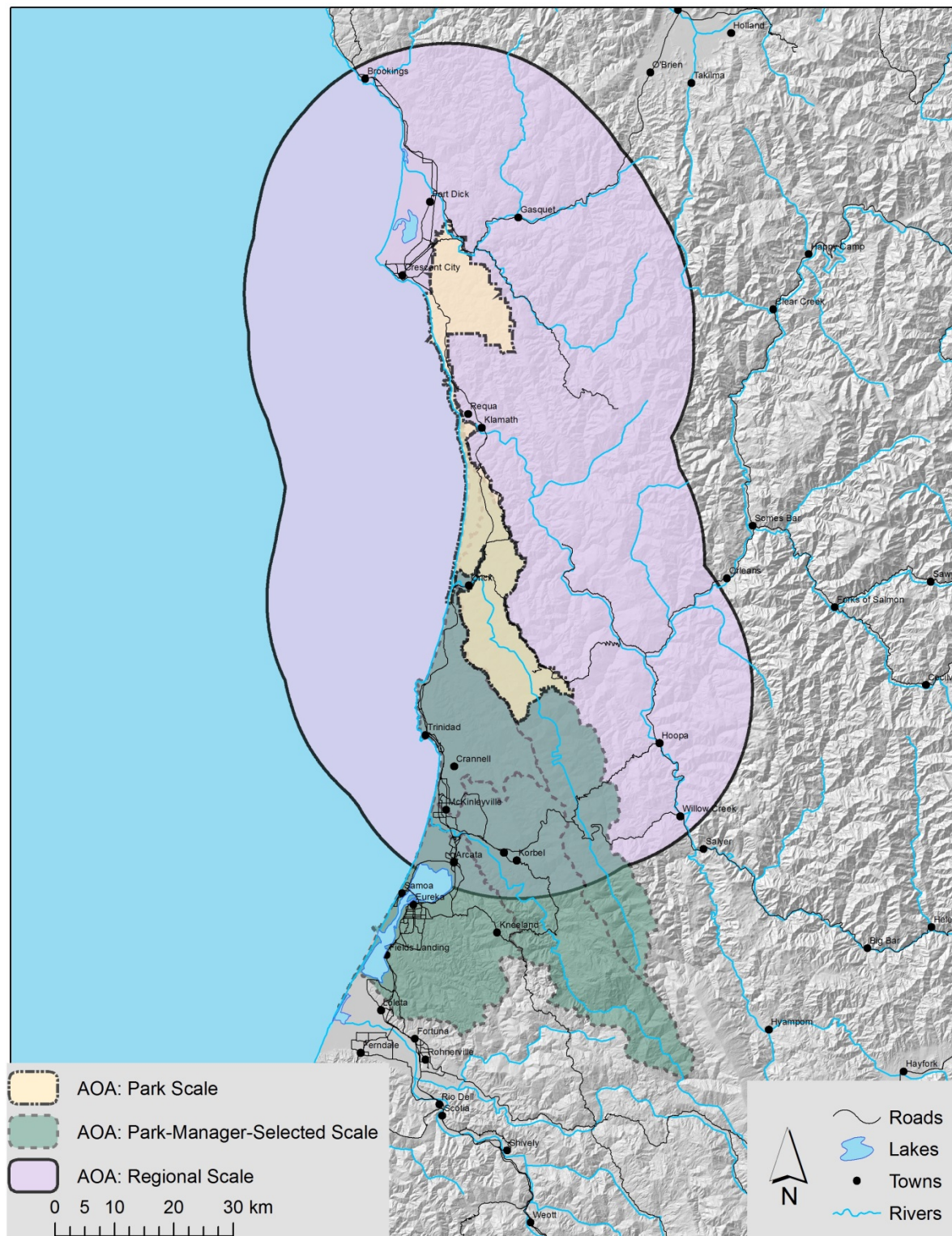


Figure 8. Reference map for Redwood National and State Parks showing the three Areas of Analysis used in this monitoring protocol.

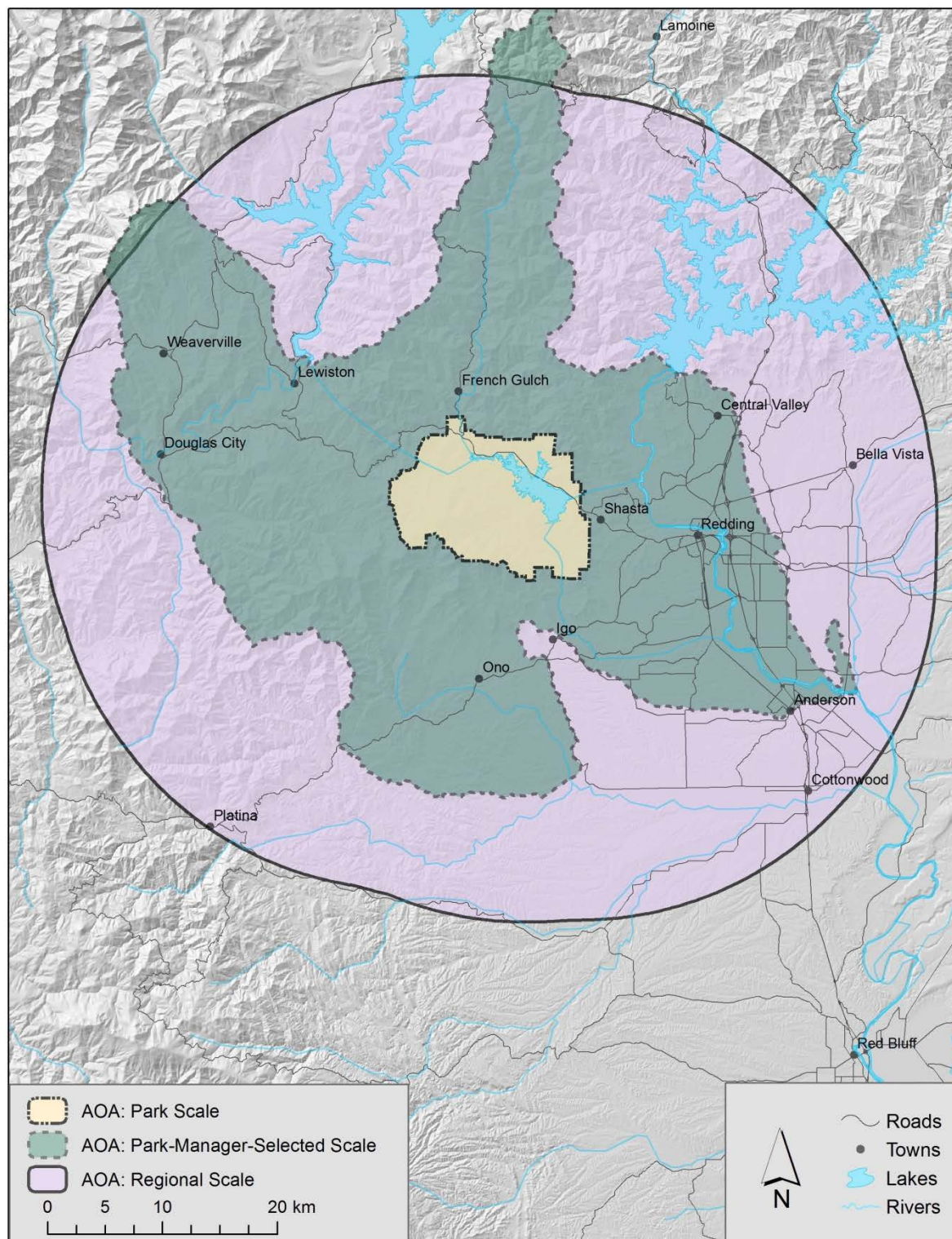


Figure 9. Reference map for Whiskeytown National Recreation Area showing the three Areas of Analysis used in this monitoring protocol.

2.3 Data Sources and Conditions

Since this protocol relies heavily on data developed by other entities (e.g., parks, United States Geological Survey [USGS]), the KLMN will have limited control over the accuracy or availability of the data we plan on using. Therefore, timelines set in this protocol (e.g., analyses completed every six years) must be flexible. For example, while census data is developed every 10 years, it may or may not be available for use every 10 years. Delays in data availability may occur that can delay the development of products related to this protocol. In addition, methodology of datasets may vary. For example, 1992 data from the U.S. Geological Survey's National Land Cover Database (NLCD) were developed using a different classification method, making comparisons with the 2001 and 2006 data more difficult.

To account for these limitations, the KLMN has selected datasets that are being produced on the most consistent basis using similar methods. This will help ensure datasets are available for spatial and statistical analyses described in the standard operating procedures (SOP) of this protocol. The KLMN will use the most accurate data available at the spatial scale of analysis that meets our objectives. For example, when examining road density we will use the park road layer to complete the in-park analysis. This will be the most accurate roads data layer for this analysis. Unfortunately, this data layer does not provide us the opportunity to compare roads in the park with roads outside the park. In order to complete the comparison analysis, we will need to utilize a data layer that is less accurate (such as Topologically Integrated Geographic Encoding and Referencing [TIGER] system roads data) but more consistent throughout the Area of Analysis.

In order to accomplish our objectives, it was determined that datasets selected for this project must meet the following criteria:

- Data already exist. We will conduct no field work, classify no imagery, and undertake no creation or compilation of entirely new datasets.
- Data are consistent across broad areas. The data must cover the scales described in the Area of Analysis section of this protocol. However, different datasets can be used at different parks and at different scales.
- Data include adequate documentation. For derived measures, the algorithms, procedures, accuracy, and other necessary code must be well documented and freely available.
- Data can be distributed to NPS staff without charge or other undue restriction. However, if a data source is desired that does cost the Network, the Project Lead will work with the Program Manager to determine if purchasing the data is an option.
- If data are used to compare trends, it must be available over multiple years and in a consistent format.

2.4 Frequency of Analysis

This protocol will be implemented every six years. Table 3 illustrates the reporting schedule and the currency of the datasets projected to be available for analysis. While data sources may be on a similar

update schedule (e.g., every 5 years), the update years for their individual cycles may vary (Table 3), thus making it challenging to prepare a report that has the most current data for all indicators. While numerous factors affect the selection of a particular reporting interval (e.g., rate of change in the indicators being monitored, park information needs, data update schedule), the availability of network funding is the primary factor determining this interval. Many of KLMN's monitoring projects are on 3 year cycles, and thus funding for this protocol would be available on 3 or 6 year intervals. Given that most datasets are updated every 5 years, a 3 year interval is too frequent, and a 6 year interval is most appropriate.

When the I&M Central Office completes the national landscape dynamics protocol and implementing the protocol for I&M networks, we will likely shift the reporting schedule to every 5 years, which would be in sync with the update schedule of one or more underlying datasets. If the I&M Central Office has the capacity to analyze a subset of the indicators more frequently, we will explore the possibility of a series of reports on specific indicators instead of a consolidated report for all indicators, thus allowing more timely reporting on individual indicators as updated datasets become available. If the latter occurs, we would also prepare an overarching report that integrates and interprets results across all indicators. While allowing more timely reporting on the indicators, the latter approach is also more time consuming and expensive because it would require more staff time every 2-3 years (Central Office, KLMN, and park), plus an extra integrative report. Funding and staff availability will be factored into the final decision.

In 2016, the latest datasets were downloaded, and an initial summary report on all indicators was developed for each park following the guidance in *SOP #10: Analysis and Reporting*. See Ives et al. (2016) for the LAVO Summary Report which serves as a model for the other parks' reports (*in prep*). Data for the first Analysis and Synthesis (A&S) report will be downloaded in FY 2021; this report will focus on trend analysis and will be a recurring report developed on a six-year rotation.

Table 3. KLMN Land Cover Land Use reporting schedule (highlighted years) and the latest datasets available for each analysis. The left-most column identifies the landscape indicator, the underlying data source(s), and in parenthesis, the frequency at which updated data are projected to be available. X's indicate the years that updated data are expected to be available. In the highlighted years, the most recent updates for each dataset will be downloaded, analyzed, and reported.

Indicator Data Source	Calendar Year																							
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Conservation Status																								
USGS PAD-US (5 yr)			x					x					x					x					x	
Housing & Population																								
US Census Bureau	x										x										x			
Land Cover																								
USGS NLCD (5 yr)		x					x					x					x					x		
NOAA C-CAP (5 yr)	x					x					x					x					x			
Landscape Pattern																								
USGS NLCD (5yr)		x					x					x					x					x		
Roads																								
Park data (continuous)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
TIGER Data (annually)			x			x			x			x			x			x			x			x
Disturbance																								
LandFire		x					x					x					x					x		

2.5 Rationale for Selection of Indicators

Six areas of interest (Conservation Status, Land Cover, Landscape Pattern, Housing and Population, Roads, and Disturbance) and the specific metrics by which we will evaluate status and trends for each area are listed in Table 4. Status and summary assessments will provide park managers with some generalized information on these indicators, whereas trend analysis will examine long-term change in the indicators. Appendix A provides the detailed indicator summaries that provide the justification for sampling most of these indicators. We have summarized the justification for each indicator and metric below.

2.5.1 Conservation Status

The conservation status (ownership, stewardship, and use) of land surrounding parks can have profound impacts on resources (GAO 1994, Hansen et al. 2005). Impacts, both positive and negative, can be driven by a number of different mechanisms within general categories of change in the effective size of reserves, changes in ecological flows, loss of critical habitat, and increased exposure to humans (Hansen and DeFries 2007). Within each category, Hansen and DeFries (2007) distinguished the types of mechanisms that drive changes, such as species-area effects, trophic structure, migration habitats outside parks, and hunting and poaching. A common feature of these effects is that they are known or strongly postulated to be directly related to land use intensification. While it can be difficult to directly measure impacts, several broad-scale datasets can provide important information to evaluate the likely condition of parks, and current or likely threats to park resources.

Understanding and examining changes in land stewards or ownership of land holdings surrounding the parks is an important measure. It offers insight into the conservation status of lands surrounding the parks, provides a basis for estimating changes in protection status and land conversion over time, serves as base data for estimating conservation risk, and reveals opportunities for cooperative management, conservation, and education (Monahan et al. 2012).

Table 4. Indicators evaluated by the land cover and land use protocol. Also included are specific measures, objectives addressed, scales of analysis, and relevant SOPs in this protocol. Abbreviations for Areas of Analysis (AOA): P = Park, PM = Park-Manager-Selected, and R = Regional.

Indicator	Measure	AOA Scale	Objective	SOP
Conservation Status	Percent & Total Protected	PM ¹ & R	1 & 2	2
	Percent & Total Ownership		1 & 2	2
Land Cover	Area/Percent in Land Cover Types	P, PM & R	1 & 2	3
	Natural vs. Converted		1 & 2	3
	Impervious Surface		1 & 2	3
Landscape Pattern	Morphological Pattern Analysis	PM & R	2	4
	Patch Size by Cover Type		2	4
	Distribution of Patch Sizes for Cover Types		2	4
	Density Analysis of Cover Types		2	4
Housing and Population	Housing Density	PM ¹ & R	3	5
	Recent Change in Housing Density		3	5
	Total Population		3	6
	Population Density		3	6
	Recent Population Change		3	6
Roads	Road Density	P, PM & R	2	7
	Road Length		2	7
	Distance to Roads		2	7
	Area without Roads		2	7
Disturbance	Total Area by Disturbance Type	P, PM & R	4	8
	Disturbance Occurrence		4	8

¹ LABE Jack Fire AOA not included

2.5.2 Land Cover

Land cover patterns are a reflection of the physical and chemical factors that shape the environment of a given land area (Whittaker 1967). Consequently, land cover composition, configuration, and connectivity help shape overall biological diversity patterns, including the complex of species occurring in an area, movements of individual organisms, and energy and material flows (Levin 1981, Noss 1990, Dunning et al. 1992, Franklin 1993, Taylor et al. 1993). Substantial changes in these land cover patterns occur in response to natural and anthropogenic processes and can have numerous impacts on ecological processes and native biodiversity.

Having the ability to track changes (natural and anthropogenic) in land cover at broad scales can provide insight into changes that are occurring in and around the parks. In parks such as WHIS, we see an expanding human population that can have direct and indirect effects on the park through land cover conversions. In some high elevation parks such as CRLA and LAVO, climate change may cause land cover types to expand or contract in elevation, changing habitat locations for native species. This is likely to be especially important as climate changes, because many species will need to use adjacent areas as migratory corridors to new climatically suitable habitats. Understanding the

status and trends in land cover composition, configuration, and connectivity within and adjacent to the parks and documenting changes in development and land conversion can be helpful in explaining changes and patterns of species diversity and distribution within the parks.

