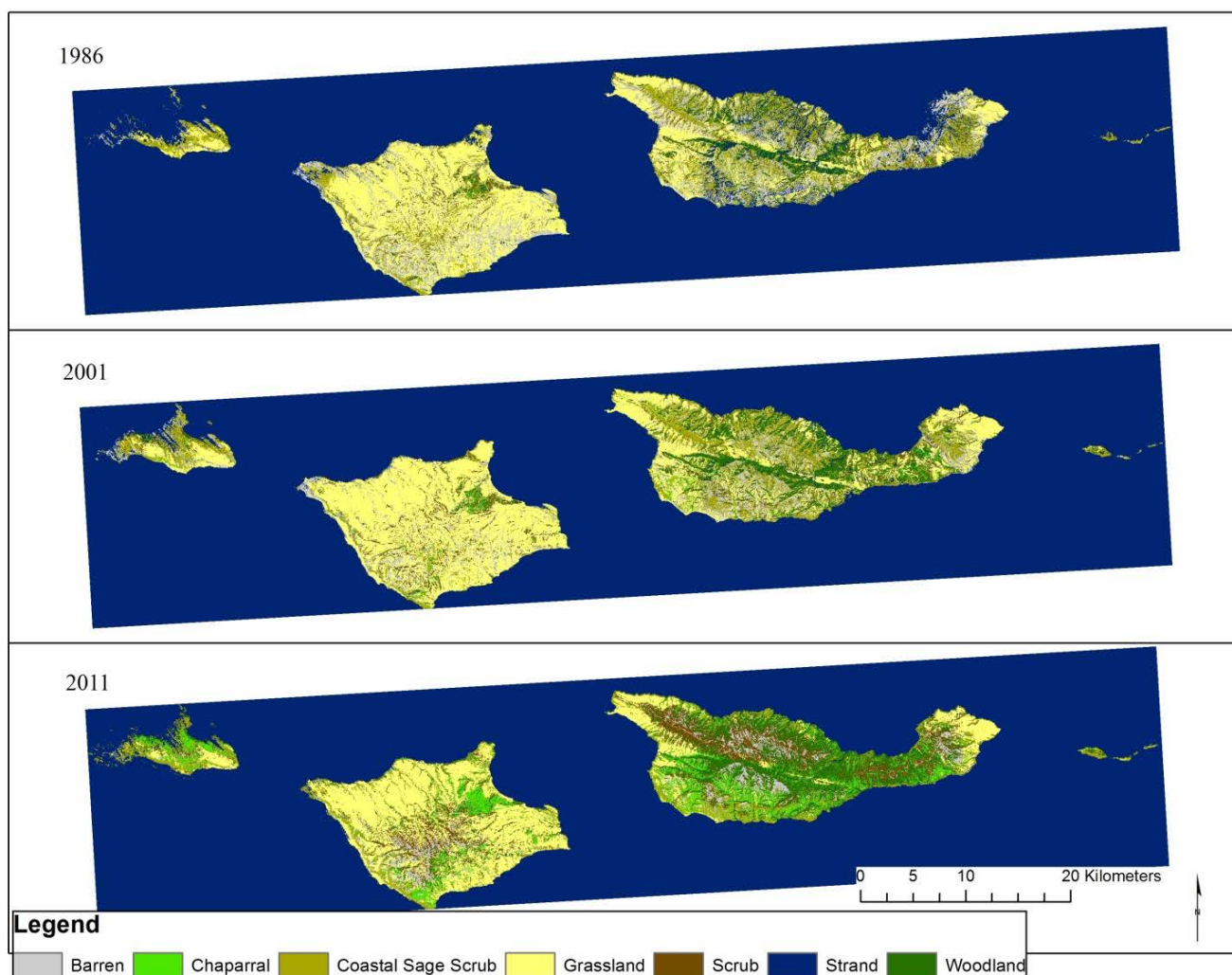




Protocol for Monitoring Landscape Dynamics in the Mediterranean Coast Network of Southern California

Natural Resource Report NPS/MEDN/NRR—2018/1830



ON THE COVER

Land cover change analysis at Channel Islands National Park. Note the increase in chaparral and scrub, which is presumably a result of the removal of feral nonnative animals from the islands.

Image credit: K. Willis

Protocol for Monitoring Landscape Dynamics in the Mediterranean Coast Network of Southern California

Natural Resource Report NPS/MEDN/NRR—2018/1830

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November 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Willis, K. S., S. Ostermann-Kelm, F. Federico, L. Lee, G. M. MacDonald, and T.W. Gillespie. 2018. Protocol for monitoring landscape dynamics in the Mediterranean Coast Network of southern California. Natural Resource Report NPS/MEDN/NRR—2018/1830. National Park Service, Fort Collins, Colorado.

Change History

Version numbers will be incremented by a whole number (e.g., Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g., Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures for publication in the series.

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Version #	Date	Revised by	Changes	Justification
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- 1) Version numbers increase incrementally by tenths (e.g., version 1.1, version 1.2, ...etc.) for minor changes. Major revisions should be designated with the next whole number (e.g. version 2.0, 3.0, 4.0 ...). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making the changes along with the new version number.
- 2) Notify the MEDN Data Manager and MEDN Program Manager of any changes to the Protocol Narrative or SOPs so that the new version number can be incorporated in the Metadata of the project database.
- 3) Post new versions on the internet and forward copies to all individuals with a previous version of the Protocol Narrative or SOPs. A list will be maintained in an appendix at the end of this document.

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Executive Summary

This protocol describes the application of remote sensing data collected via satellites to monitor changes in the landscape within three park units in the Mediterranean Coast Network of southern California (hereafter referred to as MEDN): Cabrillo National Monument, Channel Islands National Park, and Santa Monica Mountains National Recreation Area. Because southern California has a particularly high level of biodiversity in combination with high levels of existing and increasing human impact, it is both a challenge and a necessity to provide adequate monitoring in order to effectively conserve the area. The effects of humans via land use change and development are the largest and most direct impacts. Other significant forces shaping the landscape in this network include the introduction and spread of invasive species, changes in the local fire regimes, climate change, and light pollution. These forces in combination with the natural ecosystem dynamics form a complex system of landscape dynamics over the southern California region.

The protocol addresses three primary variables: land use / land cover and vegetation change, phenology, and light pollution. Land cover and vegetation communities will be compared to 1986 and 2001 baseline data to identify significant changes in land cover and vegetation extent at a 30 m pixel resolution (SOP 1). Phenology and vegetation metrics for the three parks as well as vegetation types and areas of concern will be used to identify changes since 2001 at a 250 m pixel resolution (SOP 2). Time series of light pollution data will be analyzed to identify changes in light population compared to a 1992 baseline at 1 km pixel resolution (SOP 3). The output data will include maps, tables, and graphs describing the distribution and changes in these variables.

The ongoing satellite data employed for this protocol include: Landsat ETM+/TM, MODerate-resolution Imaging Spectroradiometer (MODIS), and Defense Meteorological Satellite Program (DMSP). As part of a baseline study of land use and land cover/vegetation change, satellite data was calibrated and verified using vegetation type boundaries created from the United States Geological Survey (USGS) Gap Analysis Program (GAP). Validation points for land cover and vegetation classes were selected using a Generalized Random Tessellation Stratification (GRTS) method, examined in the field, and used to assess classification accuracy.

The monitoring and reporting outlined in this protocol will be conducted at 3-5 year intervals, at which time a contractor will work with National Park Service (NPS) staff to compile and assess past years changes at requested intervals with the Landsat, MODIS, and DMSP imagery using the following software applications or programming languages: ENvironment for Visualizing Images (ENVI), Interactive Data Language (IDL), and ArcGIS. This protocol contains examples of the summaries, statistics, and maps that will build upon the baseline reports for this protocol in future years. The example data shown in this protocol are taken from the three baseline studies conducted as part of developing and testing this protocol. A benefit of satellite-based monitoring is that standard monitoring interval does not preclude going back and examining imagery at other time intervals if required to provide information on periods of particularly rapid change.

Acknowledgments

We would like to acknowledge the help of John Tiszler, Kate Faulkner, Denise Kamradt, Rocky Rudolph, Christy Brigham, Ken Neissen, Ian Williams, Dirk Rodriguez, Lyndal Laughrin, Kathryn McEachern, and Keith Lombardo from the National Park Service as well as Travis Longcore, Kai Fung Chum, Katherine Glover, Lauren Brown, Dylan Connor, Tyler Harlan, David Gao, and Olivia Jenkins from UCLA for research, GIS, and field assistance. We would also like to thank the peer editors Gregory S. Okin and Yongwei Sheng from UCLA, and Catharine Thompson, Tom Philippi and Bill Monahan from the National Park Service. Linda Munch and Rebecca Key provided useful comments on later versions of the protocol. The protocol was improved through comments from Lisa Garrett, Penny Latham, Jon Bakker and an anonymous reviewer.

List of Acronyms

ALI:	Advanced Land Imager
ANI:	Anacapa Island
ASTER:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CABR:	Cabrillo National Monument
CHIS:	Channel Islands National Park
DEM:	Digital Elevation Model
DMSP-OLI:	Defense Meteorological Satellite Program – Operational Linescan System
DN:	Digital Number
EMZ:	Ecological Management Zone
ENSO:	El Niño Southern Oscillation
ENVI:	ENvironment for Visualizing Images (remote sensing application software)
ERA:	Ecological Reserve Area
ERDAS:	Earth Resources Data Analysis System (remote sensing application software)
ESA:	Endangered Species Act
ETM+:	Enhanced Thematic Mapper +
EVI:	Enhanced Vegetation Index
GAP:	Gap Analysis Program
GCM:	Global Climate Model
GIS:	Geographic Information System
GRTS:	Generalized Random Tessellation Stratification
I&M:	NPS Inventory and Monitoring Program
IDL:	Interactive Data Language (programming language used in ENVI)
IUCN:	International Union for Conservation of Nature
LULC:	Land Use and Land Cover

MEDN:	Mediterranean Coast Network of the NPS Inventory and Monitoring Program
MODIS:	MODerate-resolution Imaging Spectroradiometer
NDVI:	Normalized Difference Vegetation Index
NASA:	National Aeronautics and Space Administration
NDVI:	Normalized Difference Vegetation Index
NLCD:	National Land Cover Dataset
NOAA:	National Oceanographic and Atmospheric Administration
NPS:	National Park Service
OLI:	Operational Land Imager
PLECA:	Point Loma Ecological Conservation Area
RMZ:	Santa Monica Mountains Resource Management Zone
SAMO:	Santa Monica Mountains National Recreation Area
SBI:	Santa Barbara Island
SCI:	Santa Cruz Island
SMI:	San Miguel Island
SOP:	Standard Operating Procedure
SPOT:	Système Pour l'Observation de la Terre
SRI:	Santa Rosa Island
SRTM:	Shuttle Radar Topography Mission
TERRA:	Terrestrial Ecosystems Regional Research and Analysis
TM:	Thematic Mapper
USGS:	United States Geological Survey

1. Background and Objectives

1.1. The National Park Service Inventory and Monitoring Program

The purpose of the National Park Service (NPS) Inventory & Monitoring (I&M) Program is to gather and provide scientific information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. As part of the NPS's effort to improve park management through greater reliance on scientific knowledge, the primary role of the I&M Program is to collect, organize, and make available natural resource data on key vital signs and to contribute to the NPS institutional knowledge by interpreting these data through analysis, synthesis, and modeling. The I&M Program defines vital signs as a subset of physical, chemical, and biological elements and processes of park ecosystems that is selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Fancy et al. 2009).

The five goals of the I&M Program (Fancy et al. 2009) are to:

- 1) Inventory the natural resources and park ecosystems under NPS stewardship to determine their nature and status.
- 2) Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments.
- 3) Establish natural resource inventory and monitoring as a standard practice throughout the NPS system that transcends traditional program, activity, and funding boundaries.
- 4) Integrate natural resource inventory and monitoring information into NPS planning, management, and decision-making.
- 5) Share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

These goals are accomplished through parkwide inventories and a long-term monitoring program. In establishing a service-wide natural resources I&M Program, the NPS created networks of parks that are linked by geography and shared natural resource characteristics. Working within and across networks improves the efficiency of inventory and monitoring because parks are able to share budgets, staffing, and other resources to plan and implement an integrated program.

1.2. Mediterranean Coast Network (MEDN)

The Mediterranean Coast Network (MEDN) is one of 32 monitoring networks across the NPS. The MEDN comprises three NPS units (Figure 1): Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO) and totals more than 113,000 ha in land area. The MEDN Vital Signs Monitoring Plan (Cameron et al. 2005) provides the foundation for the long-term ecological monitoring programs of the network and describes the rationale and basis for the programs. During the I&M Program's vital signs selection process, landscape characteristics such as land use and land cover were determined to be critical components of ecosystem function. Changes in these characteristics resulting from urbanization are among the most important anthropogenic stressors known in our human-dominated region. As a

result, the MEDN recognized the need to monitor landscape dynamics at all three network parks. Considerable variability in landscape type and in the stressors affecting each park’s natural resources created challenges in the development of a single protocol to monitor ecosystem changes at the landscape level. However, this also provides an opportunity to compare selected indicators across these climatic and anthropogenic gradients, and to document potential differing responses among the parks to these stressors.

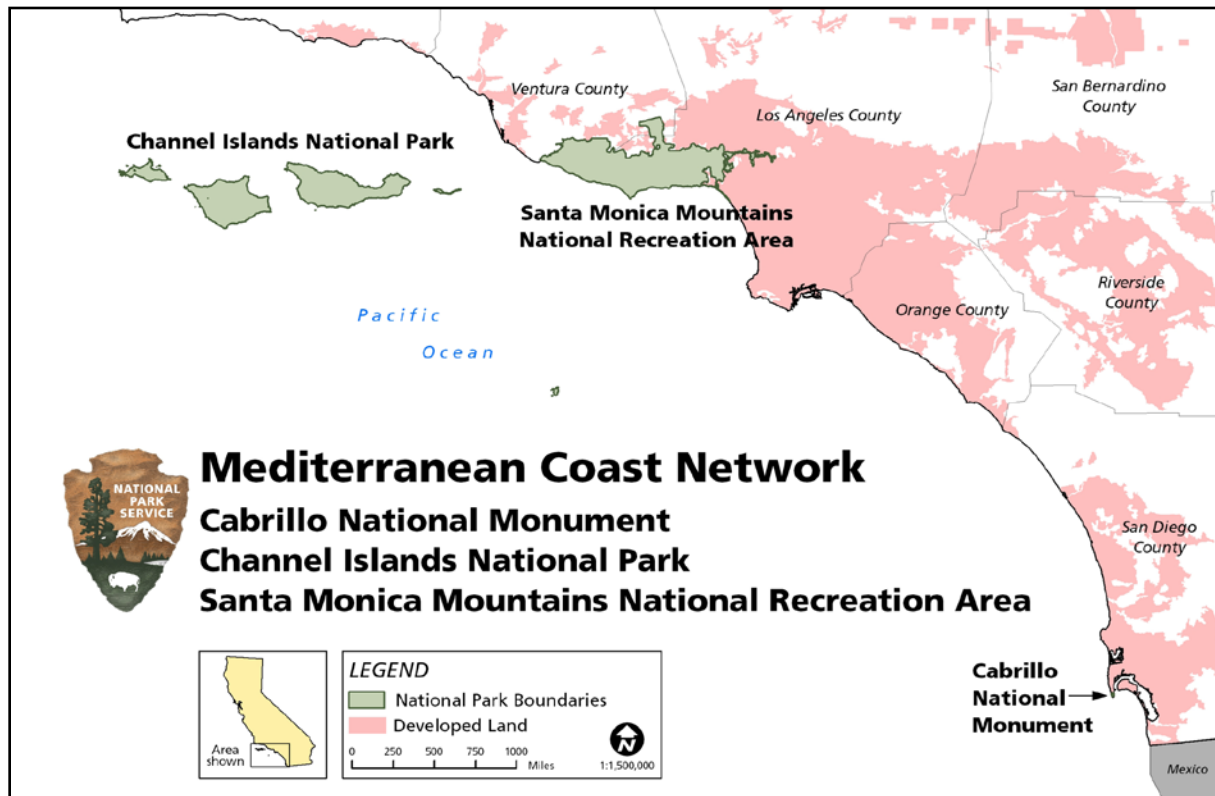


Figure 1. Locations of the three parks within the Mediterranean Coast Network of the NPS I&M Program.

Cabrillo National Monument (CABR)

Cabrillo National Monument (CABR) is located just west of San Diego at the tip of the Point Loma Peninsula (Figure 2). The Point Loma Peninsula is a four-mile long mosaic of development and sensitive natural areas unique in southern California because of their climate and geology. It is revered for its ecological as well as its historical significance. Many of the peninsula’s natural communities have remained intact because of limited development and public access at the U.S. Navy facility, the largest land holding on Point Loma. Although CABR is the smallest park in the MEDN, comprising roughly 65 ha, the park is part of the 263 ha Point Loma Ecological Conservation Area (PLECA), a non-contiguous ecological reserve area created in 1994 by several federal agencies that hold ownership or stewardship over the lands on the Point Loma peninsula. The PLECA sets aside “sensitive biological communities in amounts and configurations that would be viable in the long term on Point Loma” (Engle and Largier 2006). The main ecosystem types in the park include tide pools and coastal sage scrub/maritime chaparral.



Figure 2. Map of Cabrillo National Monument (CABR) within the Point Loma Ecological Reserve.

Channel Islands National Park (CHIS)

Channel Islands National Park (CHIS) comprises five of the eight California Channel islands – Santa Barbara Island (SBI), Anacapa Island (ANI), Santa Cruz Island (SCI), Santa Rosa Island (SRI), and San Miguel Island (SMI) – off the coast of southern California (Figure 3), with a total land area of 51,012 ha. Common plant communities that occur on the islands include coastal sage scrub, nonnative annual grassland, coyote brush scrub, Torrey pine woodland, coastal bluff scrub, Bishop pine woodland, and island chaparral.

Because of its isolation, CHIS is one of the least visited national parks today. However, the islands have a history of intensive ranching and farming since the 1800s. The introduction of nonnative species as well as the intensive grazing of the islands by large herbivores, such as thousands of domestic cattle (*Bos taurus*) and sheep (*Ovis aries*), caused profound changes to the islands' native plant communities and ecosystems (Barbour et al. 2007, McEachern et al. 2016). In recent years, park managers focused on removing nonnative animals from the islands. The removal of European rabbits (*Oryctolagus cuniculus*) from SBI, sheep and rats (*Rattus rattus*) from ANI, and the removal of sheep, domestic cattle, horses (*Equus caballus*), and pigs (*Sus domesticus*) from SCI, SRI and SMI has resulted in much natural recovery on the islands. As of 2015, all feral animals had been removed from the islands with the exception of a few horses on SRI (McEachern et al. 2016).



Figure 3. Map of Channel Islands National Park (CHIS) in southern California.

Santa Monica Mountains National Recreation Area (SAMO)

At 62,018 ha, Santa Monica Mountains National Recreation Area (SAMO) is the largest urban National Park in the United States. It is recognized by the International Union for Conservation of Nature (IUCN) as a Category V park, defined as a protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value. The park is located within both Los Angeles and Ventura Counties (Figure 4) and includes privately developed areas such as Malibu and the Hollywood Hills. Within the recreation area boundary, the NPS owns and manages about 9,383 ha, or 15% of the total area. The remaining area includes privately owned land for both residential and commercial uses, as well as land owned by California State Parks and local land conservancies. About 90% of the land within the greater boundaries of SAMO is currently relatively undisturbed, natural habitat (Cameron et al. 2005). A particular concern in this park is to better understand and mitigate the effects of urbanization and development on natural communities.



Figure 4. Map of Santa Monica Mountains National Recreation Area (SAMO) in southern California.

1.3. Landscape Dynamics

Landscape dynamics refer to a broad suite of ecological and geomorphological processes occurring across broad spatial scales. Landscape dynamics can be considered both system drivers (e.g., changes in land use) and response variables (e.g., changes in the amount of grasslands or chaparral due to fire). As a result of the landscape level threats, MEDN has identified landscape dynamics as a vital sign of ecological health.

The remainder of this section describes the conservation context that is the basis for the selection of landscape dynamics variables of most interest to park managers. It then identifies the specific variables that were selected for inclusion in this protocol following numerous meetings and discussions with managers and I&M staff. It provides a summary of other I&M Landscape Dynamics Protocols, identifies best practices, and discusses various satellite products available for use.

1.4. Conservation Context for this Protocol

California's Mediterranean-type ecosystem has been identified as one of the earth's "biodiversity hotspots" (Myers et al. 2000). Though this ecosystem is home to a number of endemic flora and fauna species, it is also one of the most highly altered ecosystems on the planet. The high degree of rapid urbanization along the southern California coastline has resulted in the loss of significant natural areas and increasing human impacts to the remaining natural systems. An increasing human population in and around parks causes increased pressure on the natural landscape. Landscape-level threats include: urbanization, land cover change (due to urbanization), changes to vegetation communities (drought, invasive species introductions, and unnaturally frequent fire), and light pollution. Below we highlight the most pressing issues associated with MEDN parks and identify needs of natural resource managers.

Urbanization

Human activities currently impact most of the terrestrial biosphere at rates and spatial extents far greater than in any other period in human history (Kerr and Ostrovsky 2003; Grimm et al 2008a). The human population in California makes up about 12% of the US population (Diffenbaugh et al. 2015) and is rising at a 0.9% crude growth rate (State of California Department of Finance 2014). This means that more land is constantly developed for residential and business purposes, which degrades natural landscapes. This increased environmental degradation puts species at risk from habitat loss and fragmentation, potentially adversely affects biodiversity, and introduces invasive plant and animal species (Donlan et al. 2003). Southern California contains 50% of California's human population (20 million people), but only 10% of its land area (Barbour et al. 2007). The most direct impacts of urbanization are conversion of natural lands to developed land cover and the fragmentation of natural lands by development and roads.

Land Cover Change

The large number of human inhabitants and associated development has fragmented and degraded the southern California landscape, causing a decrease in biodiversity and increased edge effects in conserved areas (Fancy et al. 2009; Grimm et al. 2008a, b). This is especially an issue in SAMO since the preserved areas are discontinuous within the greater park boundary. CHIS is minimally affected by fragmentation and land use change because of its remote location. CABR has already experienced a loss of biodiversity due to urbanization and habitat fragmentation (Atkinson et al 2003). The land use change of most concern within the network parks are changes from native vegetation to residential, commercial, or agricultural areas. Natural resource managers also need data on the extent of vegetation conversion (e.g. conversion of shrublands to nonnative grasslands) in protected areas, as well as documentation of vegetation recovery after nonnative species removal. Geospatial data on land cover change within and adjacent to park boundaries can be compared over time and used by natural resource managers to better understand and anticipate threats to parklands.

Ecological Light Pollution

Ecological light pollution has been of increasing concern as it relates to protected areas (Rich and Longcore 2006; Davies et al. 2014). In the past century, the extent and intensity of artificial nighttime lighting has increased such that it has substantial effects on the biology and ecology of species in the wild (Longcore and Rich 2004; Hölker et al. 2010; Gaston et al. 2013).

The introduction of artificial light, either directly or indirectly, into the natural environment can affect a wide range of natural resources, including nocturnal wildlife, migrating birds, and insects (Longcore and Rich 2004; Pawson and Baber 2014). For example, migrating passerine birds fly at night with reference to the stars and can be disoriented by lights from cities and towers (Longcore et al. 2008). Amphibians, with vision far more sensitive than that of humans, are apt to be disoriented by light. Research into the ecological consequences of artificial nighttime lighting is revealing numerous connections between light pollution and species disruption (Hölker et al. 2010; Aubé et al. 2013; Gaston et al. 2013). Quantifying the upward radiance within and adjacent to the parks will allow managers to make informed decisions and recommendations to protect the night sky, and facilitate research to better understand the effects of light pollution on species within the parks (Fancy et al. 2009; NPS 2014).

Fire History and Impacts

Natural fire events at CHIS and CABR are rare because of their maritime climates and low elevations (Anderson et al. 2010). These conditions generally hinder both ignition and fire spread. Additionally, the relative isolation of both of these parks insulates them from the anthropogenic fires that sweep many other vegetated areas in southern California. While there is an extensive intermix of military development and natural vegetation on the Point Loma peninsula, effective fire suppression by the military makes extensive fire spread unlikely.

Natural fire events at SAMO are also uncommon. However, because of development surrounding and within the recreation area, anthropogenic fires are becoming more frequent (Keeley et al. 1999; Taylor 2004; Keeley 2005). These fires are important episodic events, which are unpredictable in time and extent, and which can result in rapid and dramatic vegetation change. Fires can fully consume existing stands of shrubland vegetation and create a possibility for dramatic shifts in vegetation composition and species abundances (Keeley et al. 2005; Witter et al. 2007; Pratt et al. 2010). Natural resource managers at SAMO have access to data on the extent and frequency of fire, but lack data on the vegetation changes that occur after fire. This protocol will provide natural resource managers with vegetation change data to better understand the long-term effects of wildfire.

Climate Change

Climate change is a growing concern throughout the National Park Service, and in MEDN parks the effects of drought and vegetation community shifts are particularly concerning. Compared to 1900, temperatures in the Southwest have increased by 1-2 °C (US GCRP 2009). The average annual temperature for 2001–2009 in the Southwest was 0.8 °C warmer than the 20th-century mean (NOAA 2011). Global surface warming of an additional 2-4 °C is predicted by 2100 due to increased concentrations of atmospheric greenhouse gases. Overall, the coastal areas in southern California will likely experience less change in temperature due to the maritime effect. However, because SAMO acts as a mountainous barrier, the inland side of SAMO is likely to experience warming. Models built specifically for the Los Angeles basin predict that mountainous zones such as SAMO will warm about 2.8 °C on average from 2041-2060 (Hall et al. 2012). Resource managers want to understand how climate change might cause landscape-scale phenology changes (e.g., when and how long particular plants green-up).

The anticipated result of these changes will be a general latitudinal shift of climate zones northward with projected losses of up to 40% of existing shrublands and a concomitant increase in nonnative grasslands of over 350% (Moser et al. 2009; PRBO 2011). These climate changes will exacerbate the negative effects of past land use and continued human population growth (Stephenson and Calcarone 1999; Kus and Beyers 2005; Underwood et al. 2009). The monitoring accomplished through this protocol will provide valuable data on vegetation community shifts and land use changes (e.g. conversion of agricultural lands to developed lands) that may result from climate change.

1.5. Objectives

The objectives of the MEDN Landscape Dynamics monitoring protocol are based on the service-wide goals of the I&M Program as well as on individual park needs. They were selected following numerous meetings with managers and natural resource staff from all three parks. The objectives will

be addressed using remote sensing as the tool for detecting change at the landscape-level (Table 1). Specifically, the objectives of the protocol are to:

- 1) Determine the status and trends in land use (e.g. open space, agriculture, urban) and vegetation communities (i.e. land cover) in and adjacent to the parks. CHIS will be included in the analysis of vegetation community change, but not in the analysis of land use change because no significant changes in land use are anticipated due to the isolation of the islands.
- 2) Determine the variability and long-term trends in phenology and productivity in CABR, CHIS, and SAMO.
- 3) Determine the variability and long-term trends in the intensity and distribution of nighttime lights (more specifically, upward radiance) at all three parks.

An additional, one-time objective was to ground-truth, assess, and validate land cover and vegetation products as part of the development of this protocol.

Table 1. Monitoring objectives for the Landscape Dynamics monitoring program addressed for each MEDN park. Due to the scale of remote sensing data and the relatively small size of CABR, we were unable to include CABR in the analysis of phenology using MODIS.

Park	Land use change	Changes in vegetation communities	Phenological variability	Light pollution
CABR	X	X	–	X
CHIS	–	X	X	X
SAMO	X	X	X	X

Land Use and Vegetation Community Changes

The objective dealing with land use and vegetation community changes aims to quantify where and how the human-developed landscape and vegetation communities are changing. Land use describes human-developed uses of the land such as open space, agriculture, and residential areas, while land cover describes the vegetation communities or natural cover types such as native shrublands or sandy beaches. Landscape scale vegetation community change monitoring is an important supplement to the field-based, more detailed MEDN Terrestrial Vegetation Monitoring program (Tiszler et al. 2016). While the Terrestrial Vegetation monitoring program quantifies species abundance and diversity, the Landscape Dynamics program will use remotely sensed data to provide a landscape-level perspective of changes in vegetation communities and shifts in boundaries between communities over time.

Landsat satellites, such as Thematic Mapper (TM) and Enhanced Thematic Mapper + (ETM+), have been in operation since 1972 and are the first launch of medium spatial resolution (< 250 m) satellites to provide space-based land remote sensing data. The spectral character of the sensor allows discrimination of vegetated from non-vegetated surfaces, shrublands from grasslands, and structurally complex canopies from smoother canopies.

Phenological Variability

Phenological variability is important to monitor in natural areas to better understand how climate change affects landscapes even on relatively short timescales. One of the most well-known ecological responses to climate change is a shift in the local phenology of plants (Parmesan and Yohe 2003), including changes in the start and end of the growing season, duration of growing season, and maximum productivity. Phenology can have an impact on a large number of species that are dependent on natural cycles of vegetation. Though many California native plants are drought-resistant they often experience browning, changes in phenological timing, or dieback due to drought stress. Each of these ecological health indicators may be seen through remotely sensed imagery.

In Mediterranean regions such as coastal southern California, changes in vegetation indices from moderate spectral resolution spaceborne sensors have been significantly associated with species richness (Gillespie et al. 2014), live fuel moisture (Roberts et al. 2006; Yebra et al. 2013), post-fire regeneration (McMichael et al. 2004), and plant productivity/stress (Shoshany 2000). Moderate resolution imagery from sensors such as NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) allows for a high temporal resolution analysis of national parks (Nemani et al. 2009). The MEDN parks can be monitored with satellite imagery using the MODIS vegetation index, Normalized Difference Vegetation Index (NDVI). NDVI is based on the red and near infrared bands to determine the greenness in remotely sensed vegetation:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}),$$

where NIR is reflectance in the near infrared band and RED is reflectance in the red band (Zhang et al. 2003). NDVI ranges from 1.0 to -1.0 with positive values (e.g. 0.5) representing high greenness and negative values (i.e. -0.2) representing little or no vegetation (see example, Figure 5). It contains information the human eye cannot see from the infrared wavelength. Examples are provided in the Methods section of this protocol.

Ecological Light Pollution

The ecological light pollution objective of this protocol aims to map and quantify the overall amount of upward radiance, as well as identify local areas that have experienced a significant (5 percent) increase or decrease in light pollution over time. Long-term studies of light pollution distribution and impacts generally have used the Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS), which has provided global annual composite nighttime light imagery at a global spatial scale since 1992 (Gillespie et al. 2014). We use visible pixel intensity derived from DMSP-OLS, which is available in relative values ranging from 0 to 63 digital numbers. Example data and additional information are provided in the Methods section of this protocol.

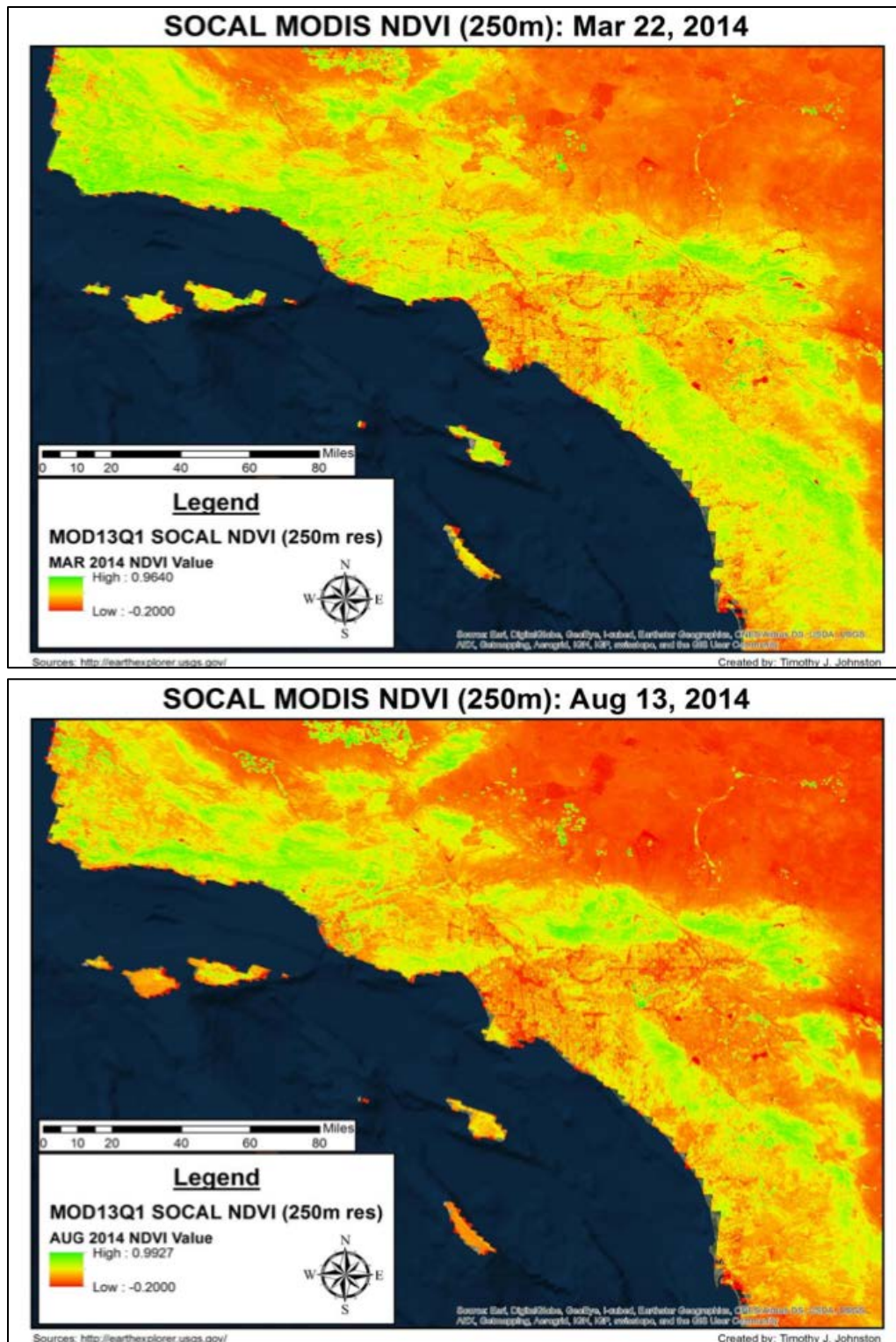


Figure 5. MODIS NDVI pixel values over southern California for March 22 (top) and August 14 (bottom), 2014.

2. Sampling Design and Data Acquisition

The first steps in beginning any remote sensing analysis are to determine the sampling domain (Figure 6) and to choose an appropriate spatial scale and temporal resolution at which to conduct the study (Rogan and Chen 2003; Willis 2015). Because satellite images provide wall-to-wall coverage of a study area, traditional sampling concerns (site selection, sample size, etc.) are not relevant. However, there are other important sampling issues. Satellite image spatial sampling is determined by pixel size, and temporal sampling is determined by the orbit characteristics of the satellite and the field of view of the sensor (Jensen 2007). Moreover, sensors differ in their sampling of the electromagnetic spectrum (Rogan and Chen 2003; Jensen 2007). Below we review the sampling domains for each of the parks, summarize the approaches used by other NPS I&M networks developing landscape dynamics protocols, and then determine the best data sources for MEDN objectives.

2.1. Sampling Domains

CABR

The PLECA is the sampling domain used for this and all other MEDN I&M monitoring programs implemented at CABR. The PLECA is a 263-hectare (650 acre) non-contiguous Ecological Reserve Area (ERA) on Point Loma to protect sensitive biological areas.

CHIS

The sampling domain for CHIS includes all five park islands: Santa Barbara, Anacapa, Santa Cruz, Santa Rosa and San Miguel islands (Table 2). Analyses focus exclusively on land and do not include the surrounding ocean, except for the night lighting analysis, which include a 1 km (0.62 mile) buffer around the perimeter of each island. The total area within the CHIS domain is 51,012 ha.

Table 2. Channel Islands National Park's islands and their area.

Island	Hectares
San Miguel Island	3,879
Santa Rosa Island	21,486
Santa Cruz Island	25,089
Santa Barbara Island	268
Anacapa Island - East	45
Anacapa Island - Middle	63
Anacapa Island - West	183
Total:	51,012

SAMO

The sampling domain for SAMO includes the entire outer boundary of the National Recreation Area as well as surrounding areas, officially known as the Ecological Management Zone (EMZ) (Tiszler et al. 2016). This allows for observation of edge effects and the changes occurring within private and

publicly owned land surrounding the park. The total area of the EMZ (which includes SAMO) is 122,639 ha.