2.5.3 Landscape Pattern

An analysis of land cover will provide park managers with the knowledge of how the arrangement and pattern of broad-scale land cover types are changing over time. Understanding how those land cover types are distributed, as well as their sizes, shapes, and juxtapositions (e.g., large vs. small patches, connected vs. fragmented) throughout the AOA is important to understanding the integrity of landscapes and park ecosystems. The composition, configuration, and connectivity of land cover types profoundly influences ecosystem properties such as the flow of materials, species movements, effects of edges between patches, microclimates, and the dynamics of populations (Levin 1981, Andr  n 1994, Turner 2005, Hansen and DeFries 2007).

Species are affected by habitat fragmentation and connectivity in tremendously different ways, depending on their habitat preferences and requirements, as well as the scale, timing, duration, and magnitude of change (Cousins 2009). Landscape patterns at multiple scales affect species, and the effects of landscape composition or pattern may be detectable only at an appropriate scale for the species or process of concern (Wiens et al. 1987, Thompson et al. 2002). This project does not focus on a specific species but instead classifies habitat pattern and changes of habitat pattern at broad scales using standard, widely accepted units (Anderson classification level 2, see Anderson et al. 1976). Identifying changes at such a broad scale will not address single species questions directly, but can provide park managers a general idea of landscape changes associated with shifts in species composition, distribution, or diversity for those species whose habitat requirements are well known. The initial analysis of landscape pattern will provide a baseline that future analysis will be compared against to help formulate an understanding of long-term changes in broad-scale land cover patterns. Once identified, park managers will have the ability to use the NPScape tools (assuming habitat data such as park vegetation maps are available) to complete a more detailed species or habitat specific analysis.

In addition to understanding how natural land cover types are changing, altered landscape patterns can occur based on the conversion of natural habitat to an altered state, usually accompanied by a loss of important habitat or changes in its quality for the species of interest. McIntyre and Hobbs (1999) provide a useful framework for conceptualizing human effects of landscape pattern. With little or no human intervention, landscapes are initially intact. As impacts increase, landscapes are described as variegated, fragmented, and relictual, reflecting increasing degrees of habitat destruction, isolation of patches, and degree of modification. Examining changes in patterns of natural versus altered landscapes will provide managers important information about human impacts on the environment in or near the parks.

2.5.4 Housing and Population

In many landscapes, humans are the primary drivers of landscape change (Vitousek et al. 1997, Sala et al. 2000). Impacts on resources, both positive and negative, may originate directly from the behaviors of humans (e.g., negative effects like deforestation and poaching or positive like

reforestation and protection of riparian zones). Alternatively, impacts can arise indirectly from the infrastructure used to support humans (e.g., roads, housing). Although the extent of impact is often difficult to measure directly, data on human population characteristics (e.g., population change, economic status, and housing) can provide important information for evaluating the likely condition of lands adjacent to parks. These cultural, political, and socioeconomic factors all contribute to land use decisions (Naveh 1995, Nassauer 2005, With 2005) and are widely used indicators of landscape quality or threats to biodiversity (Cincotta et al. 2000, Nassauer 2005). Given that human land uses tend to expand over time (Wade et al. 2003), these data also provide a window into potential threats to park resources.

High human population density has been shown to adversely affect the persistence of native habitats and species (Kerr and Currie 1995, Woodroffe 2000, Parks and Harcourt 2002, Luck 2007). In an assessment of the coterminous United States, Svancara et al. (2009) found that counties near parks had higher population densities and experienced a greater change in population between 1990 and 2000 than distant counties. They suggested that, even with more intact landscapes surrounding parks, species in these counties may be more impacted by humans. In addition, housing density may be a better indicator of environmental impacts than population density alone because it accounts for declining household size (Liu et al. 2003) and second-home ownership (Radeloff et al. 2001, 2005). In addition, Theobald (2005) examined patterns of land use and developed a Landscape Sprawl metric that attempted to capture and communicate much of the information from housing density, corrected for land ownership, distance to roads, water, and other factors.

2.5.5 Roads

Roads and associated activities can profoundly impact a broad range of physical, ecological, and social attributes important to parks. Comprehensive reviews have documented extensive direct and indirect impacts of roads on both terrestrial and aquatic environments (Spellerberg 1998, Ercelawn 1999, Trombulak and Frissell 2000, Forman et al. 2003), the effects of which may be undetectable in some taxa for decades (Findlay and Bourdages 2000). Even in areas where human population densities are relatively low and landscapes are perceived as natural, the impacts of roads are pervasive (Saunders et al. 2002) and may extend hundreds to thousands of meters from the roadside (Forman 2000, Forman and Deblinger 2000, Forman et al. 2002).

Physically altering the landscape with roads results in the direct loss of habitat, fragmentation of the remaining habitat (Carr et al. 2002), altered landscape structure (Saunders et al. 2002), increased influence of edge effects (Carr et al. 2002), and disruption of hydrological processes (Jones et al. 2000, Trombulak and Frissell 2000). Wildlife populations are further impacted directly by increased mortality of organisms from vehicles (e.g., Fahrig et al. 1995), modified behavioral patterns such as home ranges and migrations (e.g., Reijnen et al. 1996, Forman et al. 2002), and exposure to physical barriers that limit or prevent access to resources (Trombulak and Frissell 2000, Forman et al. 2003, Jaeger et al. 2005). Roads also limit gene flow and subdivide and isolate populations (e.g., Gerlach and Musolf 2000, Keller and Largiader 2003). Separation of complementary habitats (e.g., breeding and feeding) can be particularly detrimental (e.g., Pope et al. 2000). Mortality from vehicle collisions can have significant effects on wildlife populations, particularly for smaller organisms. For example,

in studying four amphibian species, Hels and Buchwald (2001) found that the probability of getting killed ranged from 0.34 to 0.61 when crossing a low to moderately traveled road (3,200 vehicles/day) and from 0.89 to 0.98 when crossing a busy road (>15,000 vehicles/day). Their results indicate that about 10% of the adult populations of these species were killed annually by traffic in their study area.

Indirect effects of roads can be as important, or more so, than direct effects. Roads have been associated with an increased incidence of fire ignitions (Cardille et al. 2001, DellaSala and Frost 2001, Brown et al. 2004). Roads are also associated with an increased occurrence of invasive species (Trombulak and Frissell 2000), with improved roads having a greater proportion of exotic species occurrence and cover than unimproved (4WD) roads (Gelbard and Belnap 2003). Wildlife may experience increased legal hunting pressure and poaching (Trombulak and Frissell 2000) and chronic disturbance from human activity such as recreation (Thurber et al. 1994, Reijnen et al. 1996). More recent studies have identified other indirect species-specific effects, such as impacts of salt runoff on amphibians (Karraker et al. 2008). In the Pacific Northwest, roads have been associated with chronic and episodic sedimentation events in forested watersheds, with detrimental effects on aquatic ecosystems and their resident species (Wemple et al. 2001, Forman et al. 2003).

2.5.6 Disturbance

In all parks, natural disturbance regimes are central to the maintenance of landscape diversity and integrity, and are likely to change over time (Odion and Sarr 2007, Sarr et al. 2007). In some cases, changes in disturbance regimes will be due to local effects such as fire suppression, fuels reduction, or synoptic effects, such as anthropogenic climate change. These human influences occur against a backdrop of natural disturbance wrought by herbivores, climatic shifts, floods, and tectonic events. Disturbance is not only highly varied in mechanism, but it is also likely variable across the larger landscape. For instance, climate change is expected to cause a minor increase in precipitation in our region as well as an increase in the proportion of rain at mid-elevation areas. For lower elevation watersheds, this will likely result in larger winter floods and lower base flows in summer, whereas at the highest elevations, this may temporarily yield deeper snowpack. The glaciers on Mt. Shasta are growing even as snowpacks are melting earlier in the mid-elevations. In mid-elevation forests, earlier snowmelt and warmer summers are predicted to increase the severity and extent of wildfire (Westerling et al. 2003). Coastal forest and dune ecosystems are strongly affiliated with another suite of disturbance agents: marine fogs, wind, and waves

Although an ability to discern between natural and anthropogenic forces of change is critical to effective management, such clarity is often elusive due to the episodic nature of most disturbances, their variability, and inherent interactions. As a whole, the indicators measured in this protocol are intended to provide a large-scale, synthetic view of rather coarse-scale changes occurring in and around the parks that complements on-the-ground measurements being taken by the implementation of field-based vegetation, streams, and invasive species protocols and the NPS Fire Effects Program. Ideally, the field protocols will provide some substantiation for the mechanisms driving changes in landscape patterns, and the land cover and land use protocol will illustrate the scope, scale, and cumulative effects of the disturbances observed. They will also be important in helping to ensure that

our NPS efforts are summarized and conveyed in a way that reflects the broader landscape and the language and concerns of conservation science in our region.

3 Methods

The KLMN plans to utilize the methods developed by the NPScape team to complete the GIS analysis of the six indicators described above. Details on the methods used to complete the GIS aspects of this protocol are described in SOPs #2–8, however, a brief description is provided below. In addition, the analysis of the GIS data is described in detail in *SOP 10: Data Analysis and Reporting*.

3.1 Data Acquisition

This protocol outlines methods to analyze data related to land cover and land use once every six years. The year prior to analysis, data sources, analysis tools, and computer programs should be reviewed to determine their status and availability and a work plan should be developed. Once the work plan has been developed and the GIS Specialist has been selected, collection of datasets needed for the analyses described in SOPs #2–8 should be completed. While collecting the data, *SOP #1: Preparation and Data Acquisition* and *SOP #9: Data Management* should be followed to ensure datasets are properly documented and stored on the KLMN server. Table 5 provides a list of the datasets the KLMN used for the initial summary report, and that will likely be utilized in future Analysis and Synthesis reports (SOP #10).

Table 5. Data sources that were used to complete the 2015 summary reports for this protocol, along with the years that the data sources are expected to be updated and the last year the data source was updated.

Dataset	Indicator	# of Years Datasets Are Available	Update Timeframe (years)	Last Year Updated
USGS Protected Areas Database-US	Conservation Status	3	5	2012
USGS National Land Cover Data	Land cover, Pattern	3	5	2011
US Census Bureau Block Data	Population, Housing	3	10	2010
Park Data	Roads (park scale)	1	Continuous	Varies by park
Topologically Integrated Geographic Encoding and Referencing	Roads (regional and park- manager-selected scale)	5	Annual	2015
LANDFIRE	Fire, Anthropogenic Vegetation Disturbance	13	5	2012

3.2 Indicator Analysis

This section provides a brief description of the methods associated with the GIS analyses of the data to meet the goals and objectives of this protocol. More detailed information on each indicator can be found in the relevant SOPs, which are noted with each indicator below.

3.2.1 NPScape Indicators

As part of the NPScape project, specialized utilities have been developed to complete the analysis of the six indicators described below. The GIS Specialist will need to ensure the data sources are

formatted in a manner that works with these tools. Once this task is complete, all analyses for these indicators should run automatically in ArcGIS.

Conservation Status: The details on how to calculate these metrics are provided in *SOP #2: Conservation Status Metrics*. The International Union for the Conservation of Nature (IUCN) categorizes protected areas based on management intent (Dudley 2008). Many countries, including the United States, have similar programs to further refine and define what is protected. In the United States, the USGS Gap Analysis Program (GAP) is responsible for assessing the conservation status of biodiversity with the laudable goal of “keeping common species common.” As such, GAP has been the primary developer of land stewardship and protected areas information and has compiled the Protected Areas Database of the United States (PAD-US) (USGS 2012) with significant contributions from the Bureau of Land Management, the U.S. Forest Service, and The Nature Conservancy (Monahan et al. 2012). Two datasets are needed to complete this analysis: ownership information and the AOA polygons. For each park, we will complete this analysis for the park-manager-selected AOA (excluding LABE Jack Fire AOA) and the regional AOA. The data sources that were selected for the analysis are provided in *SOP #2: Conservation Status Metrics*.

Ownership categories that may be used for our analysis include:

- Federal
- State
- Nonfederal/State Public
- Tribal
- Private
- Water

Status (from the GAP definitions) is divided into the following categories:

- **Status 1:** An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.
- **Status 2:** An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.
- **Status 3:** An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g.,

logging) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area, as is required by law.

- **Status 4:** There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout.

Using the ownership and status categories defined above, we will examine the total and percent of area that is protected and the total and percent of area by ownership that occurs within each of the AOAs.

Land Cover: The details on how to calculate these metrics are provided in *SOP #3: Land Cover Metrics*. Two datasets are needed to complete this analysis: land cover information and the AOA polygons. We will complete this analysis for the three AOAs described in the “Area of Analysis” section above (park, park-manager-selected, and regional). The data sources that were selected for the analysis are provided in *SOP #3: Land Cover Metrics*. For this analysis, we will use Anderson Level 2 classification scales that are presented in Table 6. We will examine the total area and proportion of the landscape that is classified at the Anderson Level 2 classification within each AOA, and investigate how these classification types have changed over time. Also, we will calculate impervious surface cover and summarize total area and percent area by range category. Natural lands vs. converted lands will also be summarized by total area and percent area, and the percent change in area.

Table 6. Anderson level 1 and 2 classes.

Anderson Level 1	Anderson Level 2
1 Open Water	11 Open Water
	12 Perennial Ice/Snow
2 Developed	21 Developed Open Space
	22 Developed Low Intensity
	23 Developed Medium Intensity
	24 Developed High Intensity
3 Barren/Quarries/Transitional	31 Barren Land
4 Forest	41 Deciduous Forest
	42 Evergreen Forest
	43 Mixed Forest
5 Shrub/Scrub	51 Dwarf Scrub
	52 Shrub/Scrub
7 Grassland/Herbaceous	71 Grassland/Herbaceous
	72 Sedge/Herbaceous
	73 Lichens
	74 Moss
8 Agriculture	81 Pasture/Hay
	82 Cultivated Agriculture
9 Wetlands	90 Woody Wetlands
	95 Emergent Herbaceous Wetlands

Landscape Pattern: The details on how to calculate these metrics are provided in *SOP #4: Pattern Metrics*. Three datasets are needed to complete this analysis: landscape morphology rasters, landscape density rasters, and the AOA polygons. We will complete this analysis for two of the AOAs described in the “Area of Analysis” section above (park-manager-selected and regional). The data sources that were selected for the analysis are provided in *SOP #4: Pattern Metrics*.

As part of the pattern analysis, we are examining two separate characteristics of land cover pattern, both at three Anderson level 1 classes (see Table 6): Forest, Shrubland, and Grassland. One characteristic measures the density of each cover type and the other is a description of the morphology. The density of each class is summarized in seven categories (see Table 7). A land cover type is considered highly dense if no other land cover type or open space is detected in its vicinity (the size of the vicinity measured can be adjusted based on pixel size). By density class, we will provide total area, percent of area of that Anderson level 1 class, and percent of the AOA.

Table 7. Area density class definitions for forest or grassland cover within a moving window GIS analysis. Area density is the proportion of a fixed-area neighborhood surrounding a location that is a given land cover type. GIS analysis window size can vary depending on pixel size and image detail. These classes follow Riitters (2011).

Area Density Class	Area Density (p)
Intact	$p = 1.0$
Interior	$0.9 \leq p < 1.0$
Dominant	$0.6 \leq p < 0.9$
Transitional	$0.4 \leq p < 0.6$
Patchy	$0.1 \leq p < 0.4$
Rare	$0.0 \leq p < 0.1$
None	$p = 0.0$

The landscape morphology analysis is a pixel-based, structural approach to identifying specific types of landscape pattern elements as defined in Table 8. A summary of total area and percent of area for each of the morphological classifications will be provided along with an examination of trends for these classifications over time. We will also provide the count and total area by patch size range.

Table 8. Area morphology pattern types for NLCD cover within the moving window.