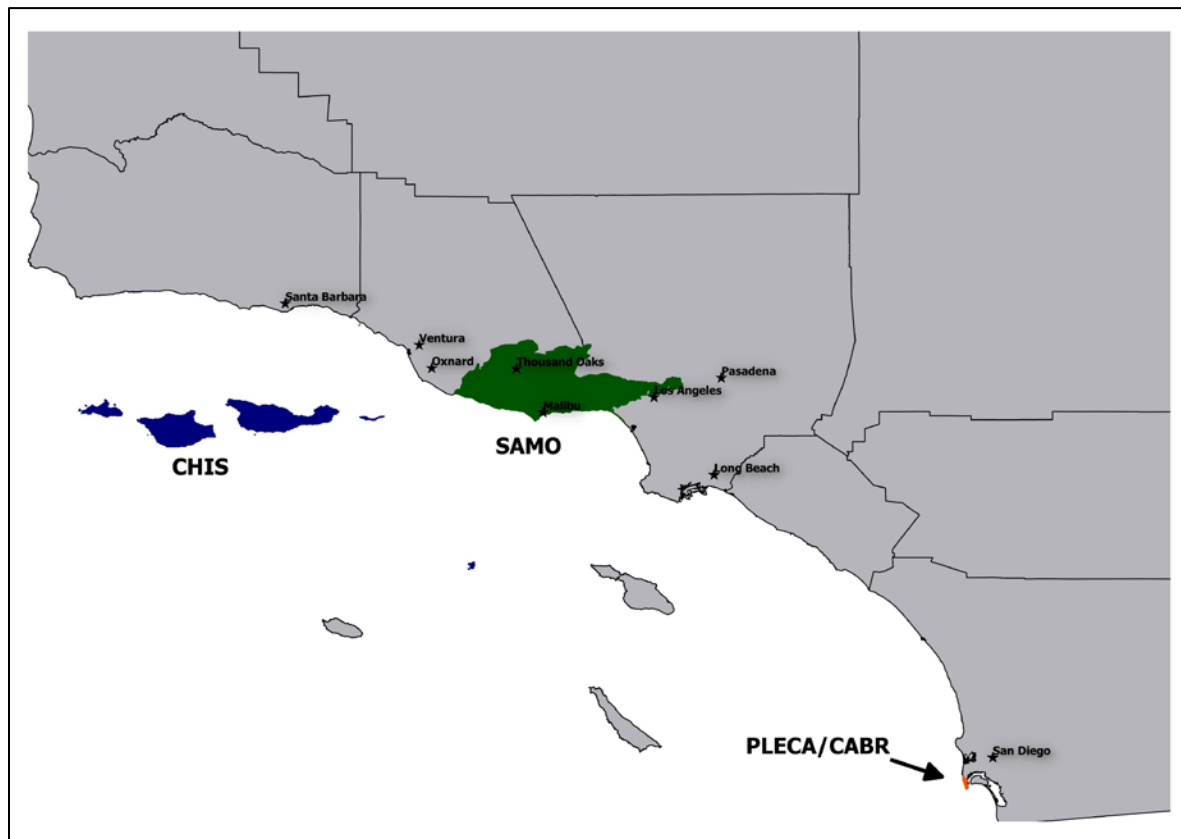


Figure 6. Image of boundaries used for CABR/PLECA, CHIS, SAMO/EMZ for use in analysis.

2.2. Review of Other I&M Protocols for Landscape Dynamics

Landscape dynamics has been identified as a high priority by many of the 32 I&M networks. In partial response to this need, a national landscape dynamics project, NPScape, was created (National Park Service 2011a), to assist parks and networks in monitoring changes in human population, housing, roads, pattern, conservation status, and broad land cover classification. Data from NPScape will complement the data generated by this protocol by providing metrics on a larger scale for parks and adjacent lands, while this protocol will provide more detailed data and analysis inside and around each MEDN park. The following effective methods identified from approved landscape dynamics protocols were incorporated into the MEDN Landscape Dynamics Protocol.

- Remote sensing methods, especially in combination with Geographic Information Systems (GIS) and on-the-ground field data, are cost-effective techniques for measuring landscape-level temporal changes over a continuous area (Franklin et al. 2000; Rogan et al. 2003; Miller and Rogan 2007).
- Remote sensing is commonly used to map biodiversity, changes in land cover type as well as within landscape types and vegetation classes, and was often the primary tool for monitoring

landscape changes in other national parks using well-established techniques in the remote sensing field (Fraser et al 2009; Nagendra et al 2012; Nemani et al. 2009).

- These techniques are often carried out using spaceborne satellite imagery, and involve various methods of classifying the landscape into discrete, mutually exclusive classes.
- These methods commonly acquire imagery on a defined temporal scale, perform classification on each image, and then compare classifications to identify differences in aerial extent, location, size, and arrangement of each of the mapped classes.
- For these protocols, Landsat Thematic Mapper (TM), Enhanced Thematic Mapper + (ETM+), Operational Land Imager (OLI) imagery data are largely used, with several using additional satellite data from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), ALI (Advanced Land Imager), Ikonos, Système Pour l'Observation de la Terre (SPOT), and Quickbird for validation (when funding is available).
- Imagery data are often validated using land cover classification maps with Anderson Level II images from the USGS National Landcover Dataset (NLCD) as well as from aerial photos and images. Processing software commonly used include ArcGIS, Earth Resources Data Analysis System (ERDAS) Imagine, and occasionally Interactive Data Language (IDL) Virtual Machine.
- Tasseled-cap transformation, unsupervised classifications of baseline images, as well as maximum likelihood supervised classifications are used for change detection analyses. Images are typically validated using ArcGIS software and field validation.

A number of networks, including the Great Lakes Network and North Coast Cascades Network, are currently implementing LandTrendr (Landsat-based detection of Trends in Disturbance and Recovery) for their landscape monitoring programs (Kennedy et al. 2010; Antonova et al. 2012). LandTrendr uses Landsat image stacking to look at change detection over multiple dates rather than the more traditional approach of comparing only two dates of imagery. Image stacking infers changes in spectral data as deviations from long-term trends using a single spectral index. This can be used to identify areas with abrupt disturbances as well as for tracking slow changes over time (Kennedy et al. 2010). Validation is completed in ENvironment for Visualizing Images (ENVI) software using IDL, as well as in the field (Kennedy et al. 2010).

Though promising, MEDN chose not to utilize LandTrendr for its landscape dynamics protocol. Due to phenological differences in vegetation and persistent cloud cover over the southern California coastline in winter and spring, MEDN will use similar techniques (described in the methods and SOP sections) with modifications to suit its region and network-specific monitoring objectives by selecting specific dates of Landsat data for comparison, rather than using stacked images from multiple years.

2.3. Spatial and Temporal Resolution

We compiled a list containing information on satellite imagery based on the specific needs of each park, the metrics necessary for each objective, and the cost of imagery for comparison (Table 3). We evaluated these various sources of data and the trade-offs between data resolution, revisit time, and cost. A summary of the data needed to meet the three monitoring objectives is provided below.

Land Use and Land Cover Change/Vegetation Communities

It is desirable to have the highest spatial resolution imagery possible in order to determine the family, genera, or possibly even species of vegetation. We used Landsat due to funding constraints, which prevented us from using higher resolution data. We chose to use Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper + (ETM+) because it is freely available and appropriate for park-wide monitoring of diverse land use and cover types, as well as vegetation communities. Having a higher temporal resolution (16-day full-Earth-coverage cycle) than some other satellites, Landsat data are most applicable for study at the regional and historical scale (Rogan and Chen 2003; Miller and Rogan 2007). With a pixel-spacing of approximately 30 meters and an extent of 180 by 180 kilometers, TM and ETM+ images capture adequate spatial detail for many landscape processes. Landsat's temporal sampling (16 days) is adequate for capture of usable cloud-free imagery at intervals appropriate for monitoring vegetation structure and composition. The new Landsat Data Continuity Mission (LDCM), with the new sensor Operational Land Imager (OLI) will be used for future monitoring purposes since its launch in early 2013. Other freely available Landsat-type data may be used as replacements in future analyses as well, including European Space Agency's Sentinel-2.

If additional funding becomes available for this monitoring in future years, we recommended that higher resolution products such as SPOT or Quickbird be used rather than Landsat. As of 2014, the approximate cost for analysis of the entire 173,914 ha sampling domain of the MEDN with Quickbird would range from \$22,608-66,087, and with SPOT this cost would range from \$41,739-\$125,218.

Phenology

Detecting changes in phenology requires datasets with high temporal resolution. Launched in 2000, the MODIS sensors on the Terrestrial Ecosystems Regional Research and Analysis (TERRA) and Aqua satellites have 36 spectral bands at 250 m, 500 m, and 1000 m pixel resolution. MODIS vegetation indices at 250 m pixel resolution can be used to monitor the phenology including the timing of green-up, peak green-up, and senescence of vegetation to understand phenological changes associated with global warming (Thoma 2011). MODIS also contains thermal bands that can map land surface temperature and fire history. MODIS data can be used map areas burned since 2001 to quantify the extent of fire and vegetation succession in parks.

Satellites carrying the MODIS sensors have a revisit time of 1-2 days year-round, making it very useful to measure temporal changes in vegetation characteristics and seasonality. The 1-2 day images are compiled in 16-day composites to allow for filtering of atmospheric disturbances to the images such as cloud cover. This high temporal resolution means that it in turn has a low spatial resolution of 250-1,000 meters. Despite its low resolution, MODIS is useful for measuring large-scale changes in the normalized difference vegetation index (NDVI) over a landscape and can be used to measure vegetation changes over a time series since the turn of the century. TERRA has shown deterioration over time in the blue band (Wang et al. 2012). However, because NDVI is measured using the red and infrared bands, this should not be an issue for our analyses.

Ecological Light Pollution

The Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) provides panchromatic nighttime light imagery at a global spatial scale. The Defense Meteorological Satellites have a near-polar orbit at an altitude of 830 kilometers and contain visible and infrared sensors that collect night light imagery at 30 arc-second or 0.9 kilometer pixel resolution across a 3000 kilometer swath (Earth Observation Group, NOAA 2012). Each pixel provides a digital number value (0-63) of upward radiance as seen from space. Nightlight imagery composites are collected annually based on stable night-lights. The stable night-light algorithm removes fires, lunar luminance, lighting features from the auroras, and cloud cover. Previous research has used nighttime lights or upward radiance to measure changes in the distribution and time series of light pollution, populations, and energy use in a given area (Elvidge et al. 1997; Small et al. 2005; Gillespie et al. 2017).

The imagery and resolution chosen for each objective are also described in more detail in the methods, data analysis, and reporting sections. In Table 4, we summarize the variables, data source, spatial resolution, baseline years, and reporting frequency for each monitoring objective. Because new satellites are launched regularly, potential data sources and their costs should be investigated before initiating each report.

Table 3. Satellite Information and metrics considered in the MEDN landscape dynamics protocol.

Satellite	Background Information	Spatial Resolution	Nominal Revisit Time	2018 Base cost estimates for archived images (per km ²)	2018 Base cost estimates for custom images (per km ²)	Spectral Resolution	Applications
MODIS	NASA product on Terra and Aqua satellite, launched 1999	250m (bands 1-2), 500m (bands 3-7), 1000m (bands 8-36)	1-2 days	Free	n/a	36 bands available at different resolutions	Phenology
Landsat TM/ETM+/OLI	NASA product since 1972	30m	16 days	Free	n/a	7 bands on Landsat 5, 8 bands on Landsat 7	Land use/land cover change
IKONOS	First high resolution color imaging satellite since 1999, owned by DigitalGlobe	0.80m pan ^a , 2.4m multi ^b	3-5 days	\$10 (minimum order 25 km ²)	\$20 (minimum order 100 km ²)	Pana, multi ^b (4-band), natural color (3-band), color IR ^c (4-band) pan-sharpened, or pan ^a + multi ^b	Data validation
GeoEye-1	Highest resolution commercial color imagery satellite since 2008, owned by DigitalGlobe	0.46m pan ^a , 1.84m multi ^b	<3 days	\$13-29 (minimum order 272 km ²)	\$22-38 (minimum order 100 km ²)	Pana or multi ^b (4- or 8-band)	Data validation
Quickbird	Owned by DigitalGlobe, launched 2001	0.61m pan ^a , 2.4m multi ^b	1-3.5 days	\$14-18 (minimum order 25 km ²)	\$22-38 (minimum order 100 km ²)	Pana or multi ^b (4- or 8-band)	Data validation

a pan – panchromatic includes one greyscale band of combined red, green, and blue of visible electromagnetic spectrum

b multi – multispectral covers multiple bands along the electromagnetic spectrum

c IR – Infrared

d DEM – Digital Elevation Model

Table 3 (continued). Satellite Information and metrics considered in the MEDN landscape dynamics protocol.

Satellite	Background Information	Spatial Resolution	Nominal Revisit Time	2018 Base cost estimates for archived images (per km ²)	2018 Base cost estimates for custom images (per km ²)	Spectral Resolution	Applications
SPOT 1-7	Launched in 1986, owned by Spot Image, France	2014: 1.5m pan ^a , 6m multi ^b ; 2002-2014: 2.5-5m pan ^a , 10m multi ^b 1986-2002: 10m pan ^a , 20m multi ^b	1-3 days	\$32 (minimum order 60 km ²)	\$24-72 (minimum order \$3600)	Pana or multi ^b (4-band)	Data validation
ASTER	NASA product on Terra satellite, launched 1999	15m visible near IR ^c , 30m shortwave IR ^c , 90m thermal IR ^c	16 days	Freed	n/a	15 bands	Supplementary data source, DEM ^d
DMSP	First launched 1962 by US Department of Defense	30 arc-second grid	12 hour	Free	n/a	Brightness index calculated for one band	Night light monitoring

a pan – panchromatic includes one greyscale band of combined red, green, and blue of visible electromagnetic spectrum

b multi – multispectral covers multiple bands along the electromagnetic spectrum

c IR – Infrared

d DEM – Digital Elevation Model

Table 4. Overview of sampling design and data acquisition. Describes variables monitored and inventoried, source and spatial resolution of satellite data, baseline year(s) of original data that serve as a reference for change detection, and desired frequency of reporting.

Variable	Data Source	Resolution	Baseline Year(s)	Frequency of Reporting
Land Use / Land Cover and Vegetation Communities	Landsat	30 m	1986, 2001, 2011	5-7 years, ideally coinciding with trend analyses from the Terrestrial Vegetation Monitoring Program (Tiszler et al. 2016)
Phenology	MODIS	250 m	2001	5 years
Light Pollution	DMSP	1 km	1992	3 years

3. Methods

As part of developing this protocol, three baseline reports (Gillespie et al. 2016; Willis et al. 2018a; Willis et al. 2018b) addressing the Land Use and Land Cover (LULC) Change, Phenology, and Nighttime Lights objectives were developed using the procedures and data sources described in this protocol. The benefits of this process included:

- Testing and validating protocol procedures
- Providing results for a baseline period against which future changes can be compared
- Providing examples of outputs and products for each protocol variable

In this section we describe the overall workflow steps to address each monitoring objective (Figure 7). Detailed descriptions of the methodology used for each objective are provided in SOPs 1-3. The example maps, charts and other products contained in this chapter are output from the baseline studies.

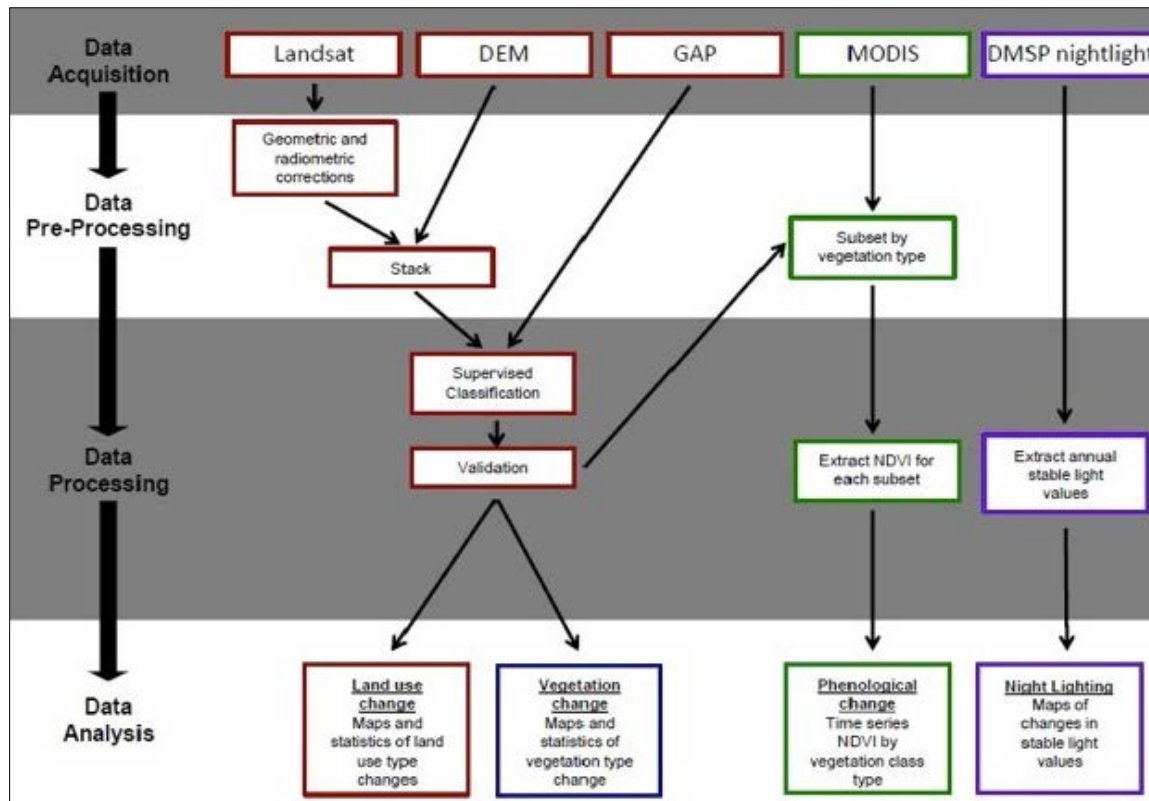


Figure 7. Workflow of methodology for the MEDN Landscape Dynamics Monitoring protocol.

In brief, the process for each objective begins with acquiring data through on-line data sources (Data Acquisition). The data are then pre-processed to correct for various anomalies (Data Pre-Processing). Once corrected, the data are then processed and validated (Data Processing), and the results exported to an appropriate format for analysis (Data Analysis).

3.1. Land Use and Vegetation Community Changes

An overview of the analysis to address objective 1 (land use and land cover change) is provided below, with detailed instructions in SOP 1. As shown in Figure 7, three types of base data are acquired to process land use and vegetation community changes: USGS GAP, DEM, and Landsat.

GAP, Landsat, and DEM data are all free, have comparable pixel sizes (30 m), and are available for the entire United States, and therefore results for MEDN parks can be placed in a nation-wide context for comparison purposes.

USGS Gap Analysis Program

The analysis began with creating a baseline dataset of LULC and vegetation classifications. The LULC and vegetation classes used to create the baseline were based on the United States Geological Survey (USGS) Gap Analysis Program (GAP) Land Cover dataset. These datasets are available at <https://gapanalysis.usgs.gov/gaplandcover/data/download/>. The GAP dataset provides detailed information on the vegetation and land use patterns for the United States. These land cover data have been updated and cross-walked to the five highest levels of the National Vegetation Classification.

The 590 land use classes in the GAP data set can be displayed at three levels of detail: Level 1 contains eight land use classes, and generalizes to the level of vegetative physiognomy (i.e. grassland, shrubland, forest); Level 2 contains 43 classes, and incorporates information on elevation and climate; Level 3 contains the full 590 classes for the entire United States. The classes used to create the baseline for both land use and land cover (vegetation community change) were chosen from the Level 2 and Level 3 classes that were applicable to the MEDN park areas (Table 5, Figure 8). The classes used for analysis (Table 6) were chosen only if they had a sufficient number of polygons within each park boundary (more than one for CABR, more than 30 for CHIS and SAMO). A full description of classes used in this protocol is available in Appendix A.

Table 5. Summary of GAP categories used in monitoring objective 1: land cover land use change/vegetation community change.

GAP Land Use / Land Cover Classification on Level	Total number of GAP categories	Total number of categories applicable to CABR	Number of categories used for CABR analysis	Total number of categories applicable to CHIS	Number of categories used for CHIS analysis	Total number of categories applicable to SAMO	Number of categories used for SAMO analysis
Level 2	43	8	5	16	9	18	12
Level 3	590	10	7	25	0	37	4

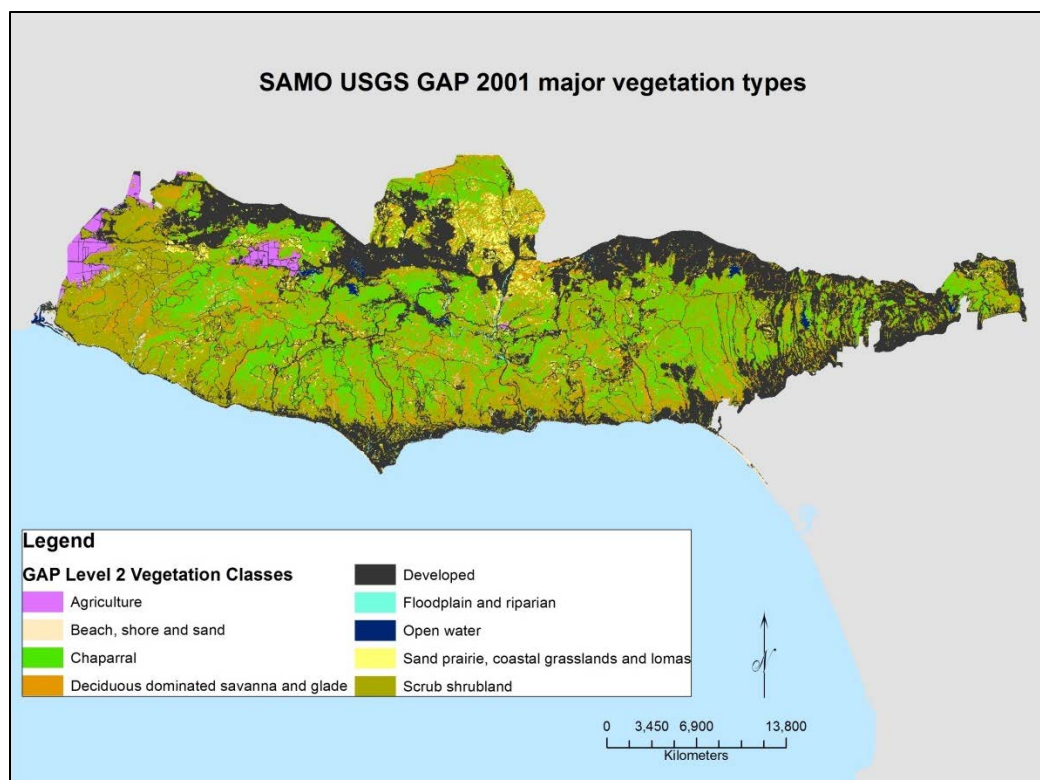


Figure 8. Gap Analysis map Level 2 vegetation classes from Landsat imagery collected in 2001.

Table 6. GAP Land Cover Classification for land use, land cover/vegetation community types in MEDN. Types with an asterisk (*) were collapsed into a single type (vegetation) for the land use analysis.

Level	Land Cover/Vegetation Community Types
Level 1	Agriculture
	Beach, Shore, Sand*
	Chaparral*
	Cliff, Canyon, and Talus*
	Coastal Grassland*
	Conifer Dominated Forest Woodland (Mesic-Wet)*
	Conifer Dominated Forest Woodland (Xeric-Mesic)*
	Deciduous Dominated Savanna Glade*
	Floodplain Riparian*
	Freshwater Herbaceous Marsh, Swamp, or Baygall
	Mixed Deciduous/Coniferous Forest and Woodland (Mesic-Wet)*
	Scrub Shrubland*
	Open Water
	Developed

Table 6 (continued). GAP Land Cover Classification for land use, land cover/vegetation community types in MEDN. Types with an asterisk (*) were collapsed into a single type (vegetation) for the land use analysis.

Level	Land Cover/Vegetation Community Types
Level 2	Developed – High Intensity
	Developed – Medium Intensity
	Developed – Low Intensity
	Developed – Open Space

Landsat

Landsat data were downloaded using GloVis online database (<http://glovis.usgs.gov/>). Images should be chosen from the summer months (July through September) to avoid the effects of winter rain (which rapidly changes the spectral properties of the landscape) and cloud cover present along the coast in spring, as well as to maintain consistency over time. The impact of rainfall on most vegetation spectral properties is minimal from mid to late summer in southern California (Garcia et al. 2010). It is recommended that precipitation records be checked prior to downloading Landsat imagery in order to account for any anomalies from average precipitation patterns. The Landsat imagery can be chosen from months containing little to low precipitation in order to ensure consistency across images from different years. Precipitation records for the area can be downloaded by station at the National Climatic Data Center by NOAA (<http://gis.ncdc.noaa.gov/map/cdo/?thm=themeDaily> or from www.climateanalyzer.org). An example of daily precipitation records obtained from the NOAA website from stations near SAMO can be seen in Figure 9.

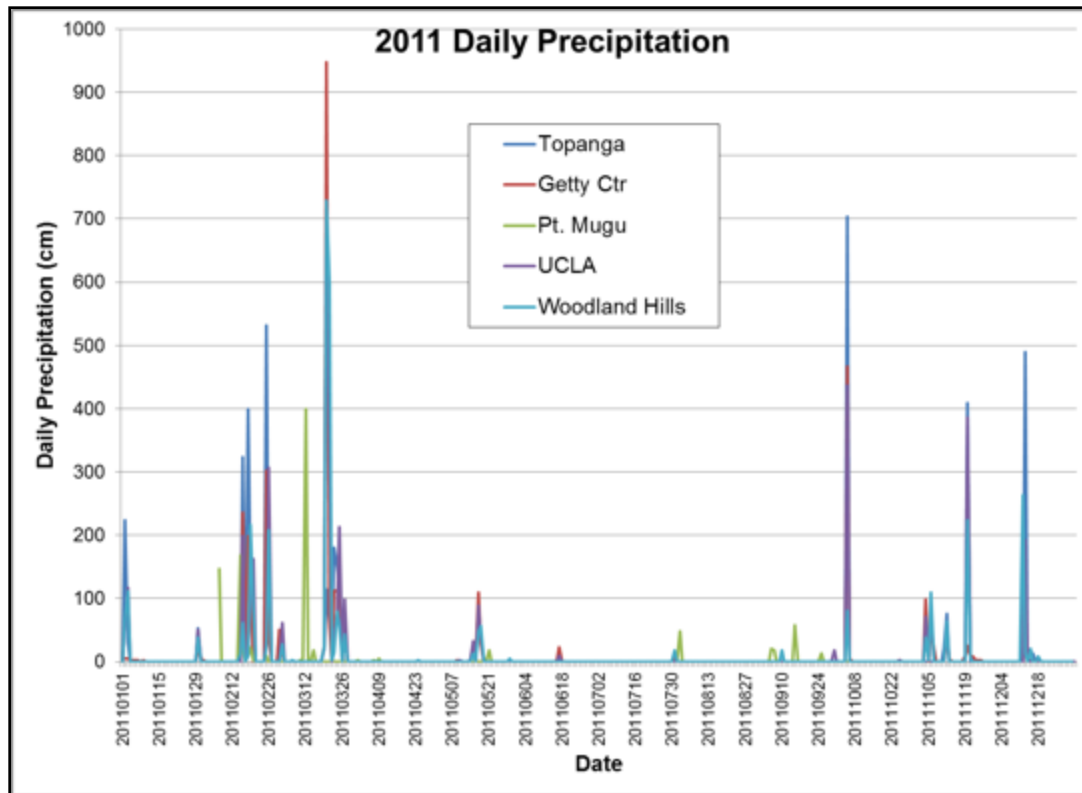


Figure 9. Daily recorded precipitation for 2011 from five field stations in and surrounding SAMO. Ideally, Landsat data should be acquired during the dry summer months to minimize temporary changes to vegetation resulting from precipitation.

Digital Elevation Model (DEM)

An elevation dataset is also used in order to improve the accuracy of classifications. Many land cover and vegetation types are geographically correlated with a particular slope, aspect, and elevational range. A Digital Elevation Model (DEM) for this region can be downloaded from the Shuttle Radar Topography Mission (SRTM) database (<http://www2.jpl.nasa.gov/srtm/>) for use in the analyses. SRTM provides elevation, slope, and aspect data at 30 m pixel resolution from 2001.

Data Pre-Processing

Once the base data are collected, the following pre-processing techniques may be applied to the Landsat images in the software platform ENVI. It should be noted that in current datasets provided by the USGS, this step has already been completed, and therefore pre-processing of these data may be skipped. However, pre-processing is important to understand when conducting remote sensing analysis and thus descriptions are included here:

- Temporal correction involves the co-registration, or transformation, of images to have comparable coordinates over time so that images in a time series can be compared in an analysis.
- Geometric correction allows for the rectification of differences between the same pixel at different points in time (Rogan and Chen 2003). These inaccuracies occur due to changes in sensor altitude and relative geographic location. Geometric correction is completed by

associating a per-pixel image feature to a per-pixel ground feature with known geographic coordinates (Rogan and Chen 2003), and is expressed as total root mean square error. (Note: in current datasets provided by the USGS this step has already been completed, thus this step may be skipped.)

- Radiometric normalization allows for relatively consistent radiance values by minimizing error due to differences in solar illumination, atmospheric scattering and absorption, and detector performance (Rogan and Chen 2003).

Data Processing: Image Classification

Image classification of datasets is the process of associating land use and land cover classes with the spectral data. Supervised classification is the most intuitive method for LULC classification (Rogan and Chen 2003; Gillespie et al. 2014). A supervised classification uses baseline data to assign LULC classes to certain pixels (in this case, the LULC classes are based on the USGS GAP land cover types). The spectral information within those pixels is then used to apply the assigned LULC classes to the remainder of an image, thereby creating a *baseline image* for the original year of data (Figure 10). Past and future classification images will be compared to this baseline image in order to calculate changes between LULC types. The accuracy of this image can then be tested by comparing with the original polygons created from the GAP dataset or ground-truthed in the field.

There are several different types of supervised classifications, including: parallelepiped, minimum distance, mahalanobis distance, maximum likelihood, spectral angle mapper, spectral information divergence, and binary encoding. Each of these methods was tested and assessed for accuracy in order to determine the most accurate method for a land use classification of the MEDN dataset. The best method was maximum likelihood. This is consistent with other NPS Landscape Monitoring Protocols discussed earlier.

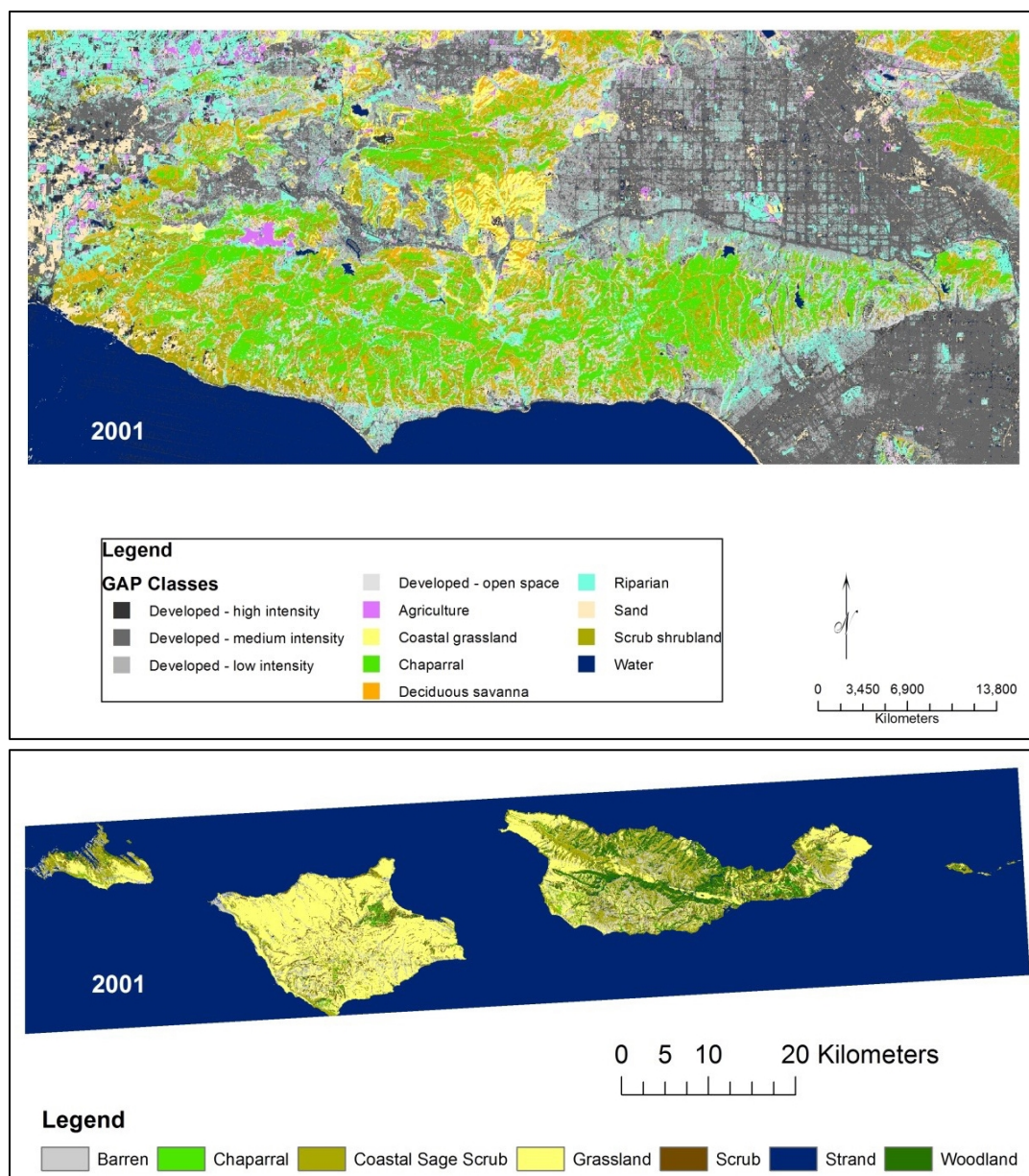


Figure 10. Baseline image of SAMO (top) and the northern four CHIS islands (bottom) created from maximum likelihood classification using the GAP 2001 dataset.

After a baseline classification image is established for each park, spectral and elevation data were extracted to build a spectral and elevation library (Figure 11) for each LULC class. These libraries were then applied to classify the remainder of the Landsat images based solely on the spectral and topography data (see Appendix A).

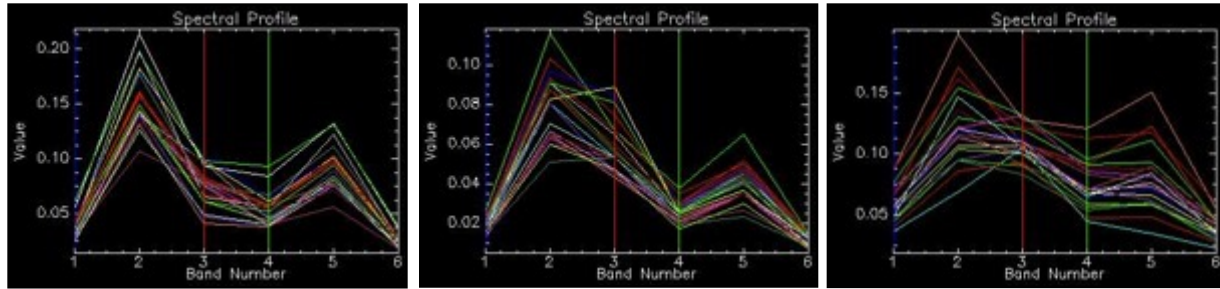


Figure 11. Spectral signatures for a) sage scrub; b) chaparral; and c) developed - low intensity (see Appendix A for the complete set of spectral signatures used in this protocol). Each color curve represents the spectral signature of one particular pixel of the given land cover class. Spectral bands correspond to the following Landsat Bands: 1: 0.45-0.52, 2: 0.52-0.60, 3: 0.63-0.69, 4: 0.76-0.90, 5: 1.55-1.75, 6: 2.08-2.35 micrometers.

Data Analysis

Results from the analysis show the starting and ending LULC class in map (Figures 12 and 13), and table format (Tables 7 and 8). Tables include the number of GRTS points used for LULC validation, number of field and Google Earth validated locations used, and the overall percent accuracy of land cover classes. The difference can be used to assess impacts to natural areas over time and can help inform and prioritize land purchasing decisions or management actions.