Pattern Type	Description
Branch	A cluster of non-core pixels connected to one edge.
Edge	Pixels within a defined distance ('edge') to the background. We used an edge of 150 m (5 pixels).
Islet	Island of pixels that is not core habitat.
Core	Pixels that are within a patch, and more than 10 m from non-patch types. In other words, core areas are areas that are not near the transition zones of classification types.
Bridge	A cluster of non-core pixels connected at two or more locations to edge.
Perforated	Inner boundary of a core area that is adjacent to a hole in the core area.
Loop	A cluster of pixels that connects to two or more locations of the same edge

Housing and Population: The details on how to calculate these metrics are provided in *SOP #5: Housing Metrics* and *SOP #6: Population Metrics*. Population metrics are based on U.S. Census Bureau data and projections from state offices. Housing density metrics are based on the Spatially Explicit Regional Growth Model (SERGoM, v3, Theobald 2005). The data will be “corrected” to account for areas where people and housing cannot persist (e.g., lakes, protected areas). For each park, we will complete this analysis for the park-manager-selected AOA (excluding LABE Jack Fire AOA) and the regional AOA. The data sources that were selected for the analysis are provided in *SOP #4: Housing Metrics* and *SOP #5: Population Metrics*.

As part of the population analyses, we will provide summaries and examine trends for the total population and population density as well as changes in population size and density, for each AOA examined.

For housing analyses, we will combine housing densities into grouped housing density classes (see Table 9). By class, we provide total area, percent of total AOA, and percent of census area.

Table 9. Grouped housing density classes represent one or more housing density classes.

Grouped Housing Density Class	Housing Density Class
Urban-Regional Park	Urban-Regional Park
Commercial / Industrial	Commercial / Industrial
Urban	>2,470 units / km ²
	1,235–2,470 units / km ²
Suburban	495–1,234 units / km ²
	146–495 units / km ²
Exurban	50–145 units / km ²
	25–49 units / km ²
	13–24 units / km ²
	7–12 units / km ²
Rural	4–6 units / km ²
	1.5–3 units / km ²
	< 1.5 units / km ²
	Private undeveloped

Roads: The details on how to calculate these metrics are provided in *SOP #7: Road Metrics*. Three datasets are needed to complete this analysis: one roads layer for the park-manager-selected and the regional AOAs, a second roads layer for the park AOA, and the spatial extent of the analysis or Area of Analysis (AOA). The data sources that were selected for the analysis are provided in *SOP #7*.

As part of the roads analysis, we will examine total road length and road density within each AOA. Additionally, we will look at the distance to the nearest road (each pixel will be assigned the value of how far it is from the nearest road). This analysis is a pixel based approach that will be used to compare areas that are virtually roadless to areas where road densities have the ability to affect ecological integrity. Finally, for roadless areas, we will summarize the count and total area by size range categories. Water bodies and polygons smaller than 0.0144 km² will be removed.

3.2.2 Disturbance Indicators

In addition to the NPScape indicators, the KLMN will also analyze data on several disturbance indicators described below. The details on how we calculated these metrics are provided in *SOP #8: Disturbance Metrics*. There are a variety of broad-scale disturbance types that are currently affecting the parks in the Klamath Network, including wildfire and prescribed burning, disease (e.g., blister rust), species expansions (e.g., bark beetle), vegetation rehabilitation projects, and resource extraction

activities (e.g., timber harvest). While it would be useful to study all of these disturbance events, consistent data sources that cover the Klamath region are often not available.

Based on the parks' needs and the datasets available, we decided to focus on examining disturbance events utilizing data from the LANDFIRE. LANDFIRE is a shared program between the U.S. Department of Agriculture Forest Service and the U.S. Department of the Interior. LANDFIRE disturbance data are currently available from 1999 to 2012. For the three AOAs, total area and percent of AOA will be provided by disturbance types defined in Table 10.

Table 10. LANDFIRE disturbance type classifications and their description that will be summarized as part of this protocol.

Classification Value	Classification Description
Development	Conversion of natural lands into housing, commercial, or industrial building sites. Involves permanent land clearing.
Clearcut	The cutting of essentially all trees, producing a fully exposed microclimate for the development of a new age class.
Harvest	A general term for the cutting, felling, and gathering of forest timber. The term harvest was assigned to events where there was not enough information available to call them one of the two distinct types, clearcut or thinning.
Thinning	A tree removal practice that reduces tree density and competition between trees in a stand. Thinning concentrates growth on fewer, high-quality trees, provides periodic income, and generally enhances tree vigor.
Mastication	Means by which vegetation is mechanically “mowed” or “chipped” into small pieces and changed from a vertical to horizontal arrangement
Other Mechanical	Catch all term for a variety of forest and rangeland mechanical activities related to fuels reduction and site preparation including; piling of fuels, chaining, lop and scatter, thinning of fuels, Dixie harrow, etc.
Wildfire	An unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to suppress or put out the fire.
Wildland Fire Use	The application of the appropriate management response to naturally-ignited wildland fires to accomplish specific resource management objectives in pre-defined designated areas outlined in Fire Management Plans.
Prescribed Fire	Any fire ignited by management actions to meet specific objectives. A written, approved prescribed fire plan must exist, and NEPA requirements (where applicable) must be met, prior to ignition.
Wildland Fire	A catch all term used to describe any non-structure fire that occurs in the wildland. Three distinct types of wildland fire have been defined: wildfire, wildland fire use, and prescribed fire. The term wildland fire was assigned to events where there was not enough information available to call them one of the three distinct types.
Weather	Weather related event that results in loss of vegetation such as blowdown, hurricane, or tornado.
Insecticide	Application of a chemical substance used to kill insects
Chemical	Application of a chemical substance. The term chemical was assigned to events where there was not enough information available to call them one of the two distinct types, herbicide or insecticide.
Insect	Infestations of unwanted insects that can affect vegetative health such as bark beetle.
Disease	Infestations of disease that can affect vegetative health such as root rot.
Insect/Disease	Infestations of insects and/or disease that can affect vegetative health. This term was assigned to events where there was not enough information available to call them one way or the other.
Herbicide	Application of a chemical substance used to kill or inhibit the growth of plants
Biological	The use of living organisms, such as predators, parasites, and pathogens, to control weeds, pest insects, or diseases
Unknown	Sources indicate that a disturbance occurred but causality is uncertain.

4 Data Management, Analysis, and Reporting

This section focuses on all aspects of managing, storing, analyzing, and reporting monitoring data according to the Network's data management plan (Mohren 2007) and the reporting schedule in the Network's vital signs monitoring plan (Sarr et al. 2007). Methodological details are located in these plans and the SOPs referenced herein. It is crucial to successful monitoring that project personnel understand all necessary data management methodologies. This includes knowing who is responsible for implementing the methods and the timelines they are expected to follow when conducting data management.

4.1 Metadata

Nearly all the data collected or created as part of this project are spatial data, and so should conform to the standards provided by the National Spatial Data Infrastructure – NSDI (FGDC-STD-012-2002). Datasets gathered from national and regional level programs should already have metadata available. Metadata for datasets obtained from the parks can vary in completeness and the GIS Specialist should work with the parks' GIS staff to make certain metadata are available. A dataset should NOT be used if the KLMN is not able to obtain or develop the appropriate metadata. *SOP #1: Preparation and Data Acquisition* provides the details on what metadata are needed prior to using a dataset

4.2 File Structure

This protocol is designed to allow the Project Lead to change or add new data sources over time provided that data source meets the criteria described in the “Data Sources and Conditions” section of this protocol. Since the data source can change, it is critical that a file structure is in place that allows the Network to manage and retrieve any dataset that was used in a current or previous analysis. In other words, a future employee should be able to access the appropriate datasets to repeat an analysis that was done in the past. The KLMN will use a series of geodatabases and a folder structure to keep data and information organized. This structure will follow the basic project folder structure used for all KLMN projects, with some minor modifications to account for the uniqueness of the data and information managed as part of this protocol (Mohren 2007). *SOP #9: Data Management* provides more details on the filing structure used for this project.

The project file structure used by the KLMN should also include all administrative documents and files that were used to develop this protocol as required by the Pacific West Region protocol development process.

4.3 Data Quality

Unlike other KLMN vital sign monitoring projects, we do not plan on creating any new field data as part of implementing this protocol. Instead, we will utilize data that are available at the time of analysis and meet the criteria described in the “Data Sources and Conditions” section above. Each year this protocol is implemented, details about the data we used will be included in Analysis and Synthesis reports.

4.4 Reporting and Analysis of Data

Unlike other KLMN protocols where monitoring projects have annual reports and Analysis and Synthesis reports, this project is implemented once every six years; we will only complete an Analysis and Synthesis report for the year the protocol is implemented.

Detailed methods for each report and analysis can be found in *SOP #10: Analysis and Reporting*. In the initial year, 2016, we completed a status and summary report that examined each of the measures described in Table 4. This report provides summaries of some past and current data that can be used as baseline information for comparison as part of future analysis. See Ives et al. (2016) for the LAVO Summary Report which serves as a model for the other parks' reports (*in prep*). In 2021 and every six years thereafter, we will begin to look at trends in each of the measures described in Table 4. By this time, most measures will have three or more data points in time so that a trend can be examined; however, since some measures will only have three points in time, care will need to be taken when describing these trends.

4.5 Report Format

All reports will use the NPS Natural Resource Publications template, a pre-formatted Microsoft Word template document based on current NPS formatting. While exceptions are possible, we plan to publish the initial summary reports in the Natural Resource Data series and future reports will be published in the Natural Resource Report series. Templates and documentation of the NPS publication standards are available at:

<http://www.nature.nps.gov/publications/NRPM/index.cfm>.

4.6 Product Distribution

It will be the Network Data Manager's responsibility to populate or update the NPS I&M databases, including Integrated Resource Management Applications (IRMA). The Project Lead is responsible for distributing any final reports and information to the parks. Details on distribution can be found in *SOP #9: Data Management*. In general:

- All reports will be posted to IRMA and links provided on the KLMN website.
- All reports will be sent to the Resource Chiefs of each park and to any park staff that are associated with the project.
- All reports, final GIS products, and any other additional appropriate materials will be posted and linked to the project record in IRMA.

4.7 Data Storage and Archiving Procedures

File structure, version control, and regular backups are carefully controlled to preserve the integrity of Network datasets (see Network's data management plan [Mohren 2007]). As described above, all data are transferred to the Network Data Manager, where they are placed on a Network server and are subject to regular archiving and backup processes as described in the Network's data management plan. Details on storage and archiving can be found in *SOP #9: Data Management*,

which contains all aspects of file management, including how to manage the administrative record for this protocol.

5 Personnel Requirements and Training

5.1 Roles and Responsibilities

Five key positions are necessary to complete this project. These are the Network Program Manager, Network Data Manager, Network Contact, Project Lead, and GIS Specialist. In some cases, multiple positions can be occupied by one individual. For example, the Network Data Manager may also be the Network Contact and the GIS Specialist may also be the Project Lead. It is most important to ensure that an individual has the skills and knowledge to complete their responsibilities as described below. Reports—both Analysis and Synthesis and Administrative—are used to document the staffing structure that is utilized each year the project is implemented.

5.1.1 Network Program Manager

The Program Manager is ultimately responsible for ensuring that the fiscal and staffing resources are available for the completion of this protocol and determining who will serve as the Network Contact. The Program Manager should be in contact with the Network Contact well in advance of analysis years to assist with determining how to staff this project (see chapter 6, Operational Requirements). During analysis years, the Program Manager should also be in continuous communication with the Network Contact to make certain the project is getting completed on time and is meeting the Network work plan. The Program Manager is also responsible for working with park staff to ensure that products are relevant and useful.

5.1.2 Network Data Manager

The Data Manager is responsible for ensuring that staff members working on the project are following the KLMN data management plan (Mohren 2007) and will oversee the data management strategy throughout the entire project. Initially, the Data Manager will ensure that personnel have access to required data and documents. In addition, the Data Manager should be consulted when there are any data processing issues and kept abreast of any problems encountered. Upon completion, the Data Manager should review all data and information developed as part of this project, along with the filing structure, to ensure products are appropriately documented and archived as necessary. In addition, it is the Data Manager's responsibility to make final deliverables available via the KLMN website and IRMA.

5.1.3 Project Lead

The Project Lead is responsible for running the day-to-day operations of this project. This individual should manage the logistics of the project, develop work plans and timelines, set priorities, and work with the GIS Specialist to develop reports. The Project Lead should work closely with the Network Contact and the Network Data Manager to make sure they have everything needed to implement the project.

5.1.4 Network Contact

If the Project Lead is not a KLMN employee, then the Program Manager should select a KLMN employee to be the Network Contact. If the Project Lead is a KLMN employee, then this person will also be responsible for the Network Contact's responsibilities. The Network Contact is the direct contact for this project and is responsible for representing the KLMN in all issues related to this

protocol. The Network Contact should be in constant communication with the Program Manager and Project Lead on issues related to this project. The Network Contact should help with logistics, personnel, and procurement issues when necessary. The Network Contact should be up to speed on the current status of this project, including what work has been done in the past, what work is currently being done, and what work is planned for the future. The Network Contact is also responsible for the initial reviewing of datasets to determine if they are available for analysis.

5.1.5 GIS Specialist

The GIS Specialist is responsible for completing any GIS analysis described in this protocol. In addition, the GIS Specialist should work closely with the Project Lead to develop any reports that are part of this protocol. It is expected that the GIS Specialist will have the largest workload related to this project and will need to budget time appropriately to complete the project within the given timeline.

5.2 Hiring, Qualifications, and Training

By April in the year prior to implementing this project, the KLMN Program Manager and Network Contact should have a discussion on what staffing vehicle (task agreement, contract, or park/network staff) the Network will use to complete this project. During this meeting potential Project Leads and GIS Specialists should be discussed.

5.2.1 Hiring Staff

If the determination is made that an individual(s) is already available to fulfill the duties of the Project Lead and GIS Specialist, then the Program Manager should assign these individuals the appropriate role, and a timeline for implementing the project should be developed.

If the determination is made that the Project Lead and/or GIS Specialist will be hired via a contract or agreement, the Network Contact should begin the process of developing the cooperative agreement, task agreement, or contracting, depending on what is necessary. The April starting date described above is necessary to ensure these contracts are in place prior to starting the project in the upcoming year. In addition to starting the contracting process, the Program Manager should be certain the budget is available and has been included in the KLMN Annual Work Plan.

5.2.2 Qualifications

To implement this protocol, it is critical that the Project Lead and GIS Specialist have the skills and knowledge needed to accurately complete the analyses and write the reports described in the protocol. Strong GIS skills, writing skills, and knowledge about the parks will be needed to address the monitoring and management objectives described in this protocol.

5.2.3 Training

This protocol relies heavily on individuals who have strong writing and GIS skills. When determining who will implement the work associated with the protocol, the Program Manager should look for individuals who already have these skills. If the Network has selected individuals who have not utilized the NPScape products or tools in the past, and training on these tools is available, then it is highly recommended that the GIS Specialist and Project Lead attend these trainings.

6 Operational Requirements

6.1 Initial Data Review

Prior to committing funding to this protocol, the Network Contact should review the status of the data sources that the KLMN plans on using or has used in the past for this protocol. The Network Contact should provide the Program Manager with a status report that informs the Program Manager of which data sources have been updated and when updates are scheduled for those data sources that have not been updated. At this time, the Program Manager should make the decision whether to fund the protocol. This process should occur every six years (starting in 2021) since that is the timeframe that the KLMN will have funding available and most datasets are expected to be updated. It is important to note that only the data sources needed for a specific analysis need to be available and it is not necessary to have all data sources updated before an analysis can be done. The Network Contact should review *SOP #10: Analysis and Reporting* to determine which data sources are needed.

Once the decision is made to implement this protocol, the Network Contact should work closely with the Program Manager to determine 1) levels of available funding, 2) which staff member(s) or partners will be assigned to implement this project, and 3) when the project will be implemented.

6.1.1 When to Implement

Since this protocol does not require a “traditional” field season and is based on data that have already been developed, it can be implemented anytime throughout the year. Once the funding, staffing, and data availability questions have been resolved for a given year, it is the assigned Project Lead’s duty to put together a work plan and timeline for implementing this protocol (*SOP #1: Preparation and Data Acquisition*). When determining the timeline, the following should be taken into consideration:

1. If this project is being completed using a contract or agreement, that procurement document should be in place prior to starting the work.
2. Generally the Program Manager and Data Manager will help review all products from this effort. The Project Lead should work with the Program Manager and Data Manager to schedule the review process.
3. In general, there are a few time periods where the workload for all staff in the KLMN increases. Some examples would be in June when task agreements, contracts, and purchasing are completed, or in November/December when data management tasks related to projects are being completed and annual reports are being written. These time periods should be avoided if KLMN staff time will be needed to implement this project.