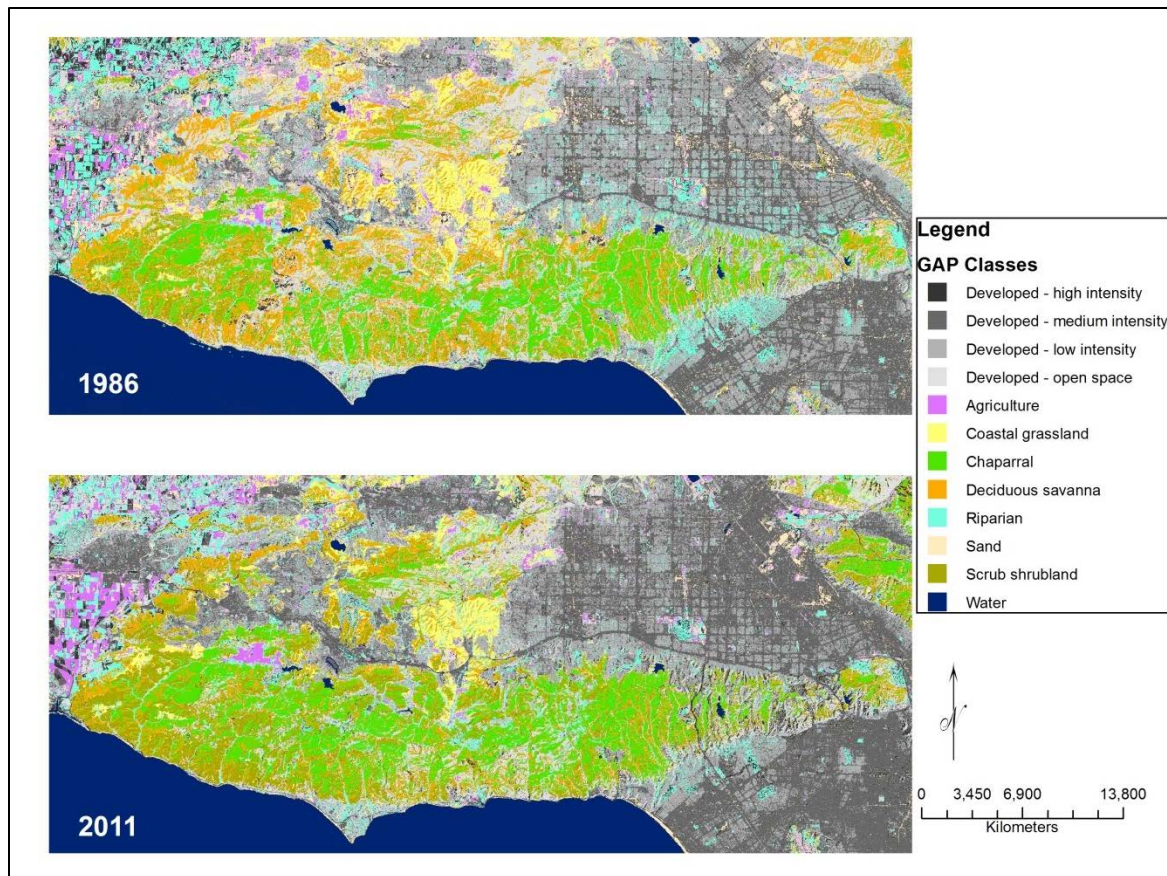


Figure 12. LULC maps of SAMO in 1986 and 2011 created from maximum likelihood image classification using the GAP 2001 dataset as a baseline.

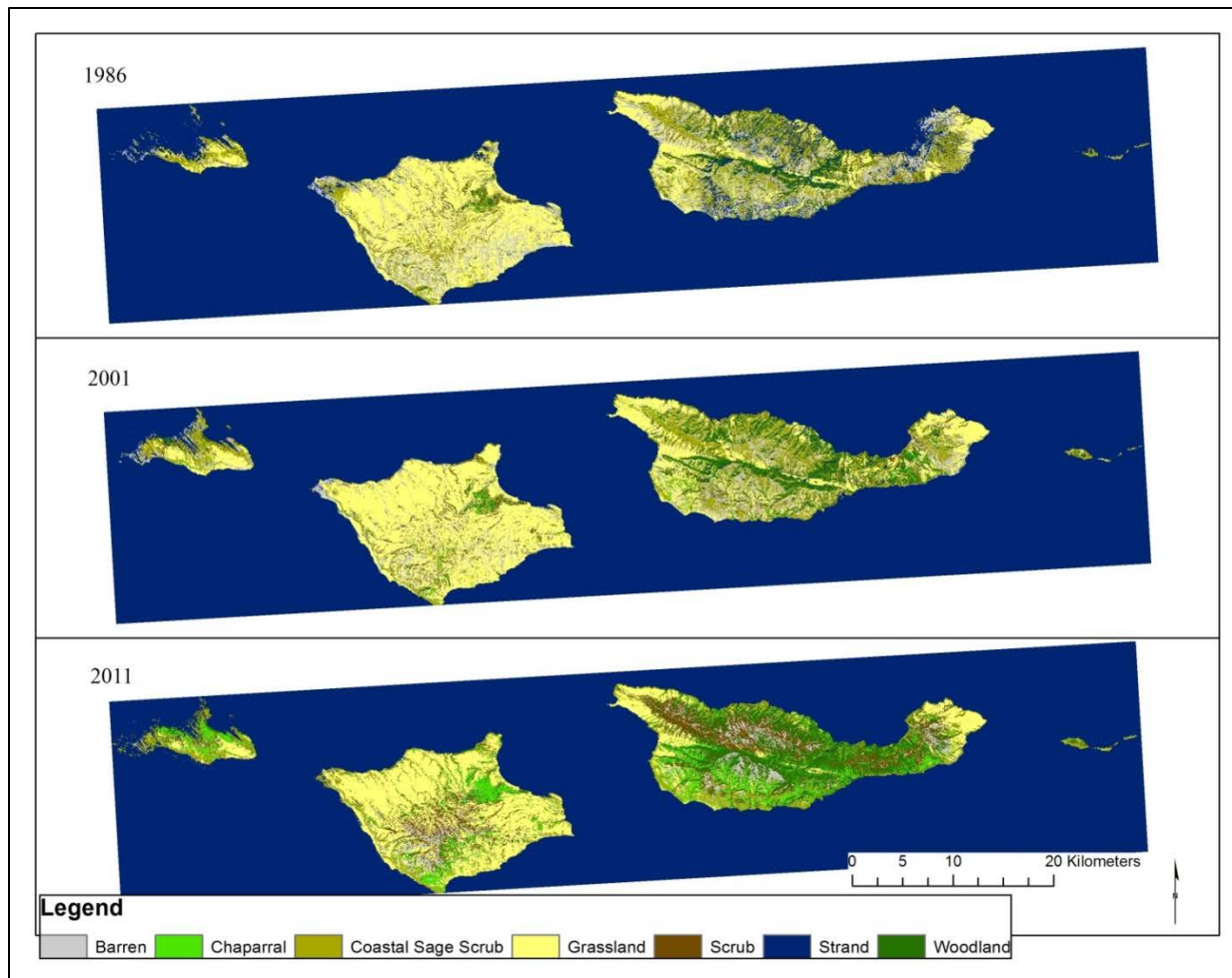


Figure 13. LULC maps of CHIS in 1986, 2001, and 2011 created from maximum likelihood image classification using the GAP 2001 dataset as a baseline.

Table 7. Validation points and percent accuracy in SAMO, 2011. Note: Google Earth number of points may be greater than GRTS number of points since additional points were added from other vegetation categories.

Land Cover Class	GRTS points (n)	Field Validated	Google Earth Validated	Percent Accuracy
SAMO – All Classes	1736	0	1582	61.6
Agriculture	69	0	114	87.7
Chaparral	149	0	235	48.5
Scrub shrubland	135	0	174	41.4
Floodplain/riparian	175	0	69	84.1
Deciduous dominated savanna/glade	110	0	42	45.2
Sand prairie, coastal grasslands, lomas	73	0	65	87.7
Sand	101	0	99	93.9

Table 7 (continued). Validation points and percent accuracy in SAMO, 2011. Note: Google Earth number of points may be greater than GRTS number of points since additional points were added from other vegetation categories.

Land Cover Class	GRTS points (n)	Field Validated	Google Earth Validated	Percent Accuracy
Water	87	0	136	88.2
Developed	837	0	648	0.56
Developed – High Intensity	123	0	164	68.9
Developed – Medium Intensity	260	0	138	58.0
Developed – Low Intensity	205	0	215	52.1
Developed – Open Space	249	0	131	44.3
Native vegetation	459	0	552	69.1
Nonnative vegetation	183	0	76	71.0
Developed	906	0	463	60.8

Table 8. Validation points and percent accuracy in CHIS, 2011. Note: Google Earth number of points may be greater than GRTS number of points since additional points were added from other vegetation categories.

Land Cover Class	GRTS points (n)	Field Validated	Google Earth Validated	Percent Accuracy
CHIS – All Classes	770	341	0	69.1
Barren	70	24	0	75.0
Chaparral	70	33	0	69.7
Coastal sage scrub	70	25	0	30.4
Grassland	70	62	0	71.0
Scrub	70	34	0	41.1
Strand	70	19	0	94.7
Conifer woodland (woodland)	70	18	0	94.4
Mixed woodland (woodland)	70	34	0	94.4
Native vegetation	140	126	0	65.2
Nonnative vegetation	420	58	0	73.0

Change detection maps can then be created to qualitatively show areas that are undergoing any types of change in LULC class from 1986 to 2011 (Figure 14), from one particular land cover type to another (Figure 15), or shifts in groups of land cover types such as native to nonnative vegetation or increasing developed land in SAMO (Figures 16) or CHIS (Figure 17).

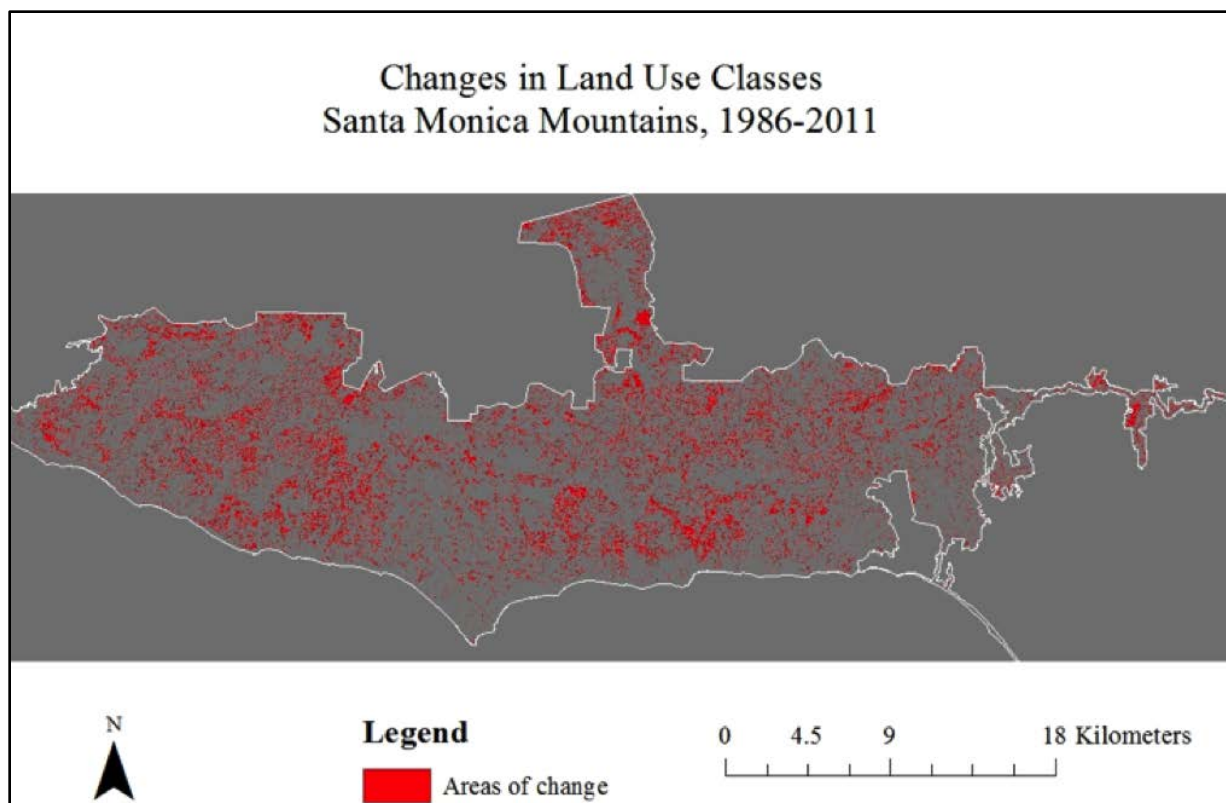


Figure 14. Changes within all land use classes in the Santa Monica Mountains National Recreation Area from 1986-2011.

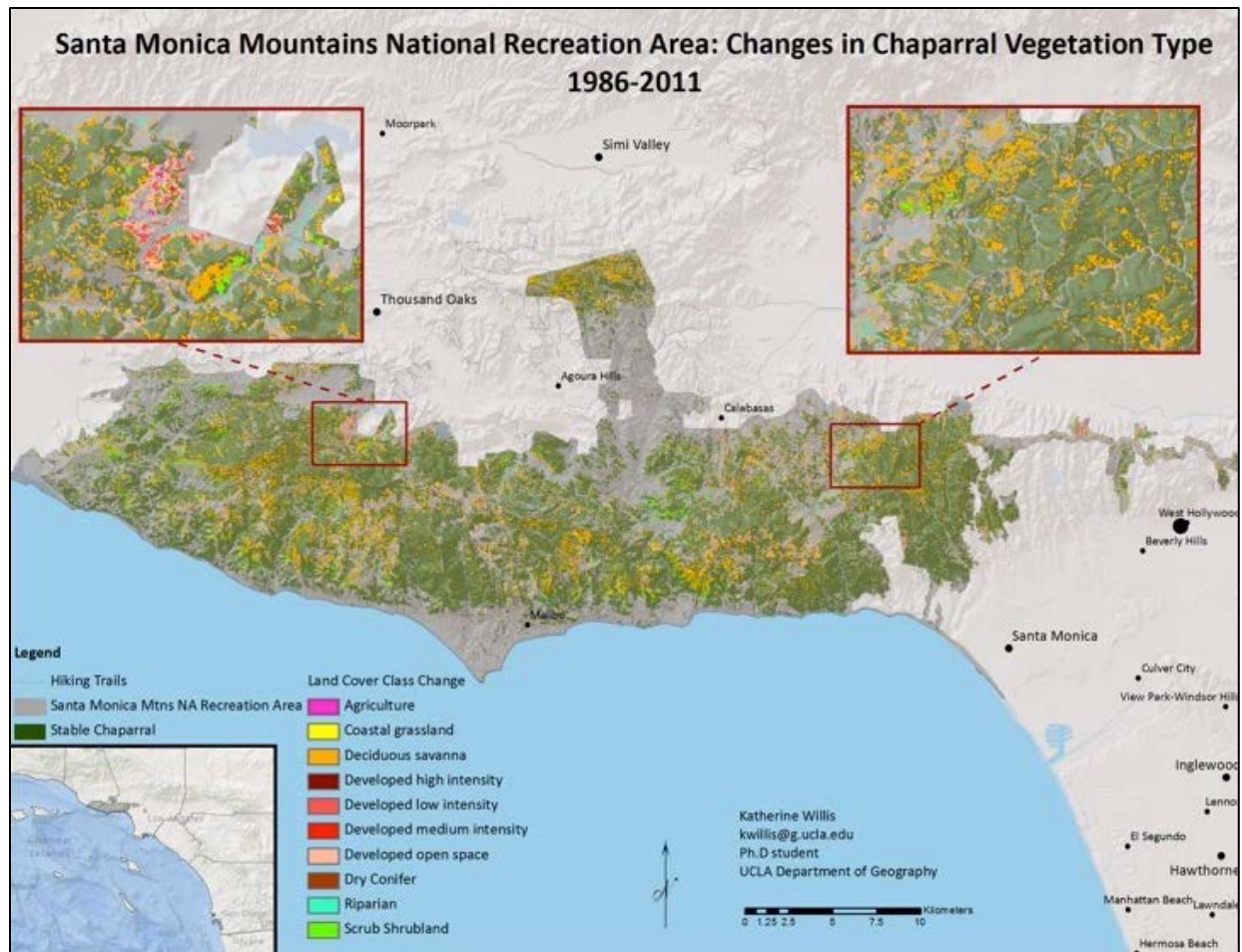


Figure 15. Example results focused on change of one specific vegetation type (chaparral) to various land cover types from 1986-2011 in the Santa Monica Mountains National Recreation Area.

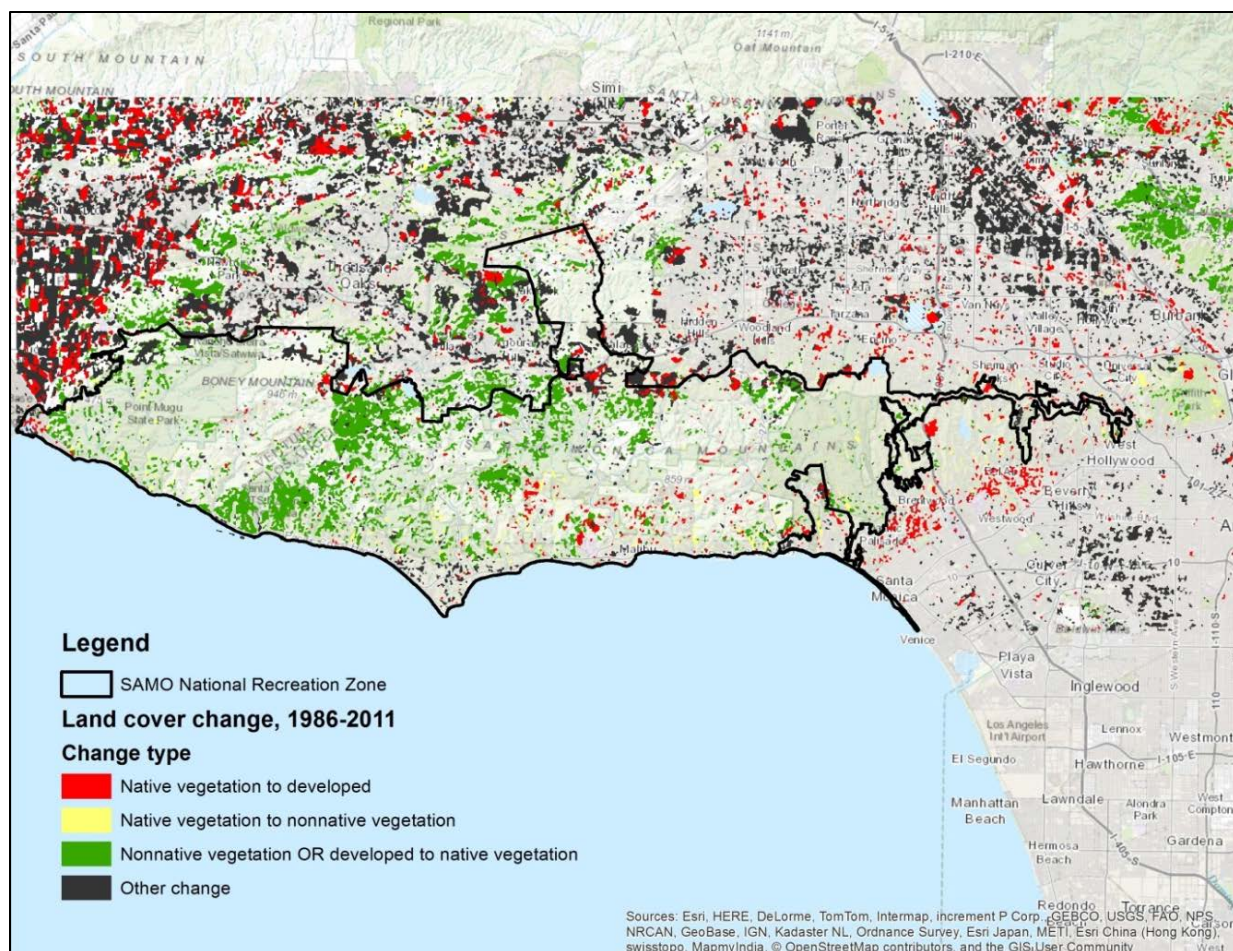


Figure 16. Change detection map for the Santa Monica Mountains National Recreation Area from 1986 to 2011 based on Maximum Likelihood spectral classification of Landsat imagery. Areas of red indicate regions changed from all vegetation types to developed land cover types, areas of yellow indicate regions changed from native vegetation types (riparian, chaparral, scrub shrubland) to nonnative vegetation types (coastal grassland, deciduous savanna), and areas of green indicate regions changed from nonnative or developed to native vegetation types.

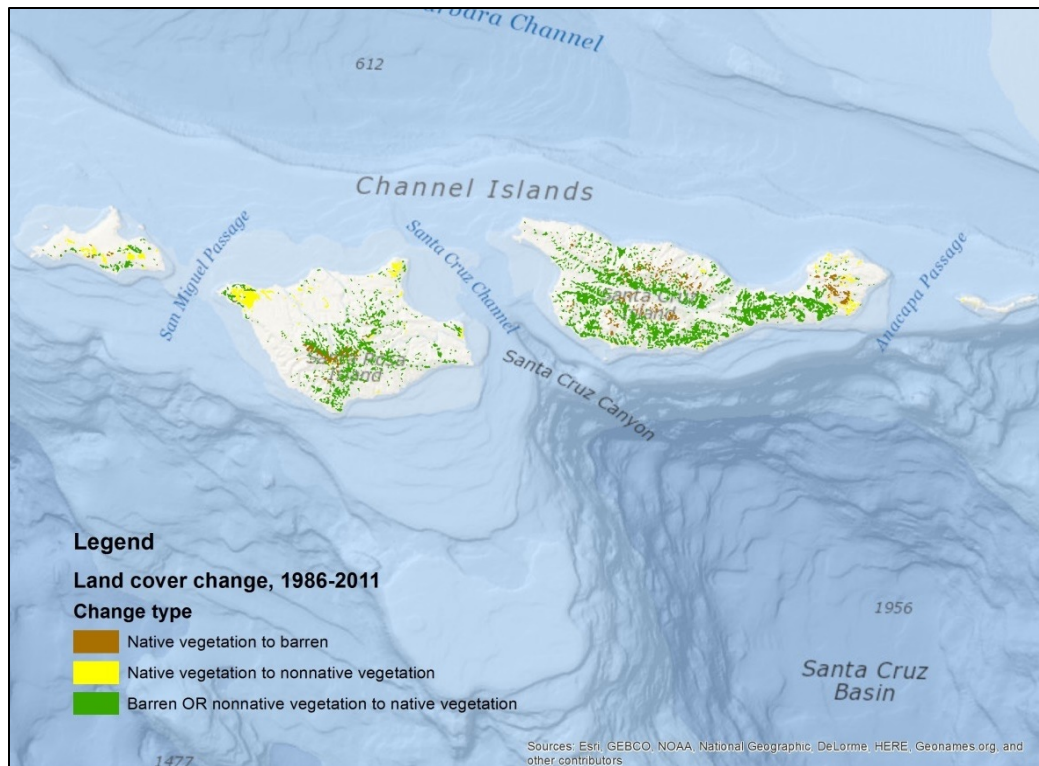


Figure 17. Change detection map of the northern four Channel Islands from 1986 to 2011 based on Maximum Likelihood spectral classification of Landsat imagery. Areas of yellow indicate regions changed from native vegetation types (chaparral, strand, conifer/woodland, marsh, mixed woodland, riparian, scrub) to nonnative vegetation types (coastal grassland, deciduous savanna). Areas of green indicate regions changed from nonnative to native vegetation types. Areas in brown indicate regions changed from native vegetation types to barren.

Quantitative change statistics are also created for the magnitude of change (number of pixels or size of land) within a particular land cover class between two time periods from one land cover class to another for SAMO (Table 9) and CHIS (Table 10), or as a qualitative summary (Tables 11 and 12). The types of changes considered in this protocol are categorical changes, or changes occurring between different LULC classification types. Thresholds are set for each LULC category according to its spectral properties, and a basic change detection analysis is applied to the data for inter-annual comparison. Percent change was detected for variation from each LULC type to another, with a particular focus on changes from natural (chaparral, woodland, coastal sage scrub, etc.) to developed landscape (urban, agricultural, etc.).

Table 9. Change detection matrix from 1986 to 2011 showing percent change to/from class changes at Santa Monica Mountains National Recreation Area.

Year	–	1986											
–	Class*	WATR	SCRB	SAND	RIPE	DVOP	DVMD	DVLO	DVHI	DSAV	CHAP	CGRS	AGRI
2011	WATR	99.51	0.00	0.45	0.17	0.02	0.01	0.02	6.25	0.00	0.00	0.01	0.05
	SCRB	0.00	77.18	0.76	0.61	11.84	0.00	0.01	1.79	21.92	4.15	7.71	0.17
	SAND	0.07	0.55	19.29	0.43	0.65	2.01	0.75	3.15	0.07	0.01	0.73	2.29
	RIPE	0.00	0.08	3.52	37.39	9.27	0.50	2.09	10.80	5.05	3.54	7.21	8.36
	DVOP	0.01	16.13	9.39	14.38	38.42	0.45	3.07	17.77	8.62	5.15	18.15	18.18
	DVMD	0.15	0.01	41.22	6.24	4.75	87.86	41.76	16.80	0.07	0.07	3.59	18.33
	DVLO	0.01	0.21	10.15	20.40	15.20	7.25	48.56	11.38	0.89	0.71	10.67	17.64
	DVHI	0.26	0.43	7.02	7.15	3.30	1.71	2.87	15.63	3.45	1.77	2.03	4.15
	DSAV	0.00	3.91	0.19	1.83	6.08	0.01	0.09	2.13	37.29	15.71	5.30	0.05
	CHAP	0.00	0.72	0.06	4.42	2.88	0.02	0.01	3.48	20.79	68.80	0.11	0.01
	CGRS	0.00	0.73	0.59	0.22	3.96	0.01	0.04	0.48	1.76	0.06	40.20	6.42
	AGRI	0.00	0.05	7.37	6.77	3.63	0.17	0.74	10.33	0.08	0.05	4.29	24.37
–	Class Changes	0.49	22.82	80.71	62.61	61.58	12.15	51.44	84.37	62.71	31.20	59.80	75.63

*Class Abbreviations: WATR (open water), SCRB (scrub shrubland), SAND (beach, shore, sand), RIPE (floodplain riparian), DVOP (developed – low intensity), DVMD (developed – medium intensity), DVHI (developed – high intensity), DSAV (deciduous dominated savanna glade), CHAP (chaparral), CGRS (sand prairie, coastal grassland, and lomas), AGRI (agriculture). More information is available in Appendix A.

Table 10. Change detection matrix showing percent change of selected to/from classes at Channel Islands National Park.

Year	–	1986						
–	Class*	BARREN	CHAP	CSS	GRASS	SCRUB	STRAND	WOODLAND
2011	BARREN	17.58	4.32	9.09	3.02	7.29	0.36	0.94
	CHAP	12.52	57.37	11.15	10.83	24.03	0.43	12.48
	CSS	12.04	4.44	19.91	2.57	5.08	0.78	1.95
	GRASS	23.52	2.30	11.80	68.59	8.47	0.24	0.32
	SCRUB	19.14	6.30	21.12	11.49	28.34	0.45	9.89
	STRAND	1.34	1.55	1.31	0.13	0.74	96.81	0.49
	WOODLAND	13.86	23.72	25.62	3.37	26.05	0.93	73.93
–	Class Changes	82.42	42.63	80.09	31.41	71.66	3.19	26.07

*Abbreviations: CHAP (chaparral), CSS (coastal sage scrub), GRASS (grassland). More information is available in Appendix A.

Table 11. Summary table of LULC occurring over Santa Monica Mountains National Recreation Area. Cover class abbreviation definitions are available in Appendix A.

Land cover class	Summary of main changes occurring
WATR	Stable
SCRB	Stable; mainly converted to developed – open space
SAND	Stable; becoming more developed
RIPE	Becoming more developed
DVOP	changing to developed – low
DVMD	Stable
DVLO	Changing to developed – medium
DVHI	Changing to developed – open/medium
DSAV	Changing to chaparral and coastal sage scrub
CHAP	Changing to deciduous savanna
CGRS	Changing to developed – open/low
AGRI	Changing to developed – open/medium/low

Table 12. Summary table of LULC occurring over Channel Islands National Park. Cover class abbreviation definitions are available in Appendix A.

Land cover class	Summary of main changes occurring
BARREN	Changing to a variety of classes, mostly grassland
CHAP	Stable; mainly converted to woodland
CSS	Changing to a variety of classes, mostly scrub
CGRS	Stable; changing to scrub and chaparral
SCRB	Changing to woodland and chaparral
STRAND	Stable
WOODLAND	Stable; changing to chaparral

Accuracy Assessment and Error

There is error inherent in any remote sensing study, which is an effect of the ability of remote sensing to assess an entire landscape. The amount of error present in this analysis has been minimized by multiple runs of the analysis and applying the appropriate changes to the methodology after identifying the sources of error. After analyses were carried out, field and satellite validation were used to further improve accuracy.

An accuracy assessment evaluates the precision of a classification by comparing its output to input ground-truth data (validation points) in a confusion matrix format calculated using ENVI. Overall accuracy is expressed as a percentage value (Thomlinson et al. 1999). Each land use class is assigned values of percent accuracy, numerical pixel value, and number of misclassified pixels.

Validation points for land use classes were chosen based on a randomized draw; specifically, a Generalized Random Tessellation Stratification (GRTS) approach was used (Stevens and Olsen 2003, 2004). GRTS is a method used for drawing spatially-balanced samples designed with true probability. It uses a combination of a true probability with systematic sampling which is drawn using R Statistical Software.

A total of 130 ground control point locations per each land cover type per park were selected for map validation (for an example, see Figure 18). A total of 30 points per LULC type per park were validated in the field, and 100 points were validated using Google Earth imagery to assess the accuracy of the vegetation and land cover class maps. The 2011 classification maps were compared to validation points to identify how well the classes match high-resolution imagery to find total accuracy (Kappa coefficient).

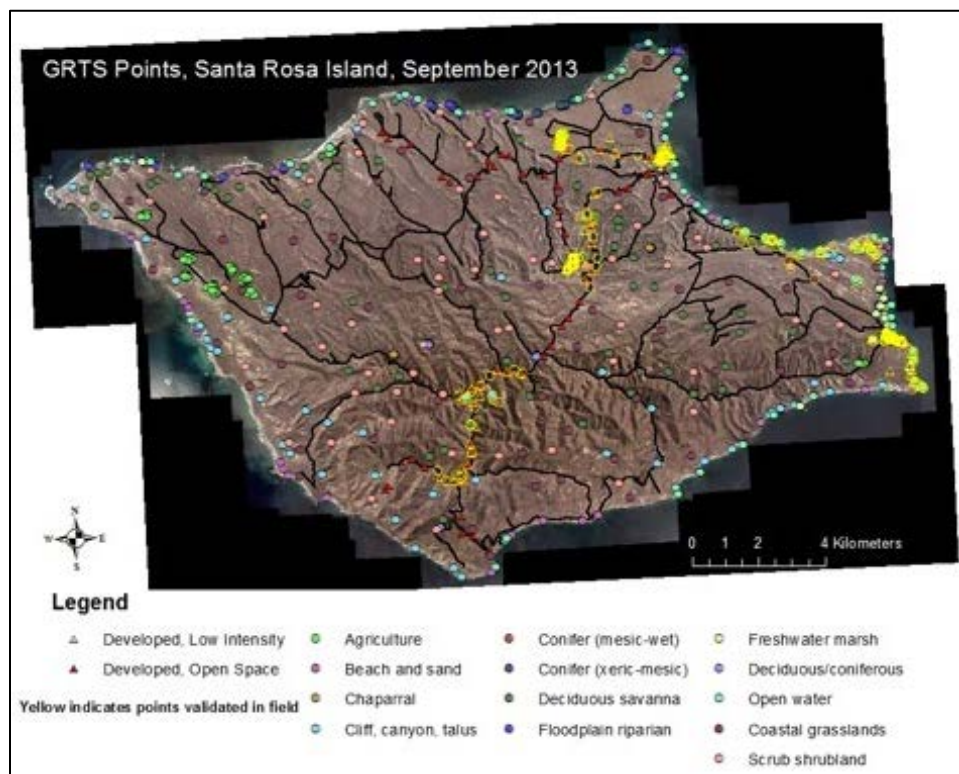


Figure 18. Map of GRTS points drawn for Santa Rosa Island (CHIS). Field validation visited points are highlighted in yellow. Access to points was restricted to minimize impacts to cultural resources as well as pinnipeds and nesting seabirds.

Field validation was completed on CHIS from 2012-2013 by importing GRTS points to a Garmin Oregon 650 GPS unit and accessing the maximum amount of points possible given time and funding constraints (Figure 19). Accuracy assessments were conducted *in situ* on CHIS using the Relevé method in order to determine the dominant land cover type similar to GAP. The CHIS vegetation classes provided by CHIS for training data were translated to fit into the GAP categories accordingly.

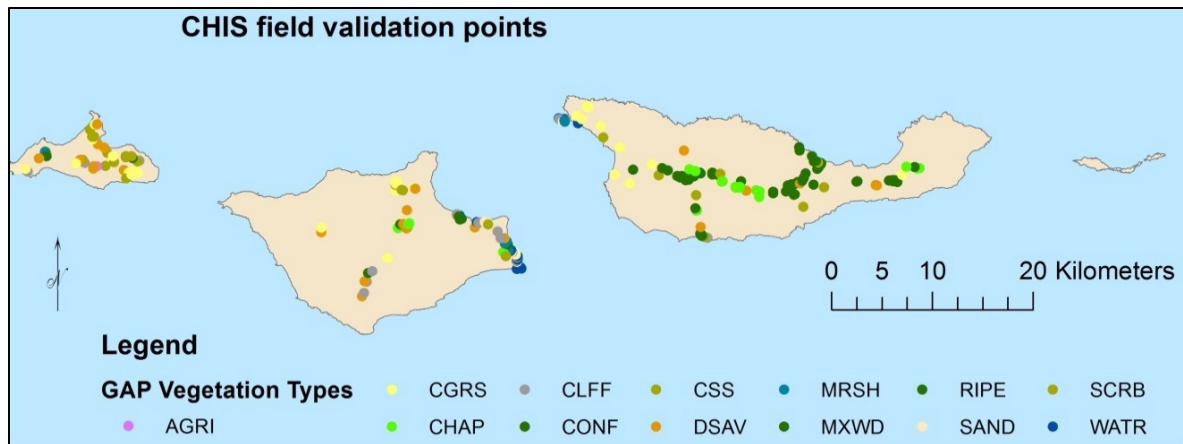


Figure 19. Map of all field validated points visited at Channel Islands National Park. Cover class abbreviation definitions are available in Appendix A.

Google Earth imagery from 2010-2012 was used for accuracy assessment in SAMO (Figure 20). Validation points were compared to the maximum likelihood 2011 classifications to calculate an error matrix and accuracy percentages. (Note: It was assumed that the land cover classes present in 2011 were similar or the same as those assessed *in situ* from 2011-2013.)