6.2 Workload and Implementation Schedule

Preparations for implementing this protocol should begin at least six months prior to the start date of the project. The main reason for starting so early is to identify who will be completing the acquisition of data, analysis, and report writing aspects of this project. If the selected person is already working for the KLMN, then the project can be started immediately. However, if the KLMN has to hire someone via a task agreement, contract, part staff, or direct hire, this may take longer and require

greater coordination. Once the GIS Specialist starts the analysis and report preparation, it is estimated that the substantive steps of this protocol can be completed in four to six months.

Upon starting the project, the GIS Specialist at each park should be informed that we will be implementing our land cover / land use protocol. Where local datasets are being used (e.g., road layers), park GIS staff can prepare data for analysis, which includes steps such as 1) making sure the attributes are correct, 2) checking topology, 3) clipping layers, and 4) checking projections. At this time, the GIS Specialist should acquire up-to-date GIS layers from the parks needed for this analysis (*SOP #1: Preparation and Data Acquisition*). In addition, data layers from additional sources (e.g., TIGER, NLCD) should be collected and stored in the appropriate location (*SOP #9: Data Management*).

Once the appropriate data have been collected, the data analysis can be completed following the guidance in *SOPs #2–8*. The GIS Specialist is responsible for completing the data analysis and as each analysis is completed, the Project Lead should review the analysis to see if any adjustments need to be made before beginning the report writing.

Once the analysis is finalized, the Project Lead and GIS Specialist should write the final report. Upon completion, this report should be reviewed in-house following the KLMN standards and then submitted to the Natural Resource Report Series following the peer review and submission process (*SOP #10: Analysis and Reporting*).

Once the data collection, analysis, and reporting processes are complete, all data and information from the project should be organized by the Project Lead and GIS Specialist following *SOP #9: Data Management*. This information should be reviewed by the Data Manager and posted to the appropriate locations (IRMA, KLMN website) prior to ending the project.

6.3 Facility and Equipment Needs

This project will require office space, computer equipment (two monitors are useful), and software (e.g., ESRI ArcGIS, Microsoft Office) to complete. If this project is being completed outside the KLMN office, the Project Lead should ensure all appropriate hardware and software are available prior to beginning the analyses. *SOP #1: Preparation and Data Acquisition* provides a list of software and specifications for hardware needed to complete this project.

6.4 Budget Considerations

We expect the majority of the costs of this protocol to be personnel salaries, benefits, and travel. The majority of the tasks and time will be divided between the GIS Specialist and/or the Project Lead, depending on their knowledge and skill level. If a Project Lead and GIS Specialist need to be hired through NPS, then the cost is approximately \$42,395 for each year it is implemented. However, if the Network already has staff that can fill the Project Lead or GIS Specialist roles, then the cost is significantly reduced (Table 11). The current budget provides for the Project Lead and GIS Specialist to travel to each park to present the results of the protocol to park staff and assumes that park housing is available. If the GIS Specialist or Project Lead is university-based, the comparable costs will need to include the appropriate indirect costs and benefits for their institution. Since the majority of the

methods described in this protocol involve data management, data analysis, and reporting, it should easily meet the minimum recommended WASO standard that 30% of time and budget are dedicated to these activities.

Table 11. Estimated project budget for the KLMN Land Cover and Land Use monitoring protocol. KLMN Program Manager and Data Manager salaries are core expenses (i.e., fixed costs) and thus are not included in the project budget total.

Position	Pay Grade	Pay Periods	Salary (FY15)
Program Manager	GS-13/05	0.5	\$2500 (fixed cost)
Data Manager	GS-11/05	1.0	\$3580 (fixed cost)
Project Lead	GS-11/05		
Logistics		0.5	\$1790
Report Writing		2.5	\$8940
Data Management		0.5	\$1790
GIS Specialist	GS-09/05		
Data Acquisition/Mgmt		3.0	\$8865
Data Analysis		3.0	\$8865
Report Writing		3.0	\$8865
Supplies			\$1000
Travel (\$190/park* 2 people * 6 parks)			\$2280
Total			\$42,395, not including fixed costs

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Appendix A: Summary of Land Cover / Land Use Indicators

This appendix includes the indicator summaries developed by the NPScape team for the conservation status, land cover, landscape pattern, housing and population, and roads indicators. Much of the material from this protocol was developed using these summaries.

1 Conservation Status

1.1 Background and Justification

The conservation status (ownership, stewardship, and use) of land surrounding parks can have profound impacts, both positive and negative, on resources (GAO 1994, Hansen et al. 2005). Different mechanisms within general categories of changes in the effective size of reserves, changes in ecological flows, loss of critical habitat, and increased exposure to humans, influence processes and biodiversity (Hansen and DeFries 2007). Within each category, Hansen and DeFries (2007) distinguished the types of mechanisms that drive changes, such as species area effects, trophic structure, migration habitats outside parks, and hunting and poaching. A common feature of these effects is that they are known or strongly postulated to be directly related to land use intensification. While it can be difficult to directly measure impacts, several broad-scale datasets can provide important information to evaluate the likely condition of parks, and current or likely threats to park resources.

The impacts articulated above may originate directly from the behaviors of humans (e.g., poaching), or indirectly from the infrastructure used to support humans (e.g., roads). Data on both direct and indirect impacts are useful, and are available from a variety of metrics currently in use.

As an example, changes in land use and stewardship near and adjacent to parks are important for assessing current threats and impacts, and for evaluating how the situation around parks might change in the future. Globally, Hoekstra et al. (2005) examined broad-scale patterns of habitat conversion and protection (stewardship) and used the ratio to estimate a Conservation Risk Index and to help identify biomes that were at greatest risk. Svancara et al. (2009) have applied this index to counties within the conterminous United States to identify counties surrounding National Park Service units and National Wildlife Refuges most at risk.

Information on the context of parks is needed to evaluate not only the current status of parks, but also to identify potential threats and key conservation opportunities.

1.1.1 Monitoring Questions

Information on context is useful from local to national scales and key for linking across scales. Monitoring questions are thus stated in a general form, recognizing that refinements are necessary to clarify the desired objectives, the area of analysis, and suitable comparisons.

General questions include:

- What percent of lands surrounding my park are protected and what does this say about future risks to resources?

- In which biomes/ecoregions/divisions are park units potentially most at risk?
- What is the spatial relationship of my park boundary with surrounding protected areas and converted lands?
- For what parks does the current conservation status of surrounding lands provide the best conservation or education opportunities?

1.1.2 Objectives

- Provide information necessary to assess the conservation status of lands surrounding parks.
- Provide a basis for estimating changes in protection status and land conversion over time.
- Reveal opportunities for cooperative management, conservation, and education.
- Provide context for evaluating conservation status among regions of the country.

1.2 Metrics

1.2.1 Percent Protected

Protected areas are often seen as the primary means of conserving biodiversity. Calculating the percent of land area protected provides an indication of conservation status and offers insight into potential threats (how much land is available for conversion and where is it located in relation to the park boundary) as well as opportunities (connectivity and networking of protected areas).

Percent protected is calculated as area of land protected divided by the total area of land. Open water may or may not be included in the total, depending on the management status and jurisdiction of the water, which, often times, is not actively owned or managed by any one entity. Various combinations of the metric can be used to gain insights into the protection status of various species and habitat types, as is done with the gap analysis process (see Scott et al. 1993).

While generic, a priori targets of 10 and 12% protected land are often seen as conservation goals for political entities, whereas goals based on scientific evidence are nearly three times as high (Svancara et al. 2005). Setting quantitative conservation targets can have utility, but those targets need to be informed by conservation planning processes based on the biological needs of species, communities, and ecosystems. In addition, social and economic constraints may apply.

1.2.2 Percent Ownership

Land ownership and stewardship often dictate and direct potential changes in land use. Identifying the percent of land area owned and managed by various entities near and adjacent to parks is important for assessing potential current threats and impacts, and for evaluating how the situation around parks might change in the future.

Percent ownership is calculated as the area of land within each of the broad ownership categories divided by the total area of land. Ownership categories will include all federal agencies (identified separately), nonfederal public (for state, county, etc.), tribal, and private. Open water may or may not

be included in the total, depending on the management status and jurisdiction of the water, which, often times, is not actively owned or managed by any one entity.

1.3 Issues and Assumptions

In addition to the issues and assumptions identified in the land cover indicator summary, the following apply:

- GAP only identifies private land as a single homogeneous category. It does not differentiate individual private land units, owners, or management status, unless the information was provided voluntarily (typically to recognize a long-term commitment to biodiversity through binding conservation easements, covenants, or institutional dedication).
- State GAP products are not necessarily consistent across state lines. Therefore, the PAD may also be inconsistent. Regional GAP products are developed across multiple states to alleviate this issue but, there may still be inconsistencies between regions.
- The described process does not account for land units smaller than the minimum mapping unit (MMU) of either of the input datasets.
- Results are valid only at the point in time that the data were acquired.
- As with all spatial analyses, inaccuracies in the input data will multiply in the output.
- Calculating the proportion of area in any manner is always a function of the sampling unit being measured (e.g., county, biome, grid cell size) and must be interpreted within that context.

1.4 Data Descriptions

1.4.1 Data Availability

Data on land use (conversion) are available at several scales from multiple sources. Those consistently available at regional and national scales include the following:

- LANDFIRE
- Gap Analysis Program (GAP)
- NatureServe Ecological Systems
- NOAA Coastal Change Program (C-CAP)
- National Agricultural Statistics Service (NASS)
- National Resources Inventory (NRI)
- Waisanen and Bliss (2002)

Data on land ownership, stewardship, and management status may be available at local scales in some areas; for regional to national assessments, sources are from the USGS National Gap Analysis Program Protected Area Database US version 1.3.

Gap Analysis Program

Land stewardship is one of the three main data layers developed and used by GAP (for additional information see GAP 2000). In GAP, land stewardship combines attributes of ownership, management, and a measure of intent to maintain biodiversity. The term “stewardship” is used in place of “ownership” in recognition that legal ownership of a land area does not necessarily equate to the entity charged with managing the resource, and that the mix of ownership and managing entities is complex and can change rapidly. At the same time, it is necessary to distinguish between stewardship and management status in that a single land steward, such as a national forest, may contain several degrees of management for biodiversity. In developing the stewardship layer, three primary pieces of information are incorporated: 1) geographic boundaries of public land ownership (and voluntarily provided private conservation lands [e.g., TNC preserves]), 2) the manager/owner attributes of each mapped land unit, and 3) the biodiversity management status rank of each mapped unit.

GAP currently uses a scale of 1 to 4 to denote the relative degree of management commitment to the maintenance of biodiversity for each land unit (status). A status of 1 denotes the highest, most permanent level of commitment, and a status of 4 represents the lowest level or unknown status. In assigning status, the gap analysis process follows certain principles. The first principle is that prescribed management, not land ownership, is the primary determinant. The second principle is that while data are imperfect, and all land is subject to changes in both ownership and management, the intent of a land steward as evidenced by legal and institutional factors can be used to assign status. The criteria used in assigning a ranking include the following:

- Permanence of protection from conversion of natural land cover to unnatural (human-induced barren, arrested succession, cultivated exotic-dominated).
- Relative amount of the land unit managed for natural cover, with 5% allowance for intensive human use.
- Inclusiveness of the management (i.e., single feature or species versus all biota).
- Type of management (e.g., suppresses or allows natural disturbance) and degree that it is mandated through legal and institutional arrangements.

Using the above criteria, the four biodiversity management status ranks can generally be defined as follows (after Scott et al. 1993, Edwards et al. 1994, Crist et al. 1996):

Status 1: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.

Status 2: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive

uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.

Status 3: An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area.

Status 4: There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout.

Status 1 and 2 lands are considered “protected” and are the basis of GAP analysis of species and habitat protection.

GAP program standards are to map stewardship to a minimum mapping unit (MMU) of 40 acres (16 ha) (quarter-quarter section) or smaller. This is based on the Public Land Survey System (PLSS), which dominates the land ownership patterns in the western United States, and therefore has some western bias. Some state and regional GAP programs actually map to a much smaller MMU. GAP data are freely distributed through the GAP portal (<http://gapanalysis.usgs.gov/>). Dates of the data vary by state and region as do revisions or updates.

Protected Areas Database

In an attempt to consistently represent protected areas in the conterminous United States, Alaska, and Canada, the original Protected Areas Database (PAD) was developed in 1999 by the Conservation Biology Institute and the World Wildlife Fund (see DellaSala et al. 2001). It built upon the Managed Areas Database (MAD), a 1:2 million scale dataset depicting major managed areas in the conterminous United States (McGhie 1996). The second (2001), third, and fourth (2006) versions of PAD have focused on only the conterminous United States and Alaska. Each version incorporates additional information from the state GAP data as it becomes available and the most current changes to agency datasets if not reflected in the GAP data. The GAP assigned management status is included.

Assembled on a state-by-state basis using existing data, PAD incorporates dozens of different data sources at varying scales (though most are 1:100,000) and accuracy levels. Metadata are provided by state for each data source.

Protected Areas Database – United States (Version 1.3)

Governmental and nonprofit organizations collaborated on a redesign process co-funded by the USGS and the Doris Duke Foundation to improve the national inventory of protected areas. The result of this partnership is PAD-US.

The first soft release of PAD-US version 1.0 was in April 2009. Version 1.3 was published in November 2012. Additional information on PAD-US can be obtained from <http://gapanalysis.usgs.gov/padus/>.

1.4.2 Data Dimensions (Spatial, Temporal, Thematic)

Gap Analysis Program (GAP)

- State level data available for all 50 states plus Puerto Rico
- 1:24,000 scale (Status 1 and 2); 1:100,000 scale (all others)
- Land ownership, stewardship, and management status
- Dates vary by state
- Available for free from the USGS national Gap Analysis Program website: <http://gapanalysis.usgs.gov/>

Protected Areas Database (PAD)

- National level data for the conterminous United States and Alaska
- Varying scale and accuracy of source data
- Land ownership, stewardship, and management status
- Dates vary by state and ownership

Protected Areas Database – United States (PAD-US)

- National level data for all 50 states
- Updates to, and combinations of, GAP and PAD
- Varying scale and accuracy of source data
- Land ownership, stewardship, and management status
- Dates vary by state and ownership
- Available for free from the USGS National Gap Analysis Program, Protected Areas Data Portal: <http://gapanalysis.usgs.gov/padus/>

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2 Land Cover

2.1 Background and Justification

Land cover patterns are a reflection of the physical and chemical factors that shape the environment of a given land area (Whittaker 1967). In turn, land cover composition, configuration, and connectivity help shape overall biological diversity patterns, including the complex of species occurring in an area, movements of individual organisms, and energy and material flows (Levin 1981, Noss 1999, Dunning et al. 1992, Franklin 1993, Taylor et al. 1993). Substantial changes in these land cover patterns occur in response to natural and anthropogenic processes and can have numerous impacts on ecological processes.

In many landscapes, humans are the primary drivers of landscape change (Vitousek et al. 1997, Sala et al. 2000). Given that human land uses tend to expand over time (Wade et al. 2003) and habitat loss is nonrandom (Seabloom et al. 2002), quantifying and monitoring the extent and pattern of natural land cover around protected areas is important in evaluating not only the current status of park biota, but also to identify potential threats and key conservation opportunities. It has been hypothesized that only protected areas with adequate expanses of surrounding habitat and linkages to other protected areas will be able to support current levels of biodiversity into the future (Hansen et al. 2001).

Maps depicting land cover and land use are necessary for nearly all planning, management, and monitoring programs at local, regional, and national levels. Generally, land cover is mapped by adopting a land cover classification system, delineating areas of relative homogeneity, then labeling these areas using classes defined by the classification system. This mapping takes many forms—no single mapping strategy will work best in all locations. The usefulness, efficiency, and cost-effectiveness of any land cover map is dependent on the scope and scale of questions being addressed, the spatial and temporal scale of imagery, the comprehensiveness of field and classification methods employed, and the level of accuracy desired. Key to selecting an adequate scale at which to evaluate the status and trends of land cover composition, configuration, and connectivity is identifying what is being managed (e.g., what species or processes; Beatley 2000) and the scales to which those species/processes respond. Appropriate application of remote sensing imagery (e.g., aerial photos, multispectral, hyperspectral, laser) and methods (e.g., photo interpretation, maximum likelihood classification, object oriented image analysis) at relevant spatial and temporal scales follows, and is dependent on the timeframe, cost allowance, and accuracy level desired.

2.1.1 Monitoring Questions

Monitoring questions are stated in a general form, recognizing that refinements are necessary to clarify the desired objectives, the area of analysis, and suitable comparisons.

General questions include:

- What is the areal extent of land cover types within and adjacent to parks?
- What proportion of adjacent land contains natural cover types and how much has been converted to urban or agricultural uses?

- What is the spatial relationship of park boundaries with converted lands?
- What are the patterns of relevant land cover types within and adjacent to parks?
- What parks are most isolated and which are potentially most at risk as evaluated by habitat conversion?
- In which biomes/ecoregions/divisions are lands surrounding parks more intact?
- How are land cover composition and connectivity changing?

2.1.2 Objectives

- Provide information necessary to assess the status and trends in land cover composition, configuration, and connectivity within and adjacent to parks.
- Provide context for evaluating status and trends of land cover composition, configuration, and connectivity among regions of the country.
- Document changes in development, land conversion, and succession within and outside of park boundaries.
- Identify areas within and adjacent to parks where land use activities are most impacting habitat.
- Reveal opportunities for cooperative management, conservation, and education.

2.2 Metrics

2.2.1 Area and Percent of Area in Land Cover Types

Knowing the area and percent of each land cover type surrounding parks is necessary for nearly all planning, management, and monitoring programs at local, regional, and national levels. The area of each land cover type is calculated in hectares (or square kilometers) and the percent is calculated as the area of each land cover type divided by the total area of land in the selected area of interest (e.g., km², county, biome).

2.2.2 Percent Natural or Percent Converted

Total change in natural land cover is perhaps the simplest indicator of biotic integrity (O'Neill et al. 1997). Calculating the percent of natural land cover remaining in an area provides a general indication of the overall landscape condition surrounding protected areas and offers insight into potential threats (i.e., how much land has been converted and where is it located in relation to the park boundary) as well as opportunities (i.e., connectivity of natural cover). Calculating the proportion of converted (agriculture and urban) land, also known as the U-index (O'Neill et al. 1988), can be used to measure general land use pressure by humans.

Percent of natural land cover in an area can be used to describe four broad types of landscapes, each associated with particular levels of loss and connectivity (McIntyre and Hobbs 1999, 2000, Hobbs 2005). These landscapes cover a gradient from intact (>90% habitat remaining) to variegated (60–90% remaining), to fragmented (10–60% remaining), and to relictual (<10% remaining). Divisions

between these four categories can be seen as critical thresholds (McIntyre and Hobbs 1999) where small changes in the spatial patterning of resources can produce abrupt ecological responses (Turner and Gardner 1991). While a single threshold value cannot adequately describe responses of all species to changes in landscape pattern or extent (Andrén 1994, With and Crist 1995, Bascompte and Solé 1996, Parker and Mac Nally 2002, Lindenmayer et al. 2005, Svancara et al. 2005), certain levels of natural land cover may act like “red flags” for some species (Hansen and Urban 1992).

The percent natural or percent converted land cover is calculated as the area of natural or the area of converted land cover divided by the total area of land in the selected area of interest (e.g., km², county, biome). The definition of “natural” will vary depending on the scope of question asked and typically requires aggregating the original land cover / land use data to broad “converted” versus “natural” categories, as shown in Table A-1 for the NLCD.

Table A-1. NLCD land cover classes and reclassification for calculating percent of natural and converted land cover.

Anderson Level 1	Anderson Level 2	Natural/Converted
1 Open Water	11 Open Water	Natural
	12 Perennial Ice/Snow	Natural
2 Developed	21 Developed Open Space	Converted
	22 Developed Low Intensity	Converted
	23 Developed Medium Intensity	Converted
	24 Developed High Intensity	Converted
3 Barren/Quarries/Transitional	31 Barren Land	Natural
	32 Unconsolidated Shore	Natural
4 Forest	41 Deciduous Forest	Natural
	42 Evergreen Forest	Natural
	43 Mixed Forest	Natural
5 Shrub/Scrub	51 Dwarf Scrub	Natural
	52 Shrub/Scrub	Natural
7 Grassland/Herbaceous	71 Grassland/Herbaceous	Natural
	72 Sedge/Herbaceous	Natural
	73 Lichens	Natural
	74 Moss	Natural
8 Agriculture	81 Pasture/Hay	Converted
	82 Cultivated Agriculture	Converted
9 Wetlands	90 Woody Wetlands	Natural
	95 Emergent Herbaceous Wetlands	Natural

2.2.3 Changes in Percent Natural or Percent Converted

The change in percent natural and/or converted for each area of interest is calculated as the percent change in natural or converted land cover type between time x and time x+1. This metric can be calculated using the NLCD, C-CAP, or the USGS Land Cover Trends data.

2.2.4 Changes in Area of Land Cover Type

The change in area and percent of each land cover type for each area of interest is calculated as the percent change in each land cover type between time x and time x+1. This metric can be calculated using the NLCD, C-CAP, or the USGS Land Cover Trends data.

2.2.5 Area in Impervious Surface

The area of impervious surface is calculated in hectares (or square kilometers) and the percent is calculated as the area divided by the total area of land in the selected area of interest (e.g., km², county, biome).

2.3 Issues and Assumptions

The issues and assumptions inherent in land cover / land use analyses are a result of 1) thematic scale, 2) spatial scale, 3) spectral scale, and 4) overall study objectives. The standards and methodologies employed by each mapping effort will differ, as will the overall applicability of those data to any given situation. The following issues and assumptions are general in nature, applying to any and all land cover mapping products:

- Land cover / land use classes assume single homogeneous categories based on the dominant type and do not necessarily differentiate patch/stand characteristics, such as stand age or understory composition. In many cases, such as the NLCD, the classes do not isolate disturbances. For example, an area with a great deal of forest clearing (e.g., logging) may be classified as forest, grass, or shrub.
- Boundaries between vegetation types along real environmental gradients are seldom as sharp as implied by land cover maps. Transition areas between classes represent gradients of condition that likely change positively and negatively with time. Similarly, aggregating thematic classes (e.g., “natural” versus “converted”) implies simple relationships when realistically they are also gradients variable with temporal and spatial scale.
- Products are not necessarily consistent across mapping extents. For example, GAP products are often inconsistent across state lines. Regional GAP products are developed across multiple states to alleviate this issue, but there may still be inconsistencies between regions. Similarly, NLCD and LANDFIRE products are developed by mapping zone, and while efforts are made to eliminate inconsistencies, they may still occur.
- Calculating the proportion of area in any manner is always a function of the sampling unit being measured (e.g., county, biome, grid cell size) and must be interpreted within that context.

- The described metrics will not account for land units smaller than the minimum mapping unit of the input datasets.
- Results are valid only at the point in time that the data were acquired.
- As with all spatial analyses, inaccuracies in the input data will multiply in the output.

2.4 Data Descriptions

2.4.1 Data Availability

Data on land cover and/or land use is available from multiple sources at several spatial and temporal scales. Those consistently available at regional and national scales include:

- National Land Cover Data (NLCD)
- USGS Land Cover Trends Project
- LANDFIRE
- Gap Analysis Program (GAP)
- NatureServe Ecological Systems
- NOAA Coastal Change Program (C-CAP)
- National Agricultural Statistics Service (NASS)
- National Resources Inventory (NRI)
- Waisanen and Bliss (2002)

National Land Cover Data

The National Land Cover Database (NLCD) has encompassed three major successful data releases under the Multi-Resolution Land Characteristics (MRLC) Consortium, a group of federal agencies working together to obtain imagery and derive land cover data for the nation. These products include a 1992 conterminous U.S. land cover dataset with one thematic layer of land cover (Vogelmann et al. 2001); an updated 50-state/Puerto Rico land cover database with three thematic layers, including land cover, percent imperviousness, and percent tree canopy (NLCD 2001); and an NLCD 1992–2001 land cover change product that was specially designed to identify land cover change between the two datasets (Fry et al. 2009). A fourth dataset was released in 2006 using NLCD 2001 as a base map and reflects changes between 2001 and 2006. NLCD 2011 is the most recent product. It keeps the same 16-class land cover classification scheme as earlier versions. NLCD data currently serve numerous federal, state, local, and nongovernmental programs that seek to understand the impact of land cover on both ecological and social systems.

The 16 land cover classes (modified from Anderson et al. 1976, Level II) that make up the NLCD were derived from consistent analysis of multi-date Landsat Thematic Mapper (TM) imagery. Different methodologies were used for the 1992 and the 2001 products. For NLCD 1992, early to

mid-1990s TM multi-band mosaics were processed using an unsupervised clustering algorithm (Vogelmann et al. 2001). Both leaves-off and leaves-on datasets were analyzed and the resulting clusters were labeled using aerial photography and ground observations. Clusters that represented more than one land cover class were identified, and using various ancillary datasets, models were developed to split the confused clusters into the correct land cover classes. For NLCD 2001, image mosaics from the late-1990s to 2000 were processed using a decision tree classification and following a carefully planned methodology to offer users a full range of flexible applications (see Homer et al. 2004 for overall database philosophy and methodology). NLCD 2006 was produced using a basic model of change detection developed by the NOAA program, with areas identified as change (2001–2006) extracted from the image sets and classified according to NLCD 2001 methods. NLCD 2011 is based primarily on a decision-tree classification of circa 2011 Landsat satellite data. Plans are to update NLCD on a five year cycle.

Given the different methodologies used in NLCD 1992 and 2001 products, as well as inherent differences in source image seasonality and georegistration, classification accuracy, and map legends, direct comparison of the two datasets is subject to error. To optimally compare the products, the USGS NLCD design team created the NLCD 1992–2001 Retrofit Change product using a multistage processing method incorporating both NLCD products in procedures that included 1) reclassification of both eras of land cover using a decision tree classifier at Anderson Level 1, 2) filtering intermediate results with confidence parameters, 3) determining changed versus nonchanged pixels, and 4) labeling the final change product using a "from-to" change classification code.

USGS Land Cover Trends Project

The USGS Land Cover Trends Project is focused on understanding the rates, trends, causes, and consequences of land cover change from 1973 to 2000 within the conterminous United States. The goals of the project are to 1) develop a comprehensive methodology for estimating regional land cover change, 2) characterize the spatial and temporal characteristics of change for five time periods (1973, 1980, 1986, 1992, 2000), 3) document the regional driving forces and consequences of change, and 4) prepare a national synthesis of land cover change. The classification system consists of 11 general land cover classes (Anderson Level 1, Anderson et al. 1976). Full discussion of project methodology is available in Loveland et al. (2002).

Results for several ecoregions across the conterminous United States are available, including all of the eastern and Great Plains portions of the United States. All data and reports are freely available from the USGS Land Cover Trends Project website (<http://landcoverrends.usgs.gov/>). The project was completed in 2012.

LANDFIRE

The Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) is a five-year, multipartner project producing consistent and comprehensive maps describing vegetation, wildland fuel, and fire regimes across the United States. Developed products include existing vegetation type, biophysical setting, fire regime groups, and fire regime condition class departure index and are designed to facilitate regional- and national-level strategic planning and reporting of wildland fire management activities. These maps are produced at scales that may be useful for prioritizing and

planning hazardous fuel reduction and ecosystem restoration projects; however, the applicability of data products varies by location and specific use, and products may need to be adjusted by local users.

The Existing Vegetation Type (EVT) layer represents the vegetation currently present at a given site. Existing vegetation is mapped through a predictive modeling approach using a combination of field reference information, Landsat imagery, and spatially explicit biophysical gradient data.

The Biophysical Settings (BpS) layer represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime. The BpS concept is similar to the concept of potential natural vegetation groups used in mapping and modeling efforts related to fire regime condition class (Schmidt et al. 2002; <http://www.landfire.gov/NationalProductDescriptions20.php>). Existing vegetation and biophysical setting map units are based on NatureServe's Ecological Systems classification, which is a nationally consistent set of mid-scale ecological units (Comer et al. 2003).

The Fire Regime Groups layer represents an integration of fire frequency and severity simulated using the vegetation and disturbance dynamics model LANDSUM (Keane et al. 2002). These groups are intended to characterize the presumed historical fire regimes within landscapes based on interactions between vegetation dynamics, fire spread, fire effects, and spatial context (Barrett et al. 2010).

The Fire Regime Condition Class (FRCC) Departure Index depicts the amount that current vegetation has departed from simulated historical vegetation reference conditions (Hann and Bunnell 2001, Hardy et al. 2001, Barrett et al. 2010, Holsinger et al. 2006). This departure results from changes to species composition, structural stage, and canopy closure. Historical vegetation reference conditions were simulated using the vegetation and disturbance dynamics model LANDSUM (Keane et al. 2002, Keane et al. 2006, Pratt et al. 2006). Definitions and methodologies for both products were derived from the Interagency Fire Regime Condition Class Guidebook (Barrett et al. 2010, Holsinger et al. 2006).

LANDFIRE has implemented an Operations and Maintenance Strategy, the first product of which is known as "Refresh." Refresh involves a systematic critique of existing data products and a consistent update of vegetation layers according to changes resulting from disturbance processes. In addition, products will be updated to correct some mapping inaccuracies that were detected after the initial mapping effort as part of a long-term endeavor to continually improve LANDFIRE data.

Gap Analysis Program

The Gap Analysis Program (GAP), conceived and launched in the late 1980s, represented the first comprehensive effort to map elements of biodiversity (land cover and species distribution) over large areas and identify those which were underrepresented (i.e., "gaps") in the network of conservation lands. Actual (existing) land cover is one of the three main data layers developed and used by GAP to 1) determine species and natural community representation within areas being managed for

biodiversity conservation, 2) provide spatial data that can be used to model wildlife habitat distributions, and 3) provide a single temporal dataset for monitoring trends (GAP 2000). As part of the MRLC, GAP works with federal partners to obtain imagery and derive land cover products for the nation.

Since the initial GAP project in Idaho (1989), a wide range of tools and procedures have become available including standardized vegetation classifications, consistent sets of satellite images, and vastly improved methodologies. Because of this, inconsistencies may arise when comparing across state lines. Recently, the GAP program has initiated regional efforts (ReGAP) to update and extend the analyses across broader areas.

GAP does not require rigid compliance with a certain methodology or imagery source, but rather implements standards for products. At a minimum, GAP land cover maps meet or exceed the following: 1) a nominal map scale of 1:100,000, 2) thematic classes based on the National Vegetation Classification System (NVCS) alliances or aggregations of alliances (though more recent efforts have used Ecological Systems, Comer et al. 2003), 3) complete metadata, and 4) Landsat TM imagery as a primary source of data with the base year for all TM scenes less than three years old at the start of the project. While initial state GAP efforts had a minimum mapping unit of 100 ha for uplands and 40 ha for special features such as riparian areas, more recent efforts typically use 2 ha and 0.5 ha, respectively. Lastly, GAP requires a standardized method for assessing the accuracy of all land cover maps (for additional information see GAP 2000).

GAP is operational nationwide and has also been implemented in several other countries. GAP data are freely distributed through the GAP portal (<http://gapanalysis.usgs.gov/>). Dates of the data vary by state and region as do revisions or updates.

NatureServe Ecological Systems

NatureServe developed a national composite map of ecological systems based on LANDFIRE and GAP data sources. The thematic classes are ecological systems (see Comer et al. 2003) and are attributed with the upper levels of the 2008 National Vegetation Classification System (Class, Subclass, Formation, Division). An additional level (“macrogroup”) between the 44 Divisions and 512 ecological systems is being developed. As a composite product, these data reflect the same spatial and temporal scale, as well as inherent errors and assumptions, as do the original source data. The data are provided at 30m spatial resolution.

These data are available from the NatureServe website under Conservation Tools:
<http://www.natureserve.org/conservation-tools/terrestrial-ecological-systems-united-states>.