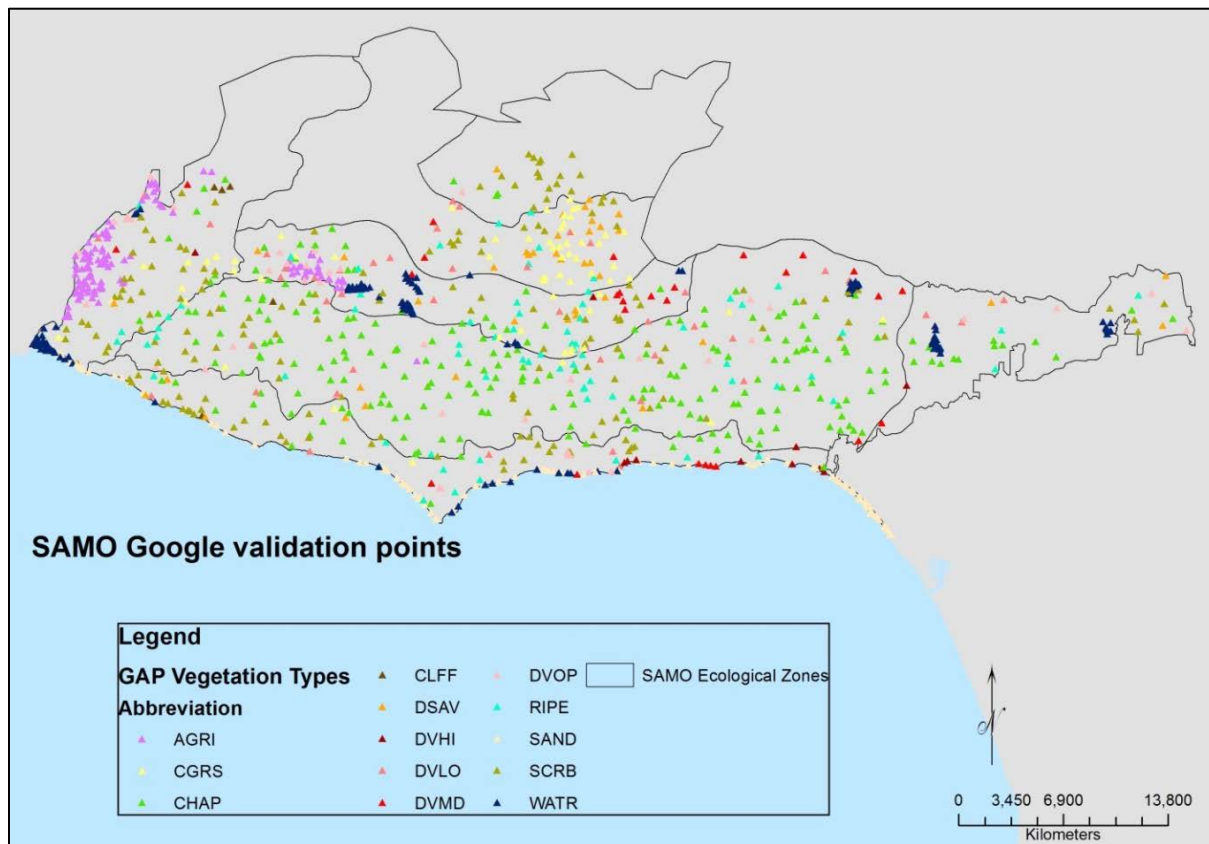


Figure 20. Map of GRTS points validated by Google Earth for Santa Monica Mountains National Recreation Area. Cover class abbreviation definitions are available in Appendix A.

Validation Results

There were 371 points validated *in situ* for CHIS and 1737 validated by Google Earth for SAMO (Tables 7 and 8). Final accuracies for all MEDN classifications used were between 85-88%. The LULC classes that achieve the highest accuracy level on SAMO include sand (93.9%), water (88.2%), agriculture (87.7%), and sand prairie, coastal grasslands, lomas (87.7%). Further grouping these categories into native, nonnative vegetation, and developed landscapes returned medium accuracy results in SAMO: 69.1% for native vegetation, 71.0% for nonnative vegetation, and 60.8% for developed landscapes. On CHIS, only two LULC classes achieved high accuracy levels: conifer/mixed woodland (94.4%) and sand (94.7%). Native vegetation was classified as 65.3% accurate and nonnative vegetation was 60.4% accurate on CHIS. These results are further discussed in the Land Use Cover and Vegetation Communities Report (Willis et al. 2018a).

3.2. Phenological Variability

The MODIS sensors on the TERRA and AQUA satellites have 36 spectral bands at 250 m, 500 m, and 1000 m pixel resolution with a nominal revisit time of 1-2 days year-round, making it very useful to measure fine-scaled changes in vegetation characteristics and changes in seasonality over time. The 1-2 day images can be compiled into 16-day composites in order to allow for filtering of atmospheric disturbances to the images such as cloud cover, and can be useful for measuring large-scale changes in the NDVI over a landscape.

NDVI metrics are a part of a complex system, especially in terms of changes in moisture levels. Precipitation records may be consulted in this objective to gain an explanation of anomalies in NDVI records (Figure 21), and should be kept in mind when analyzing NDVI metrics. In order to qualitatively observe precipitation patterns prior to NDVI assessment, precipitation records may be downloaded at the National Climatic Data Center by NOAA (<http://gis.ncdc.noaa.gov/map/cdo/?thm=themeDaily>) or (<https://www.ncdc.noaa.gov/cag/>). An example of daily precipitation records obtained from this website from stations near SAMO can be seen in Figure 21.

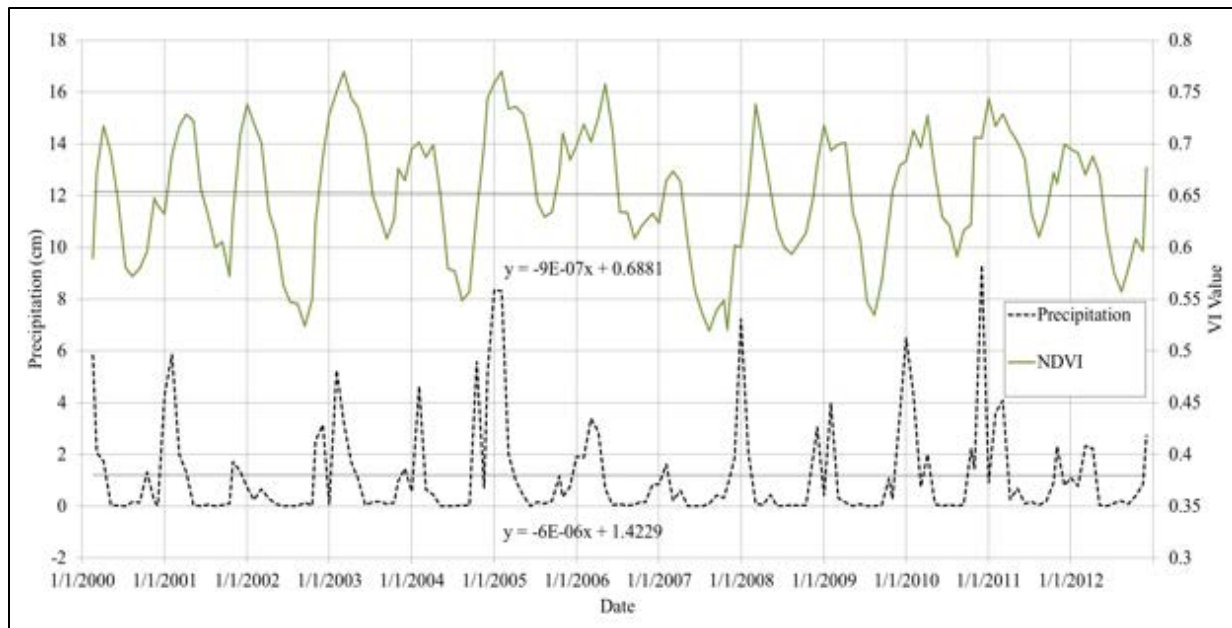


Figure 21. Graph shows continuous changes in MODIS NDVI for chaparral compared to monthly precipitation at Santa Monica Mountains National Recreation Area for 2000-2011.

There is often a lag in timing between major rain events and the maximum NDVI value that results from these rain events (Salinas-Zavala et al. 2002; Garcia et al. 2010). This lag depends on the El Niño Southern Oscillation (ENSO) phase, with a warm ENSO yielding a 4-6 month delay in vegetation strength response (Salinas-Zavala et al. 2002). This vegetation lag has also been shown to vary across vegetation systems. For example, the lag between maximum annual rainfall (which usually occurs around January in southern California) and maximum annual NDVI is two months for grasslands, four months for chaparral and evergreen forest, and five months for wetlands (Garcia et al. 2010). However, the lag between seasonally adjusted precipitation and seasonally adjusted NDVI is one month for evergreen forest, chaparral, and wetlands, while there is no lag in grasslands (Garcia et al. 2010).

Fire also has a significant influence on vegetation spectrally, and must be accounted for when assessing NDVI via satellite remote sensing. Burned areas will often begin a new cycle of vegetation succession rather than of phenology. To avoid anomalies from charred areas, burn zones may be identified from MODIS MOD14/MYD14 Fire and Thermal Anomalies product (NASA 2013 “Active Fire Data,”). These burn zones have been masked out of the analysis in the Baseline Reports resulting from this protocol, and can be mapped onto resulting images post-classification for visual analysis.

Data Acquisition

To begin this analysis, MODIS data are first downloaded using the Reverb on-line database (http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type=rectangle). All images used for the baseline were selected year-round every 16 days from 2000 until present

day. MODIS NDVI is a product created by NASA that is readily available and can be directly extracted from the downloaded dataset.

Data Pre-Processing

Pre-processing steps, such as atmospheric corrections, are unnecessary since they are inherent in the dataset.

Data Processing

NDVI values for each 250 x 250-meter pixel are extracted using International Data Language (IDL) coding software. Values are then plotted along an axis of time to indicate the continuously changing cycle of NDVI averaged over each study area. Study areas include individual parks (Figures 22 and 23), islands, and native vegetation types – namely chaparral, coastal sage scrub, and grassland – within parks. Study areas may be adjusted according to the interest of the user to include other vegetation types or particular regions of the parks (Figure 24).

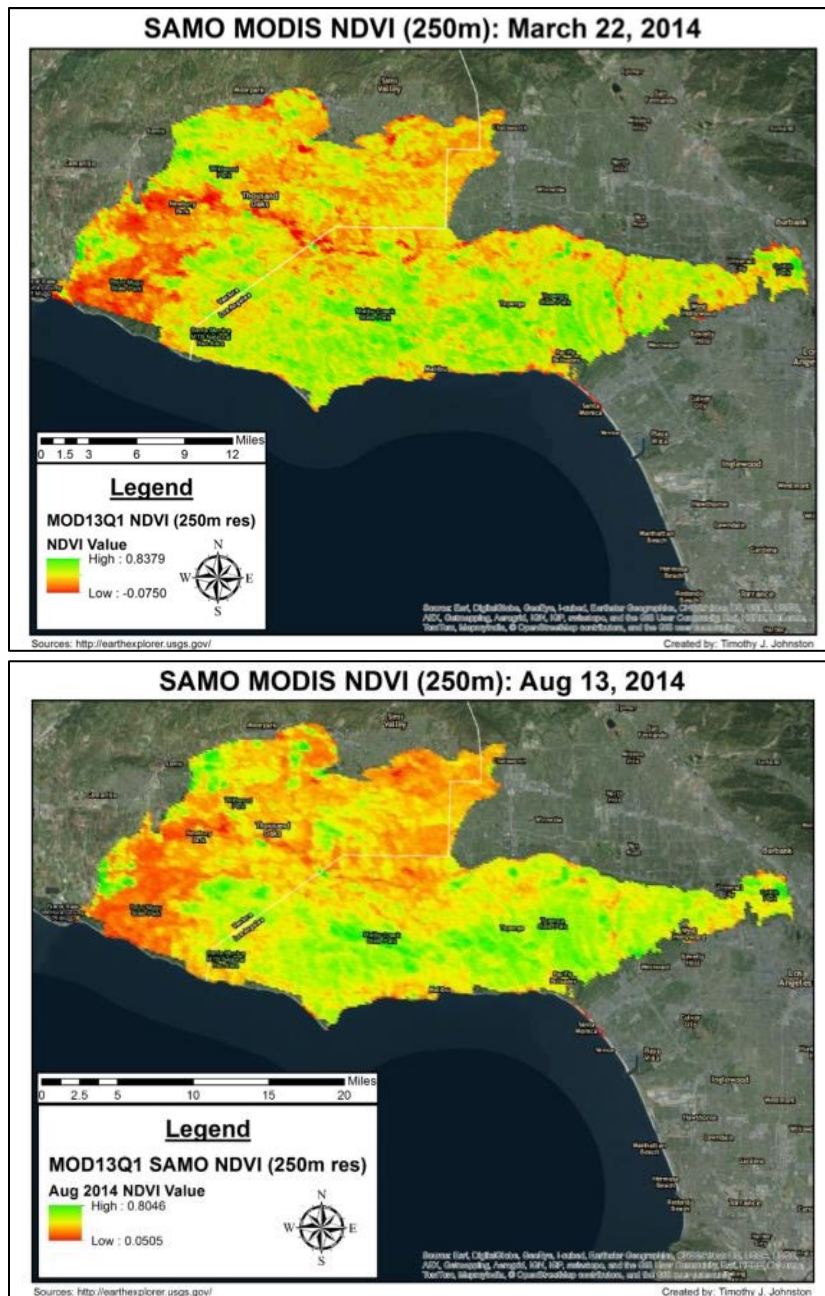


Figure 22. MODIS NDVI for March (top) and August (bottom) 2014 over Santa Monica Mountains National Recreation Area.

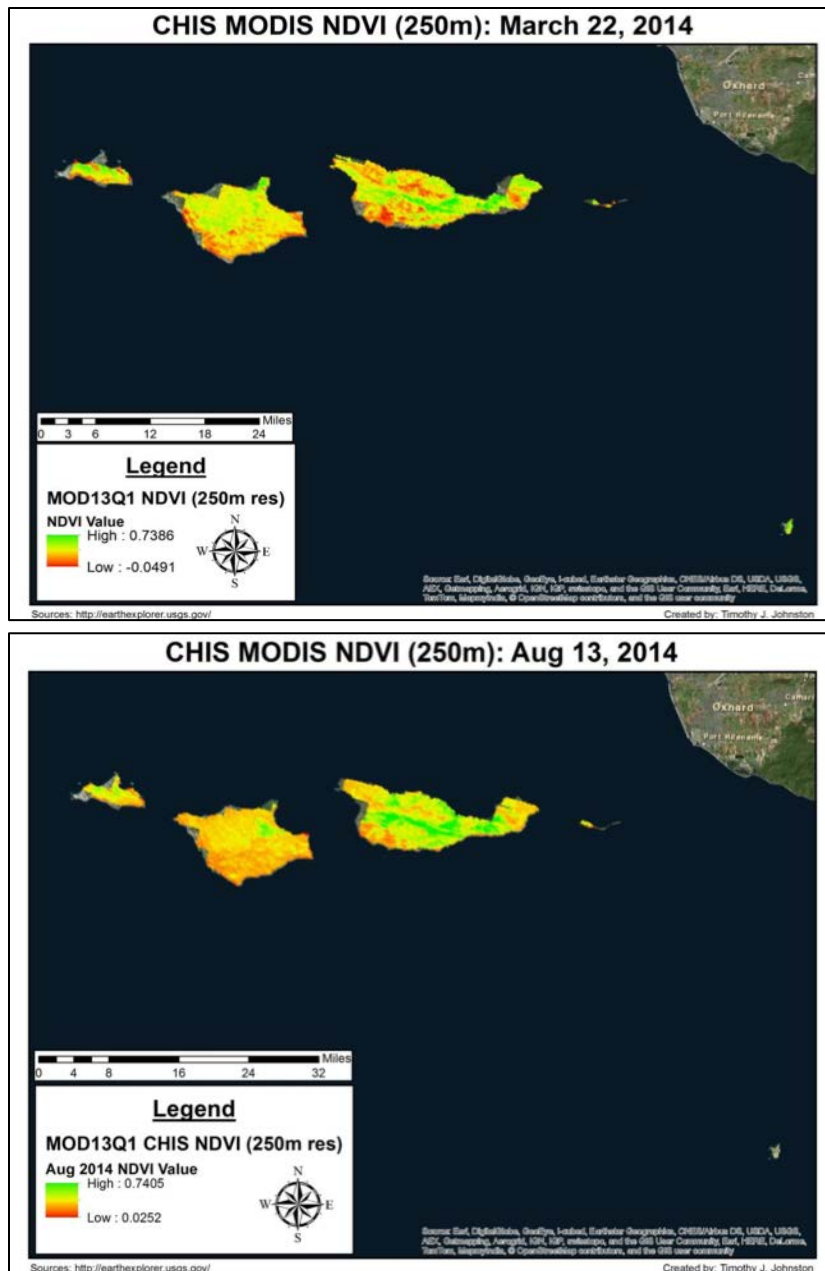


Figure 23. MODIS NDVI for March (top) and August (bottom) 2014 over Channel Islands National Park. These baseline snapshots of NDVI show large pixel (250 m) patterns of greenness in each protected area over different seasons.

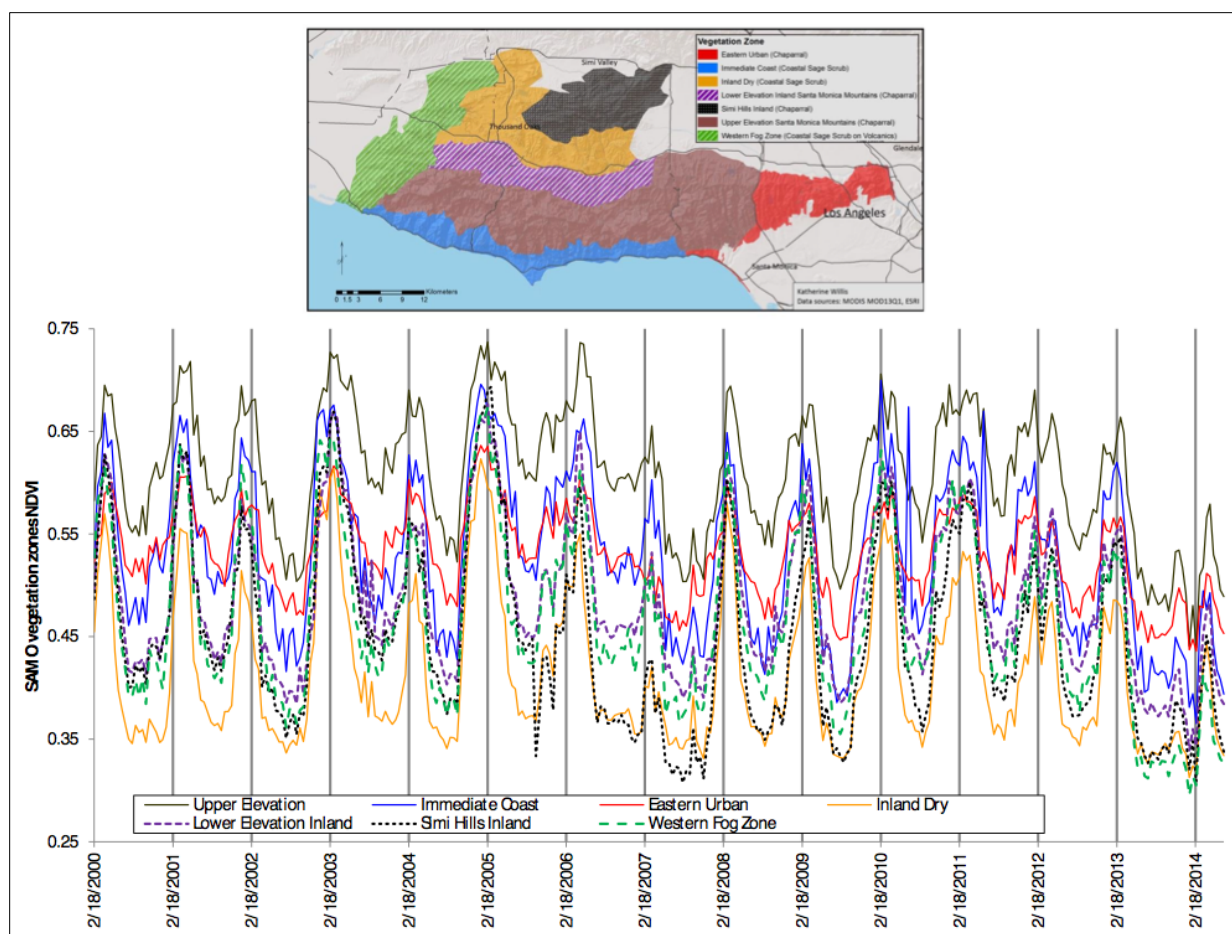


Figure 24. MODIS NDVI values for management and vegetation zones at Santa Monica Mountains National Recreation Area.