NOAA Coastal Change Analysis Program

The Coastal Change Analysis Program (C-CAP) is a nationally standardized land cover and land change database for the coastal regions of the United States. Developed from Landsat TM satellite imagery, C-CAP data are mapped at 1:100,000 scale with a minimum mapping unit of one acre (i.e., four Landsat pixels). Similar to NLCD, C-CAP follows the Anderson classification system and maps 22 land cover classes representing major land cover types. A partnership between NOAA and USGS

establishes NOAA as the provider of land cover data for the coastal regions of the NLCD. C-CAP data maintain average accuracies of 85%, though some classes are higher, and some lower.

Standard baseline data consists of a recent coastal land cover map, an earlier land cover map (usually five years previous), and a database of change between the two. Products generally reflect 1996, 2001, 2006, and 2010 time periods. Although C-CAP only maps coastal areas that fall within defined estuarine drainage areas (EDA), these areas are quite extensive. A graphic of the areas mapped by C-CAP is available from the NOAA Coastal Change Analysis Program> _C-CAP Land Cover Classification Story Map link:

(<http://noaa.maps.arcgis.com/apps/MapTour/index.html?appid=3c3cd6ef622946898f46e0760239d8cd&webmap=1cb111a1550647259d420938221aa1e9>).

The goal of C-CAP is to inventory coastal intertidal areas, wetlands, and adjacent uplands and monitor these habitats every five years. These data are freely available at the NOAA C-CAP website (<http://www.coast.noaa.gov/dataregistry/search/collection/info/ccapregional>).

National Agricultural Statistics Service

The USDA's National Agricultural Statistics Service (NASS) provides consistent, comparable, and detailed agriculture data by conducting the Census of Agriculture every five years for every county in the United States, Puerto Rico, Guam, the U.S. Virgin Islands, and the Commonwealth of Northern Mariana Islands. The first agricultural census was taken in 1840 as part of the sixth decennial census of population. A separate mid-decade census of agriculture was conducted in 1925, 1935, and 1945. From 1954 to 1974, the census was taken for the years ending in 4 and 9. In 1976, Congress authorized the census of agriculture to be taken for 1978 and 1982 to adjust the data reference year so that it coincided with other economic censuses. This adjustment in timing established the agriculture census on a 5-year cycle, collecting data for years ending in 2 and 7.

The census aims to include all operators of U.S. farms or ranches that sold or normally would have sold \$1000 worth of agricultural products during the census year. NASS maintains a list of these farms and ranches to which one of two census report forms are mailed in December of the census year. All operators provide crop acreage and quantities harvested, inventories of livestock and poultry, value of products sold, land use and ownership, irrigation activities, amount of commodity credit loans, number of hired laborers, federal program payments (e.g., Conservation Reserve Program), and operator characteristics. Selected operators provide additional information on production expenses (including interest), fertilizer and chemical use, machinery and equipment, market value of land and buildings, and income from farm-related sources. Statistical estimation procedures are used to account for nonresponse and incomplete coverage.

Census of Agriculture data at county and state levels is freely available through their USDA website: www.nass.usda.gov or www.agcensus.usda.gov.

Natural Resources Inventory

The USDA Natural Resources Conservation Service's National Resources Inventory (NRI) is a scientifically designed, longitudinal panel survey of land use and natural resource conditions and

trends on U.S. nonfederal lands, including those lands owned privately, by tribes, by trust, and by state and local governments. The NRI was conducted every five years between 1977 and 1997; in 2000 a continuous approach began.

A historical overview, as well as sample design, data collection, and estimation procedures used in the periodic five-year NRI are provided in Nusser and Goebel (1997) and USDA (2000). NRI data were collected at more than 800,000 sample sites nationwide and the data can be legitimately used to analyze issues at many geographic levels—national, regional, state, and substate (multicounty). The NRI was not designed to provide statistical estimates for counties or 8-digit hydrologic units; however, examining the data at various geographic levels, including county or 8-digit hydrologic unit, is a legitimate analytical technique for gaining additional insight into the database. Anyone who intends to work with NRI data, especially at the county or 8-digit hydrologic unit scales, should read carefully the technical guidance as to the suitability and limitations of the data and the error-estimation procedures (USDA 2000).

For the Annual NRI, data are gathered each year for a scientifically selected subset of the foundation sample sites established for the periodic NRI. This subsample includes a set of Core sample sites that are sampled every year, and Rotation (or supplemental) sample sites that vary by inventory year and allow an inventory to focus on an emerging issue.

Data for the 48 conterminous states, Hawaii, Puerto Rico, and the U.S. Virgin Islands are available at a cost from the USDA Natural Resources Conservation Service website:

<http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/>.

Waisanen and Bliss (2002)

In 2002, Pamela Waisanen and Norman Bliss published an article summarizing changes in population and agricultural land in counties of the conterminous United States from 1790 to 1997. Although this is not an ongoing monitoring effort, the data represent one of the best (if not the only) historical compilations of data on agricultural land in the country.

These data are freely available from the USGS Land Cover Institute website:

<http://landcover.usgs.gov/cropland/>.

2.4.2 Data Dimensions (Spatial, Temporal, Thematic)

National Land Cover Dataset 1992 (NLCD1992)

- State level data available for conterminous United States
- Early to mid-1990s Landsat TM
- 30m spatial resolution, intended for regional-national application only
- 21 thematic classes (modified Anderson 1976, Level 2)
- Available for free at the Multi-Resolution Land Characteristics Consortium website:
<http://www.mrlc.gov/>

National Land Cover Database 2001 (NLCD2001)

- Mapping zone level data available for all 50 states plus Puerto Rico
- Late-1990s to 2000 Landsat TM and ETM
- 30m spatial resolution, intended for regional–national application only
- 21 thematic classes (modified Anderson 1976, Level 2)
- Imperviousness and Tree Canopy data also available
- Available for free at the Multi-Resolution Land Characteristics Consortium website:
<http://www.mrlc.gov/>

National Land Cover Dataset 1992/2001 Change

- Mapping zone level data available for conterminous United States
- 2000–2002 Landsat TM and late-1990s to 2000 Landsat TM and ETM
- 30m spatial resolution, intended for regional–national application only
- 8 thematic classes (Anderson 1976, Level 1), 55 from-to change classes
- Available for free at the Multi-Resolution Land Characteristics Consortium website:
<http://www.mrlc.gov/>

USGS Land Cover Trends Project

- Ecoregion level data for the conterminous United States
- Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+)
- 5 time periods: 1973, 1980, 1986, 1992, 2000
- 30m spatial resolution, intended for regional-national application only
- 11 thematic classes (Anderson 1976, Level 1)
- Available for free at the USGS Land Cover Trends Project website:
<http://landcover Trends.usgs.gov/>

LANDFIRE

- Mapping zone level data available for conterminous United States (Alaska and Hawaii in progress)
- Early to mid-1990s Landsat TM and late-1990s to 2013 Landsat TM and ETM
- 30m spatial resolution, intended for regional–national application only

- 400–450 thematic classes based on Ecological Systems (Comer et al. 2003)
- Available for free at the LANDFIRE website: <http://www.landfire.gov>

Gap Analysis Program (GAP)

- State level data available for 49 states plus Puerto Rico (AK pending) and three regions (Southwest, Southeast, Northwest)
- 1:100,000 scale with a typical minimum mapping unit of 2 ha (upland) and 0.5 ha (riparian and special features).
- Thematic classes based on NVCS alliances or Ecological Systems
- Standardized accuracy assessments
- Dates of the data vary by state and region, as do revisions and updates
- Available for free at the USGS GAP website: <http://gapanalysis.usgs.gov/>

NatureServe Ecological Systems

- Composite of LANDFIRE and GAP products
- Dates and imagery sources vary with original LANDFIRE /GAP data
- 30m spatial resolution, intended for regional–national application only
- Thematic classes based on Ecological Systems (Comer et al. 2003), attributed with higher levels of NVCS
- Available from the NatureServe website under Conservation Tools:
<http://www.natureserve.org/conservation-tools/terrestrial-ecological-systems-united-states>

NOAA Coastal Change Assessment Program (C-CAP)

- All coastal areas of the conterminous United States and Hawaii
- Late-1990s to 2010 Landsat TM
- Updated every five years
- 30-meter resolution
- Up to 25 thematic classes (modified Anderson 1976, Level 2)
- Change data also available
- Available for free at the NOAA Office for Coastal Management website:
<http://www.coast.noaa.gov/dataregistry/search/collection/info/ccapregional>

National Agricultural Statistics Service (NASS)

- County level data for all U.S. states, Puerto Rico, Guam, the U.S. Virgin Islands, and the Commonwealth of Northern Mariana Islands
- Several agricultural related variables including crop acreage and quantities harvested, inventories of livestock and poultry, value of products sold, land use and ownership, irrigation activities, amount of commodity credit loans, number of hired laborers, federal program payments, operator characteristics, production expenses, fertilizer and chemical use, machinery and equipment, market value of land and buildings, and income from farm-related sources
- Every 5 years for years ending in 2 and 7
- Available for free at the USDA National Agricultural Statistics Service website: www.nass.usda.gov, or the USDA Census of Agriculture website: www.agcensus.usda.gov

National Resources Inventory (NRI)

- Sample data for all nonfederal lands in the 48 conterminous states, Hawaii, Puerto Rico, and the U.S. Virgin Islands
- Nationally consistent results for 1982–2012
- Available at a cost from the USDA Natural Resources Conservation Service website: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/>

Waisanen and Bliss (2002)

- County level data for conterminous United States
- Area and proportion of agricultural land from 1850 to 1997 and population size and density from 1790 to 1990.
- Available for free from the USGS Land Cover Institute website: <http://landcover.usgs.gov/cropland/>

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3 Landscape Pattern

3.1 Background and Justification

Landscape pattern—the spatial attributes of habitat patches and landscapes—profoundly influences ecosystem properties such as the flow of materials, species movements, effects of edges between patches, and the dynamics of populations (Levin 1981, Andrén 1994, Hansen and DeFries 2007, Turner 2005). Landscape patterns in the United States reflect the dynamics of natural ecological processes (Watt 1947), biophysical constraints (Whittaker 1967), and extensive modification resulting from a very long history of human occupation (Riitters et al. 2002, Heilman et al. 2002, Mann 2005).

For evaluating effects on park resources, the landscape pattern attributes of most interest are typically those modified by human activities. Altered landscape patterns are the result of converting natural habitat to an altered state, usually accompanied by a loss of habitat—specifically a conversion from habitat (e.g., forest) to a nonhabitat type (road, agricultural field, parking lot, etc.). Habitat loss, per se, is usually measured as the area of a land cover type, perhaps modified by proximity to something else (water, road, etc.), and while area and pattern are usually correlated, they are typically measured via independent methods. Nonetheless, the effects of area and shape are difficult to separate and they are often closely related (Trzcinski et al. 1999). Landscape composition, as described by proportion of cover types, is a very important attribute of a system, and there are strong theoretical relationships between cover and attributes like landscape percolation (Gardner and O'Neill 1991).

McIntyre and Hobbs (1999) provide a useful framework for conceptualizing human effects on landscape pattern. With little or no human intervention, landscapes are initially intact. As impacts increase, landscapes are described as variegated, fragmented, and relictual, reflecting increasing degrees of habitat destruction, isolation of patches, and degree of modification.

Loss and the resulting fragmentation of habitat is one of the most pervasive effects of land use intensification. The effects of fragmentation have been extensively studied, debated, and reviewed (Andren 1994, Harrison and Bruna 1999, Debinski and Holt 2000, Fahrig 2003, Ewers and Didham 2006). In summary, the effects of habitat fragmentation vary tremendously with the habitat preferences and requirements of different species, including predators and competitors, parasites, and with the scale at the time and magnitude of habitat changes (Cousins 2009). Landscape patterns at

multiple scales affect species, and the effects of landscape composition or pattern may be detectable only at an appropriate scale (Wiens et al. 1987, Thompson et al. 2002).

Long-lived plant species or communities may not respond significantly to landscape changes for decades or centuries. While there is a consensus that landscape pattern is extremely important, mitigating factors do exist that preclude broad generalizations about the impacts of landscape pattern on ecological resources.

Despite all the complexity, pattern metrics seek to describe elements of the landscape that reflect attributes that are ecologically relevant to many species. Important spatial attributes include landscape composition, patch area, patch shape, isolation or connectivity of patches, density of habitat at different scales, core habitat, and the contrast between patches (edge contrast). Multiple metrics are required to capture these features, and no single metric or small set of metrics will address information at all scales or for all issues.

3.1.1 Monitoring Questions

For the landscape pattern metric, we provide general monitoring questions that can be tailored to specific areas of analysis. General questions include:

- How has the size and number of forest and nonforest patches of natural habitats changed in the lands surrounding parks? For large parks, how have the sizes of patches within the park changed?
- How has the area of “core” habitat changed over time?
- How has the shape of patches changed in lands within and adjacent to parks?
- How has the connection between patches of natural habitats changed within parks and with key habitats outside parks?
- How has the isolation of parks changed over time?

3.1.2 Objectives

- Provide information to facilitate assessments of species-specific habitat requirements.
- Evaluate condition and integrity of the landscape at a very broad level.
- Provide context for evaluating status, trends, and consequences of changes in other metrics, such as changes in housing density, roads, and land use.
- Identify locations that retain the larger and more important intact areas of habitat that may be important to sustain park resources.
- Identify opportunities for cooperative management, conservation, and education.

3.2 Metrics

Pattern metrics can be categorized in many different and nonexclusive ways. Pattern metrics can describe individual patches (size, shape), properties of cover classes (connectivity, isolation), or

landscape-level metrics that are functions of the composition and arrangement of patches throughout the entire area of analysis (richness, evenness, diversity). Landscape *composition* metrics respond to the abundance and variety of patches within the entire landscape, but they do not explicitly consider the location, size, shape, or spatial configuration of patches.

Spatial configuration is difficult to quantify in simple measures, and most measures of spatial configuration are of little value by themselves. Some metrics, like patch size distribution, reflect the aggregate of individual patch characteristics across an area of analysis, while other measures, like isolation or connectivity, describe the specific spatial relationship between patches.

Description of pattern metrics can further be divided between those that describe *structural* versus *functional* characteristics of the landscape. Structural metrics measure physical attributes without regard to any specific species or ecological function. Patch size distribution, and nearest-neighbor distances between patches are examples of structural pattern metrics. The determination of structural pattern measures are (in theory) invariant across applications.

By contrast, *functional* pattern metrics measure spatial landscape attributes that are relevant to properties of specific species or processes. Functional metrics thus require parameters that apply to focal species or processes, and different applications may yield different results. Connectivity measures are typically functional, and they include parameters that account for dispersal abilities of a species or group of species. For example, graph analyses can evaluate landscape connectivity at a scale relevant to the short-distance movements characteristic of amphibians (Lookingbill et al. 2008), or at broader scales that reflect the movement abilities of species like spotted owls (Keitt et al. 1997). A key factor in all these analyses is the selection of what constitutes the “patch” and what constitutes the “matrix.”

There are many excellent reviews of landscape metrics. The FRAGSTATS web site provides a particularly lucid overview.

There is a confusing plethora of landscape metrics that are easily calculated using widely available software such as *r.le* (Baker and Cai 1992), FRAGSTATS (McGarigal and Marks 1995), and Patch Analyst (Rempel 2009). These packages facilitate computations using vector or raster-based landscape maps. The basic attributes of most of these measures have been studied, and it is apparent that many measures are highly correlated (Cain et al. 1997, Riitters et al. 1995, Calabrese and Fagan 2004, Cushman et al. 2008).

We selected pattern metrics (Table A-2) that are informative and relevant to many natural resource issues, that can be repeated over time, and that are likely to be sensitive to the more common types of landscape change.

Table A-2. Landscape pattern metrics and their importance. These metrics can be sensitive to both the area of analysis, and to the scale at which the metric is defined.

Metric	Description	References
Composition	Proportion of area. Usually an aggregate class (forest/nonforest, natural/converted). Can be elegantly expressed at multiple scales.	Heinz Center 2008 (pattern report), Riitters et al. 2002, Wickham et al. 2007, 2008
Patch size distribution	Simple and understandable measure. Does not describe spatial relationships between patches.	Turner 1989, Gardner et al. 2008 (and many others)
Landscape morphology	A pixel-based, structural approach to identify specific types of landscape elements. The key types are described below. Analyses used by NPScape are based on maps that aggregate classes in to forest/nonforest, or natural grassland/nonnatural-grassland. See text for a more detailed and complete description.	Vogt, Riitters, Iwanowski et al. 2007, Vogt, Riitters, Estreguil et al. 2007, Vogt et al. 2009, Riitters et al. 2007, Riitters, Vogt et al. 2009, Ostapowicz et al. 2008.
Core	Pixels that are within a patch, and more than a defined “edge” distance from a nonpatch type.	
Edge	Pixels within a defined distance from the boundary of a patch (e.g., forest) and nonpatch (e.g., nonforest). We report analyses with edges of 30 m (1 pixel) and 120 m (4 pixels).	
Patch	Distinct area with foreground pixels that does not contain any core pixels (i.e., all edge or other classes).	
Connector	A cluster of noncore pixels connected at two or more locations to edge.	
Perforation	Inner boundary of a core area that is adjacent to a hole in the core area.	

3.2.1 Morphological Pattern Analysis

Morphological spatial pattern analysis (MSPA) is based on pixel-level analysis of cover maps using image segmentation to classify individual pixels into a set of pattern types. The main types are core, patch, connector, perforation, edge, and background (Vogt, Riitters, Estreguil et al. 2007; pattern types are defined in Table A-2) describe the advantages of this method over approaches that require identification and delineation of specific patches. For NPScape, two key advantages are 1) an ability to apply the algorithms over very large spatial extents, and 2) the greater sensitivity of pixel-based maps and analyses to detect changes in patterns over time.

Vogt, Riitters, Estreguil et al. (2007) describe the process of MSPA and provide an example application. Riitters et al. (2007), Riitters, Wickham et al. (2009), and Ostapowicz et al. (2008) examined the behavior of the metrics across scales and in landscapes with various statistical properties. Vogt, Riitters, Iwanowski et al. (2007, 2009) focused on the use of MSPA to characterize landscape connectivity and identify corridors. Software used to calculate the landscape measures is part of the GUIDOS package, available from the European Commission Joint Research Centre (<http://forest.jrc.ec.europa.eu/download/software/guidos/>).

We provide results of pattern analysis at multiple scales because species and processes respond across such a broad range of scales.

3.2.2 Forest, Grassland, and Shrubland Density

Forest and grassland area density are calculated using a moving window analysis. First, a square neighborhood (window) for analysis is defined by the number of pixels on each side. Then proportion of pixels in the window of a particular type (forest or grassland in this case) is calculated and assigned to the pixel in the center of the window (Riitters et al. 2002, Wickham et al. 2007, 2008).

3.3 Issues and Assumptions

A key assumption is that land cover / land use classes represent a single homogeneous category based on the dominant vegetation type. At the level of the NLCD, patch/stand characteristics such as stand age or understory composition are not differentiated. In many cases, the classes do not isolate disturbances. For example, an area with a great deal of forest clearing (e.g., logging) may be classified as forest, grass, or shrub. The quality of a particular patch, or large area, can vary considerably simply due to the heterogeneity within a class.

Boundaries between vegetation types along real environmental gradients are seldom as sharp as implied by land cover maps. Transition areas between classes represent gradients of condition that likely change positively and negatively with time. Similarly, aggregating thematic classes (e.g., “natural” versus “converted”) implies simple relationships when realistically they are also gradients variable with temporal and spatial scale. Many pattern metrics represent the landscape as a binary map, and patches are either “habitat” or “matrix”. Few species are likely to view the world in such a black-and-white way.

Estimate of metrics will not account for land units smaller than the minimum mapping unit of the input datasets and they are valid only at the point in time that the data were acquired. In all spatial analyses, inaccuracies in the input data will multiply in the output.

The morphological spatial pattern analyses are less well studied than most of the more traditional pattern measures. A key advantage of this technique is the ability to objectively classify landscape elements. Additional research is still needed to better quantify effects (e.g., effects of corridors on species movements).

3.4 Data Descriptions

National Land Cover Data

Analyses of landscape pattern are based on land cover data from the National Land Cover Database (NLCD, Homer et al. 2004, Fry et al. 2009). These data and the data attributes most relevant to NPScape are described in detail by Story et al. (2009).

There are strong arguments to either include or exclude roads. For all the morphological pattern analyses, we did not include the effects of roads. This decision was founded on two key factors. The first was simply our ability to adequately process the data. Efforts to “burn” roads into the land cover datasets results in many processing errors that could not be easily corrected. The second consideration is that we conducted extensive analyses based on our roads metrics, and these metrics (road density, distance to a road) supplied highly detailed information that can easily be used to extend our analyses.

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4 Housing and Population

4.1 Background and Justification

In many landscapes, humans are the primary drivers of landscape change (Vitousek et al. 1997, Sala et al. 2000). Impacts on resources, both positive and negative, may originate directly from the behaviors of humans (e.g., poaching), or indirectly from the infrastructure used to support humans (e.g., roads, housing). Although the extent of impact is often difficult to measure directly, data on human population characteristics (e.g., population change, economic status, housing) can provide important information for evaluating the likely condition of lands adjacent to parks. These cultural, political, and socioeconomic factors all contribute to land use decisions (Naveh 1995, Nassauer 2005, With 2005) and are widely used indicators of landscape quality or threats to biodiversity (Cincotta et al. 2000, Nassauer 2005). Given that human land uses tend to expand over time (Wade et al. 2003), these data also provide a window into potential threats to park resources.

High human population density has been shown to adversely affect the persistence of habitats and species (Kerr and Currie 1995, Woodroffe 2000, Parks and Harcourt 2002, Luck 2007). In an assessment of the conterminous United States, Svancara et al. (2009) found that counties near parks had higher population densities and experienced a greater change in population between 1990 and 2000 than distant counties. They suggested that, even with more intact landscapes surrounding parks, species in these counties may be at greater risk. In addition, Svancara et al. (2009) found that counties near parks had significantly higher per capita income than distant counties. While economic activity has been shown to impact biodiversity (Naidoo and Adamowicz 2001, McKinney 2002), there is debate whether increasing per capita income fuels land conversion (Sisk et al. 1994) or is necessary to solve environmental problems (Beckerman 1992).

Increasing human population results in development, and that development often leads to more development, with more land being converted to expand transportation networks, build schools, and accommodate businesses, which in turn may create a demand for still more housing (Heinz 2008). Conversion of natural landscapes to agriculture, suburban, and urban landscapes is generally permanent (Heinz 2008), and this loss of habitat is the primary cause of biodiversity declines (Wilcove 1998). Thus, there is great concern about the rate of development of rural landscapes around parks (Hansen et al. 2005). For example, growth in low-density, exurban areas (1 home/0.4–16.2 ha, Brown et al. 2005) has been shown to have numerous biological impacts (Hansen et al. 2002, Hansen et al. 2005) and is increasingly recognized as a primary driver of ecological processes and biodiversity (McKinney 2002, Miller and Hobbs 2002). In the Greater Yellowstone Ecosystem, exurban development has occurred disproportionately in low elevation riparian areas and is predicted to result in up to 40% habitat conversion by 2020 (Gude et al. 2007).

Housing density may be a better indicator of environmental impacts than population density alone because it accounts for declining household size (Liu et al. 2003) and second-home ownership (Radeloff et al. 2001, 2005). In addition, Theobald (2005) examined patterns of land use and developed a Landscape Sprawl metric that attempted to capture and communicate much of the information from housing density, corrected for land ownership, distance to roads, water, and other factors.

This housing and population indicator summary focuses on population and housing information consistently available across the United States. Additional questions and analyses at local levels that incorporate finer spatial and temporal scale data are encouraged and expected.

4.1.1 Monitoring Questions

Monitoring questions are stated in a general form, recognizing that refinements are necessary to clarify the desired objectives, the area of analysis, and suitable comparisons. General questions include:

- What is the population and housing density within and adjacent to parks?
- How has total population and population density changed in lands adjacent to parks?
- What is the spatial relationship of park boundaries with areas of high housing density?
- Which areas are most impacted by population growth?
- Which parks are most likely to be impacted by future changes in housing density?
- How has housing density changed in low-density suburban and rural areas around parks?
- What is the economic status of surrounding communities?

4.1.2 Objectives

- Provide information necessary to assess the status and trends in population and housing within and adjacent to parks.
- Provide context for evaluating status and trends of other metrics, such as land cover / land use and conservation risk, among regions of the country.
- Document changes in development and land conversion within and outside of park boundaries.
- Identify areas within and adjacent to parks where human activities are most impacting habitat.
- Reveal opportunities for cooperative management, conservation, and education.

4.2 Metrics

Population metrics are calculated using relevant U.S. Census data at the block-group level unless otherwise noted.

4.2.1 Total Population

The total estimated population for each area (block-group) is the number of persons counted as inhabitants of their usual place of residence.

4.2.2 Population Density

Population density for each area (block-group) is measured as the average number of people per square kilometer. This number is calculated by dividing the total number of people by the total square kilometers of the area of interest (i.e., block-group within the scale of interest). Excluding the area of the park and other lands protected from human establishment would result in higher population densities.

4.2.3 Recent Population Change

The recent population change for each area (block-group) is reflected by change in both the total numbers and the percent of population from time t (e.g., July 1, 2000) to time $t+1$ (e.g., July 1, 2008).

4.2.4 Overall Population Change

The recent population change for each area (county) is the percent change in population from time t (e.g., 1790) to time $t+1$ (e.g., 1990). Population data from Waisanen and Bliss (2002) will be used for time periods prior to 1990.

4.2.5 Projected Population Change

The projected population change for each area is reflected by both projected total numbers and percent change in population from current time t_c (e.g., 2000) to projected time t_p (e.g., 2030).

4.2.6 Seasonal Housing

Seasonal housing is the percent of total housing units that are used for seasonal, recreational, or occasional use.

4.2.7 Housing Density

Housing density for each area is measured as the average number of housing units per square kilometer. This number is calculated by dividing the total number of housing units by the total square kilometers of the area of interest (i.e., block-group). Excluding the area of the park and other lands protected from development would result in higher housing densities. Housing density data from SERGoM (v3) will be used to supplement U.S. Census data results.

4.2.8 Recent Change in Housing Density

Change in housing density for each area is measured as both the total number and the percent change in the number of housing units per square kilometer in various time periods. Housing density data from SERGoM (v3) will be used to supplement U.S. Census data results.

4.2.9 Projected Housing Density Change

The projected housing density change for each area (block-group) is measured by both the projected total numbers and percent change in housing density from current time t_c (e.g., July 1, 2008) to projected time t_p (e.g., 2030). Projected housing density data are from SERGoM (v3).

4.3 Issues and Assumptions

The issues and assumptions inherent in population and housing analyses are typical of large, statistical analyses. Though the standards and methodologies employed by each effort differ, most use the U.S. Census Bureau data as the original source, and thus are subject to errors inherent with that data. The following issues and assumptions should be considered:

- Not all population, housing, and socioeconomic variables are collected in each U.S. Census, and for those that are continually collected, changes in definitions may influence the comparability of the results. Census technical documents should be consulted.
- The U.S. Census assumes total enumeration of people and households. Several steps are in place to reduce the nonsampling error resulting from nonresponses, respondent and enumerator errors, and processing errors.
- Calculating the proportion of area in any manner is always a function of the sampling unit being measured (e.g., county, biome, grid cell size) and must be interpreted within that context.
- The described metrics will not account for land units smaller than the minimum mapping unit of the input datasets.
- Results are valid only at the point in time that the data were acquired.
- As with all spatial analyses, inaccuracies in the input data will multiply in the output.

4.4 Data Descriptions

4.4.1 Data Availability

Data on population and housing is available from multiple sources at several spatial and temporal scales. Those consistently available at national scales include:

- U.S. Census Bureau
- U.S. Census Grids (Socioeconomic Data and Applications Center, SEDAC)
- Regional Economic Information System (U.S. Bureau of Economic Analysis)
- ESRI Data & Maps (v9.3)
- Waisanen and Bliss (2002)
- Woods & Poole Economics
- SERGoM
- SILVIS

U.S. Census Bureau

Through the decennial census, the U.S. Census Bureau provides information on diverse topics from population density to rents and mortgages, and to commuting modes and times. On April 1 of the last year of each decade, every household in the United States receives a questionnaire (the “short form”) regarding income, ethnicity, and housing. The short form information (SF1) includes the following variables:

- Age
- Sex
- Hispanic or Latino origin
- Tenure (whether home is owned or rented)
- Household relationship
- Vacancy characteristics
- Race

Every 6th household receives the “long form,” with detailed questions regarding their commute, rent, number of bathrooms, and other information. Long form variables (SF3) include:

- Ancestry
- Disability
- English
- Grandparents as caregivers
- Heating fuel
- Income in last year
- Labor force status
- Languages spoken
- Marital status
- Migration
- Number of rooms
- Occupation, industry, class

- Place of work, journey to work
- Plumbing and kitchen facilities
- School enrollment, attainment
- Telephone service
- Units in structure
- Utilities, mortgage, taxes, fuel costs
- Value of home or monthly rent paid
- Vehicles available
- Veteran status
- Year moved into residence
- Year structure built

Census summary statistics are available at several spatial scales: block, block-groups, tracts, counties, and states. Census blocks, in urban areas, are approximately equal to city blocks. Only a subset of the short form data are released at this level. Block groups are areas that are supposed to contain approximately 1200 people, but the actual count varies widely. Census tracts are larger than block groups, usually with between 2500 and 8000 people, and are designed to be homogenous with respect to population characteristics, economic status, and living conditions. Census tracts are nested within county boundaries. All short and long form data are available at both the block group and tract levels, and summarized data are provided at county and state levels.

The first official U.S. Census was conducted in 1790 and has been collected every 10 years since. In addition, the Population Projections Program constructs future projects of population by age, sex, race, Hispanic origin, and nativity for each year from 1990 through 2100. Not all data have been collected in all years, and those that are collected are not always comparable due to changes in definitions—see the U.S. Census technical documents (U.S. Census Bureau website>Publications; <http://www.census.gov/library/publications.html>) for additional information.

Census data can be freely downloaded from the Census Bureau’s American Factfinder site (<http://factfinder.census.gov>).

U.S. Census Grids

The U.S. Census Grids, developed by the Socioeconomic Data and Applications Center (SEDAC), provide rasterized data products of population and housing counts as well as a variety of socioeconomic characteristics. The grids cover all 50 states and Puerto Rico, with a resolution of 30 arc-seconds, approximately 1 km. The datasets are created by taking population and housing counts

at the block level and proportionally allocating the counts in the census blocks to a latitude-longitude quadrilateral grid. If a grid cell contains 40% of the area of one census block and 30% of the area in a second census block, the population count for that grid cell will be 40% of the population of the first census block and 30% of the population of the second census block.

The grids use the 2000 TIGER/Line files for the census block boundaries and the 2000 data tables (SF1 and SF3) for demographic and socioeconomic characteristics of each block. Grids of 43 variables are available, including information on the number of housing units built in four time periods (pre-1950, 1950–1969, 1970–1989, and 1990–2000). Summarized state and city (Metropolitan Statistical Areas) data are also available.

U.S. Census Grids for 2000 can be freely downloaded from the SEDAC website (<http://sedac.ciesin.columbia.edu/usgrid/>).

Regional Economic Information System (U.S. Bureau of Economic Analysis)

The Regional Economic Information System, produced by the U.S. Bureau of Economic Analysis, provides information on the geographic distribution of economic activity and growth. Annual estimates of local area personal income provide indications of economic activity within the local areas, a measure of fiscal capacity, and overall economic well-being of the local area residents.

Local area personal income estimates include annual estimates of the total and per capita personal income, earnings, compensation, and employment by industry, as well as farm gross income and expenses. Estimates of total and per capita personal income are available for all counties in the United States, beginning in 1969. Changes in definitions have occurred and consultation of the technical documents is advised.

Local area personal income data are freely available from the U.S. Bureau of Economic Analysis website (<http://www.bea.gov/regional/>).

ESRI Data & Maps 10

ESRI Data & Maps is a set of map data that is bundled with the ArcGIS software products (current version is 10.3). Several datasets are included covering the United States, Canada, Mexico, and the world. Among these are the U.S. Census tracts, block groups, block centroid populations, urbanized areas, and 2010 population estimates. All layers of census geography are derived originally from Census 2000 and all census-derived attributes are from the U.S. Census 2000 Summary File 1 (SF1) and/or Census 2000 TIGER/Line documentation.

These data are freely available from ESRI with the purchase of ArcGIS software.

Waisanen and Bliss (2002)

In 2002, Pamela Waisanen and Norman Bliss published an article summarizing changes in population and agricultural land in counties of the conterminous United States from 1790 to 1997. Although this is not an ongoing monitoring effort, the data are included here because they represent one of the most complete historical compilations of population by county.

These data are freely available from the USGS Land Cover Institute's website:
<http://landcover.usgs.gov/cropland/>.

Woods & Poole Economics

The Woods & Poole database contains projections of more than 900 economic and demographic variables for every county in the United States. for every year from 1970 to 2040. Updated annually, this database includes population data by age, sex, and race; employment and earnings by major industry; personal income by source of income; retail sales by kind of business; and data on the number, size, and income of households.

These data are available at cost from the Woods and Poole Economics website:
<http://woodsandpoole.com>

Spatially Explicit Regional Growth Model

The Spatially Explicit Regional Growth Model (SERGoM v3) methods used to generate historical and current estimates of housing density (as well as a forecasting model) are described in detail by Theobald (2001, 2003, 2005), and Theobald and Romme (2007). In short, using census data, the number of housing units built by decade was used to estimate the historical number of housing units in each block. Census data were combined with data on land ownership from PAD-US, which is largely a consolidation of USGS Gap stewardship maps. The density of major roads (interstates, state highways, county roads) was computed to provide a more accurate allocation of the location of housing units within a block.

These data are not currently available to the public. For access and more information, contact Dave Theobald at Colorado State University.

SILVIS

The SILVIS model depicts housing density by decade from 1940 to 2030 and methodologies are detailed in Radeloff et al. (2005), Hammer et al. (2004), and Radeloff et al. (2001). Mapping units are “partial block groups,” intermediate in scale between Census blocks and block groups. Two estimation methods were used, one for “backcasting” houses that existed before 2000, and the other for forecasting houses likely to exist in 2010, 2020, and 2030.

These data are freely available from the SILVIS Lab at <http://silvis.forest.wisc.edu/maps/housing>

4.4.2 Data Dimensions (Spatial, Temporal, Thematic)

U.S. Census Bureau

- Block, county, and state level data for all states and territories
- Every 10 years from 1790 to 2000, with annual population estimates to 2007 and population projections to 2100
- Hundreds of cultural, social, and economic variables
- Available for free from the U.S. Department of Commerce, Census Bureau, Fact Finder webpage: <http://factfinder.census.gov>

U.S. Census Grids (SEDAC)

- Block level data available for all 50 states plus Puerto Rico
- Datasets are available for 1990 and 2000
- 30 arc-second (approximately 1 km) spatial resolution
- Many population, housing, and socioeconomic variables available
- Available for free from the NASA Socioeconomic Data and Applications Center website: <http://sedac.ciesin.columbia.edu/usgrid>

Regional Economic Information System (U.S. Bureau of Economic Analysis)

- County level data available for all 50 states plus Puerto Rico
- Estimates every year since 1969
- Hundreds of variables available regarding personal income, employment, earnings, industry compensation and income, and farm income and expenses
- Available for free from U.S. Department of Commerce, Bureau of Economic Analysis website: <http://www.bea.gov/regional/>

Waisanen and Bliss (2002)

- County level data for conterminous United States
- Area and proportion of agricultural land from 1850 to 1997 and population size and density from 1790 to 1990.
- Available for free from the USGS Land Cover Institute website: <http://landcover.usgs.gov/cropland/>

Woods & Poole Economics

- County level data available for all U.S. states
- Estimates annually from 1970 and projections to 2050
- Hundreds of variables
- Available for cost from the Woods and Poole Economics website: <http://woodsandpoole.com>

SERGoM (version 3)

- Available for conterminous United States, Alaska, and Hawaii
- 100m spatial resolution based on U.S. Census blocks and ESRI source data

SILVIS (version 2012)

- Available for conterminous United States

- Used source data from 2010 U.S. Census and PAD-US
- Available for free from the University of Wisconsin SILVIS Lab website:
<http://silvis.forest.wisc.edu/maps/housing>

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5 Roads

5.1 Background and Justification

Roads and associated activities can profoundly impact a broad range of physical, ecological, and social attributes important to parks. Comprehensive reviews have documented extensive direct and indirect impacts of roads on both terrestrial and aquatic environments (Spellerberg 1998, Ercelawan 1999, Trombulak and Frissell 2000, Forman et al. 2003), the effects of which may be undetectable in some taxa for decades (Findlay and Bourdages 2000). Even in areas where human population densities are relatively low and landscapes are perceived as natural, the impacts of roads are pervasive (Saunders et al. 2002) and may extend hundreds to thousands of meters from the roadside (Forman 2000, Forman and Deblinger 2000, Forman et al. 2002).

Physically altering the landscape, roads result in the direct loss of habitat, fragmentation of the remaining habitat (Carr et al. 2002), altered landscape structure (Saunders et al. 2002), increased influence of edge effects (Carr et al. 2002), and disruption of hydrologic processes (Jones et al. 2000, Trombulak and Frissell 2000). In fact, Noss (1993) argues that roads may be the single most destructive element in the process of habitat fragmentation.

Wildlife populations are further impacted directly by increased mortality of organisms from collisions with vehicles (e.g., Fahrig et al. 1995), modified behavioral patterns such as home ranges and migrations (e.g., Reijnen et al. 1996, Forman et al. 2002), and exposure to physical barriers which limit or prevent access to resources (Trombulak and Frissell 2000, Forman et al. 2003, Jaeger et al. 2005). Roads also limit gene flow and subdivide and isolate populations (e.g., Gerlach and Musolf 2000, Keller and Largiader 2003). Separation of complementary habitats (e.g., breeding and feeding) can be particularly detrimental (e.g., Pope et al. 2000). Mortality from vehicle collisions can have significant effects on wildlife populations, particularly for smaller organisms. For example, in studying four amphibian species, Hels and Buchwald (2001) found that the probability of getting killed ranged from 0.34 to 0.61 when crossing a low to moderately traveled road (3200 vehicles/day)

and from 0.89 to 0.98 when crossing a busy road (>15,000 vehicles/day). Their results indicate that about 10% of the adult populations of these species were killed annually by traffic in their study area.

Many times, even in “pristine” protected areas, wildlife populations are affected by several, if not all, of these direct impacts, resulting in the highest risk of mortality in areas of high road density (e.g., grizzly bears - Boyce et al. 2001, Johnson et al. 2005). For example, research on grizzly bears in Yellowstone National Park indicates that the effects of roads and associated development are disproportionately high on adult females and subadults, resulting in higher mortality and lower productivity (Mattson et al. 1987). Similarly, in Banff and Yoho National Parks (Alberta, Canada), where grizzly bears are protected from hunting, as much as 100% of known adult grizzly bear mortalities occurred within 500 m of roads or 200 m of high use trails (Benn and Herrero 2002).

Indirect effects of roads can be as important, or more so, than direct effects. Roads have been associated with an increased incidence of fire ignitions (Cardille et al. 2001, DellaSala and Frost 2001, Brown et al. 2004) and higher probability of large fires in the upper Midwest (Cardille et al. 2001, but see Dickson et al. 2006). Roads are also associated with an increased occurrence of invasive species (Trombulak and Frissell 2000), with improved roads having a greater proportion of exotic species occurrence and cover than unimproved (4WD) roads (Gelbard and Belnap 2003). Wildlife may experience increased legal hunting pressure and poaching (Trombulak and Frissell 2000) and chronic disturbance from human activity such as recreation (Thurber et al. 1994, Reijnen et al. 1996). More recent studies have identified other indirect species-specific effects, such as impacts of salt runoff on amphibians (Karraker et al. 2008).

Estimating trends with road data is notoriously difficult because changes could have resulted from construction of new roads, or simply from an update of the map and mapping techniques that improved coverage. In addition, comparisons of different map sources have proved problematic (Hawbaker and Radeloff 2004) as scale and completeness of the data differ. These problems are exacerbated in areas where remotely sensed data is less reliable—for example, to detect small roads under dense and tall tree canopies. Despite the considerable issues associated with using spatial road data, the impacts of roads are so pervasive and important that they must be addressed either as a core metric, input to additional analyses, or both.

For example, road data are needed to estimate and evaluate landscape metrics such as patch size and fragmentation (Riitters et al. 2004).

5.1.1 Monitoring Questions

Information on roads is useful from local to national scales. Thus, monitoring questions are stated in a general form, recognizing that refinements are necessary to clarify the desired objectives, the area of analysis, and suitable comparisons. General questions include:

- What is the density of roads (km/km^2) in parks and adjacent areas?
- How do these density values compare to densities thought to affect wildlife or other resources?

- How far are park resources from the nearest roads?
- What percent of the park and surrounding lands are roadless?

5.1.2 Objectives

- Provide information necessary to estimate the amount of area without roads.
- Provide the basis for estimating changes in road density over time.
- Serve as base data for estimating travel times.
- Reveal opportunities for cooperative management, conservation, and education.
- Provide context for evaluating landscape pattern among regions of the country.

5.2 Metrics

5.2.1 Road Density

Road density, measured as the average total road length (km) per unit of area of landscape (km²), is perhaps the most common and convenient overall measure of the amount of road in an area (Forman et al. 2003). Road density must be estimated for a given area, and therefore is sensitive to the area over which it is calculated. Refined values based on road type (e.g., primary and secondary roads versus rural, 4WD roads) may provide additional insights.

Various thresholds of road densities have been reported as important for wildlife. Gibbs and Shriver (2002) suggest that areas with road densities >1 km/km² and with traffic volumes of >100 vehicles/lane/day, typical of the eastern and central United States, may jeopardize population persistence of some land turtles. Similar high road density (>1.5 km/km²) resulted in male-biased sex ratios in painted and snapping turtles, potentially indicating incipient changes in turtle populations (Steen and Gibbs 2004). For wolves in the Great Lakes region (Mladenoff et al. 1999) and mountain lions in Utah (Forman and Alexander 1998), populations appear to thrive only where road density is less than 0.6 km/km². Wolf packs were most likely to occur in areas with <0.23 km/km², nearly all wolves occurred in areas with <0.45 km/km², and no wolf pack territory was bisected by a major highway (Mladenoff et al. 1999).

5.2.2 Distance to Roads

Distance to the nearest road is a simple measure of potential road impacts that is easily understood and can be estimated for a point. Refined values based on road type (e.g., primary and secondary roads versus rural, 4WD roads) may provide additional insights.

Recent reviews suggest that most road impacts occur within 1000 m of roads (Forman et al. 2003); however, various distances, also referred to as the depth-of-edge influence and road-effect zones, have been identified as important depending on the species and population characteristic of interest, ecosystem, season, time of day, road width, road surface, proximity to water, and traffic density. For example, in Canada national parks where grizzly bears are protected from hunting, as much as 100% of known adult grizzly bear mortalities occurred within 500 m of roads or 200 m of high use trails

(Benn and Herrero 2002). In Massachusetts, presence and breeding of grassland birds was decreased within 1200 m of heavy traffic areas (multilane highway with >30,000 vehicles/day) and within 700 m of moderately heavy traffic areas (two-lane highway with 15,000–30,000 vehicles/day). Moderate traffic (8000–15,000 vehicles/day) had no effect on bird presence but reduced regular breeding within 400 m of a road (Forman et al. 2002). For macroinvertebrate soil fauna, however, even relatively narrow, lightly travel roads through continuous forest have significant impacts up to 100 m away (Haskell 2000).

5.2.3 Effective Mesh Size

Network form, or the spatial arrangement of roads, may be a better measure of potential impacts of roads by determining the relative size, shape, and arrangement of enclosed patches (Forman et al. 2003). Mesh size—the area or diameter of patches enclosed within a road network—is inversely related to road density and focuses on the enclosed habitat fragments.

Effective mesh size has been shown to be a useful measure for monitoring landscape fragmentation (Jaeger 2000, Jaeger et al. 2008) and has been applied in a variety of landscapes (e.g., Padoa-Schioppa et al. 2006, Moser et al. 2007). The effective mesh size is related to the probability of two random points in a region being connected, that is, not separated by barriers such as roads, railroads, or other features, depending on the criteria selected (Jaeger 2000, Jaeger et al. 2008). This measure explicitly addresses the movement of individuals between habitat patches in the landscape and can be interpreted as the average size of the area that an animal placed randomly in the landscape would be able to access without crossing barriers (Girvetz et al. 2007).

The calculation of effective mesh size requires specification of the landscape elements that cause fragmentation (e.g., roads, railroads) and definition of the scale over which fragmentation will be determined (e.g., counties, ecoregions).

5.3 Issues and Assumptions

Analyses of road data require acknowledgment of several inherent issues and assumptions, including the following:

- Difficult to map consistently over broad areas.
- Continually out of date.
- The described process does not account for land units smaller than the MMU of either of the input datasets.
- Results are valid only at the point in time that the data were acquired.
- As with all spatial analyses, inaccuracies in the input data will multiply in the output.
- Calculating the proportion of area in any manner is always a function of the sampling unit being measured (e.g., county, biome, grid cell size) and must be interpreted within that context.

5.4 Data Descriptions

5.4.1 Data Availability

Road data are available at several spatial scales from multiple sources. Those consistently available at regional and national scales include:

- ESRI Data & Maps 10
- US Census TIGER Line Files
- Tele Atlas (formerly GDT)

ESRI Data & Maps10

ESRI Data & Maps is a set of map data that is bundled with the ArcGIS software products (current version is 10.3). Among these is the StreetMap North America dataset, which includes 2005 Tele Atlas streets for North America as well as 2009 Tele Atlas North America basemap data. There are 27 datasets, of which 25 contain both U.S. and Canada data, and two contain only U.S. data. The datasets include detailed streets, streets with a reduced feature and attribute set for cartographic display, highway exits, street and highway maneuvers, states and provinces, counties and county boundaries, postal areas and points, highways, major roads, interstate highways, railroads, city areas and points, water features, institutions, large area landmarks, parks, recreation areas, retail centers, airports, and transportation terminals. Twelve of the datasets have multiple feature classes that provide several levels of generalization for displaying the data at different scales.

These data are available from ESRI with the purchase of ArcGIS software.

U.S. Census TIGER Line Files

The TIGER/Line shapefiles are extracts containing selected geographic and cartographic information from the U.S. Census Bureau's MAF/TIGER® (Master Address File / Topologically Integrated Geographic Encoding and Referencing) database. The MAF/TIGER database was developed at the U.S. Census Bureau to support a variety of geographic programs and operations, including functions such as mapping, geocoding, and geographic reference files that are used in decennial and economic censuses and sample survey programs. Spatial data for geographic features such as roads, railroads, rivers, and lakes, as well as legal and statistical geographic areas are included in the product. Other information about these features, such as the name, the type of feature, address ranges, and the geographic relationship to other features, also are included.

These data were originally derived from the USGS 1:100,000 scale Digital Line Graphs (DLG), USGS 1:24,000 scale quadrangles, and geographic base files from the 1980 Census. Updates from the 1990 and 2000 Census have since been incorporated. In addition, the U.S. Census Bureau began a multiyear project called the MAF/TIGER Accuracy Improvement Project (MTAIP) in 2002 to realign and update street features. This project was completed in 2008 and the most current data are now available. As part of this project, the horizontal spatial accuracy of the data were verified, and 95% of the time the distance between sample control points and the corresponding street centerline does not exceed 7.6 m (about 25 ft). Ongoing updates will be reflected in subsequent releases of the

TIGER/Line shapefiles. These data are freely available from the U.S. Census Bureau web page at <http://www.census.gov/geo/www/tiger/>.

5.4.2 Data Dimensions (Spatial, Temporal, Thematic)

ESRI Data & Maps10

- Available for all 50 states, Canada and Mexico
- Scales vary
- Based on the 2005 Tele Atlas streets
- Available from the ESRI website, <http://esri.com>, with purchase of ArcGIS products

U.S. Census TIGER Line Files

- Available for all 50 states
- Scales vary (1:24,000–1:100,000)
- Most recent update released August 19, 2015
- Available for free from the U.S. Census Bureau website:
<http://www.census.gov/geo/www/tiger/>

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