Data Analysis

Change detection can be used to identify variations for a specified pixel. For instance, resulting data can show variations in NDVI from 2000 until present on a continuous timescale (Figure 25).

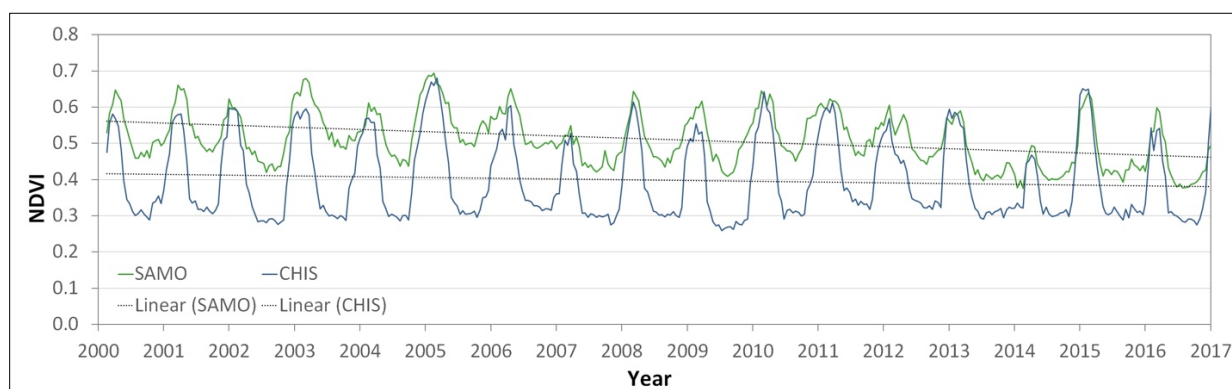


Figure 25. Time series of MODIS NDVI values for Santa Monica Mountains National Recreation Area (SAMO) and Channel Islands National Park (CHIS).

Future data may be added to this continual measurement and plotted for comparison. Initial results also display an NDVI time series for chaparral and coastal sage scrub GAP vegetation zone in SAMO (Figure 26) as a time series by vegetation zone.

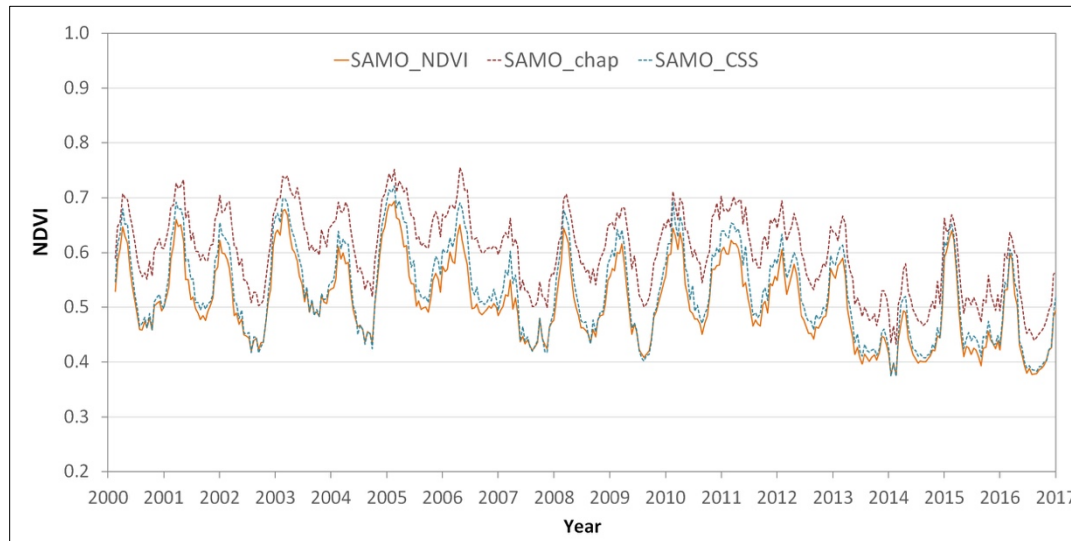


Figure 26. MODIS NDVI values for vegetation zones and chaparral (chap) and coastal sage scrub (CSS) in Santa Monica Mountains Recreation Area.

These data may also be displayed by use of a change detection map in order to compare the inter-annual difference in NDVI between the same exact dates of different years or by comparing the past average (from 2000-2012) to select years (Figures 27 and 28).

This analysis can also be used to monitor more detailed vegetation change within MEDN parks to examine the impacts of nonnative species removals, and areas of concern by examining a small group of pixels or even a single pixel's values over time.

Detailed methods (along with IDL code) are further described in SOP 2.

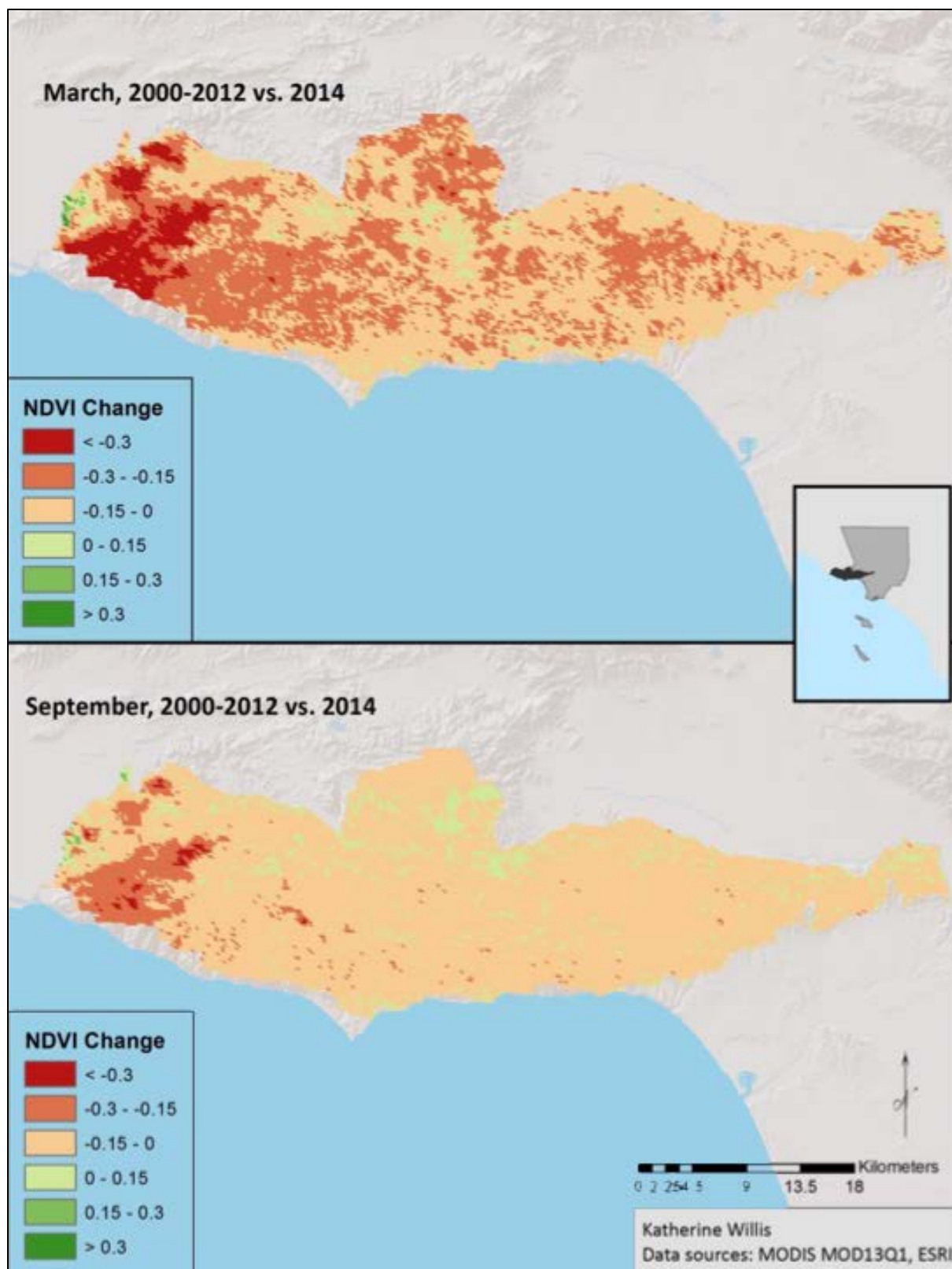


Figure 27. Change detection of MODIS NDVI from averages from 2000 to 2012 compared to data from 2014 in March (top) and September (bottom) for Santa Monica Mountains National Recreation Area.

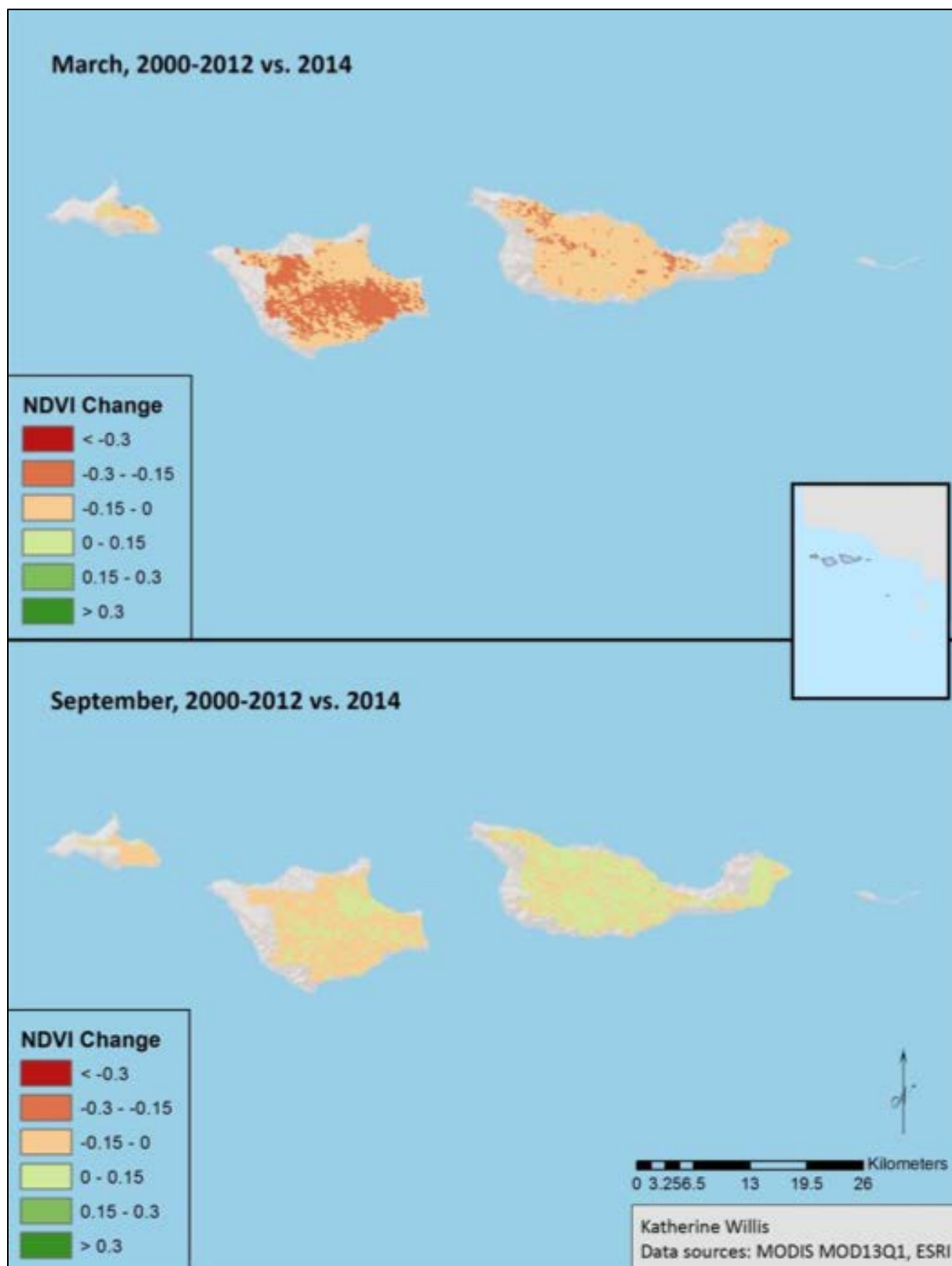


Figure 28. Change detection of MODIS NDVI from averages from 2000 to 2012 compared to data from 2014 in March (top) and September (bottom).

3.3. Ecological Light Pollution

The ecological light pollution objective of this protocol aims to map and quantify the overall amount of upward radiance, as well as identify local areas that have experienced a significant increase or decrease in light pollution over time. Long-term studies of light pollution distribution and impacts generally have used the Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS), which has provided global annual composite nighttime light imagery at a global spatial scale since 1992 (Gillespie et al. 2014). We use visible pixel intensity derived from DMSP-OLS, which is available in relative values ranging from 0 to 63 digital numbers (Figure 29).

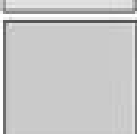
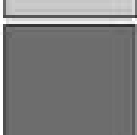
Value	Pixel Color	Image
63		
55		
50		
41		
29		
16		
8		
0		

Figure 29. Digital number (DN) value from DMSP nightlight data, gradients of DMSP nightlight intensity, and images of corresponding land cover type in southern California.

Data are obtained directly through the Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) website

Data Processing

Data Analysis

[illegible]

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A time series of nightlight intensity (digital numbers, or DN) can also be examined to identify changes in light pollution intensity from 1994 to 2012 (Figure 31).

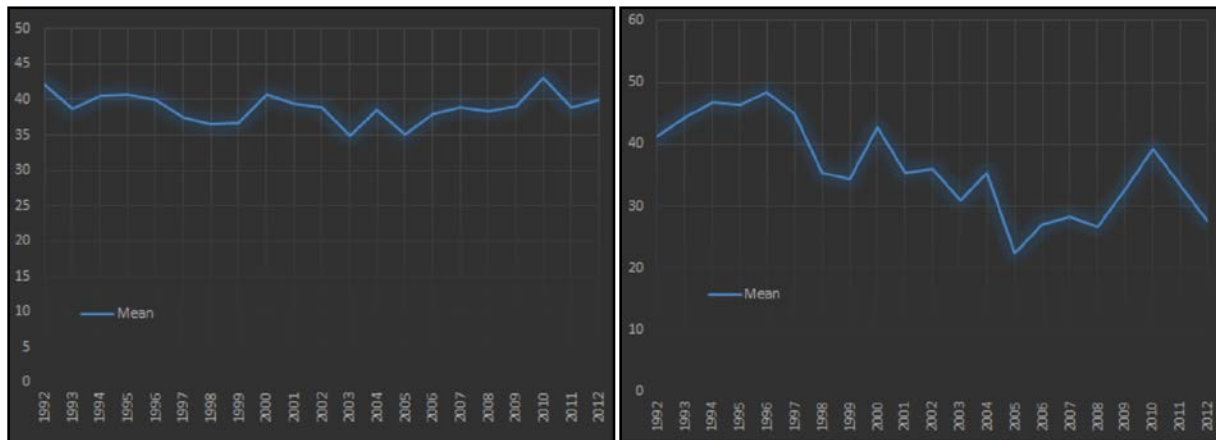


Figure 31. Changes in nightlight pollution in entire park for SAMO (left) and CABR (right) from 1992 to 2012.

Nightlight imagery can also be used to identify minor changes in light pollution due to commercial fishing fleets that use artificial light to attract species such as squid off the coast of CHIS (Figure 32 and 33).

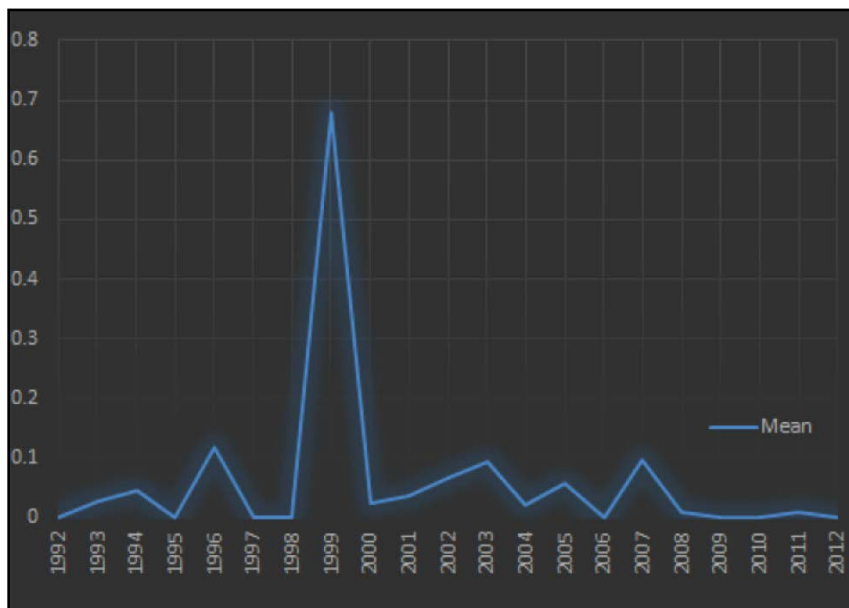


Figure 32. Graph displays the change in overall brightness value over the entirety of CHIS from 1992 - 2012. The year 1999 appears to show the impact of squid fishing off the coast of CHIS.

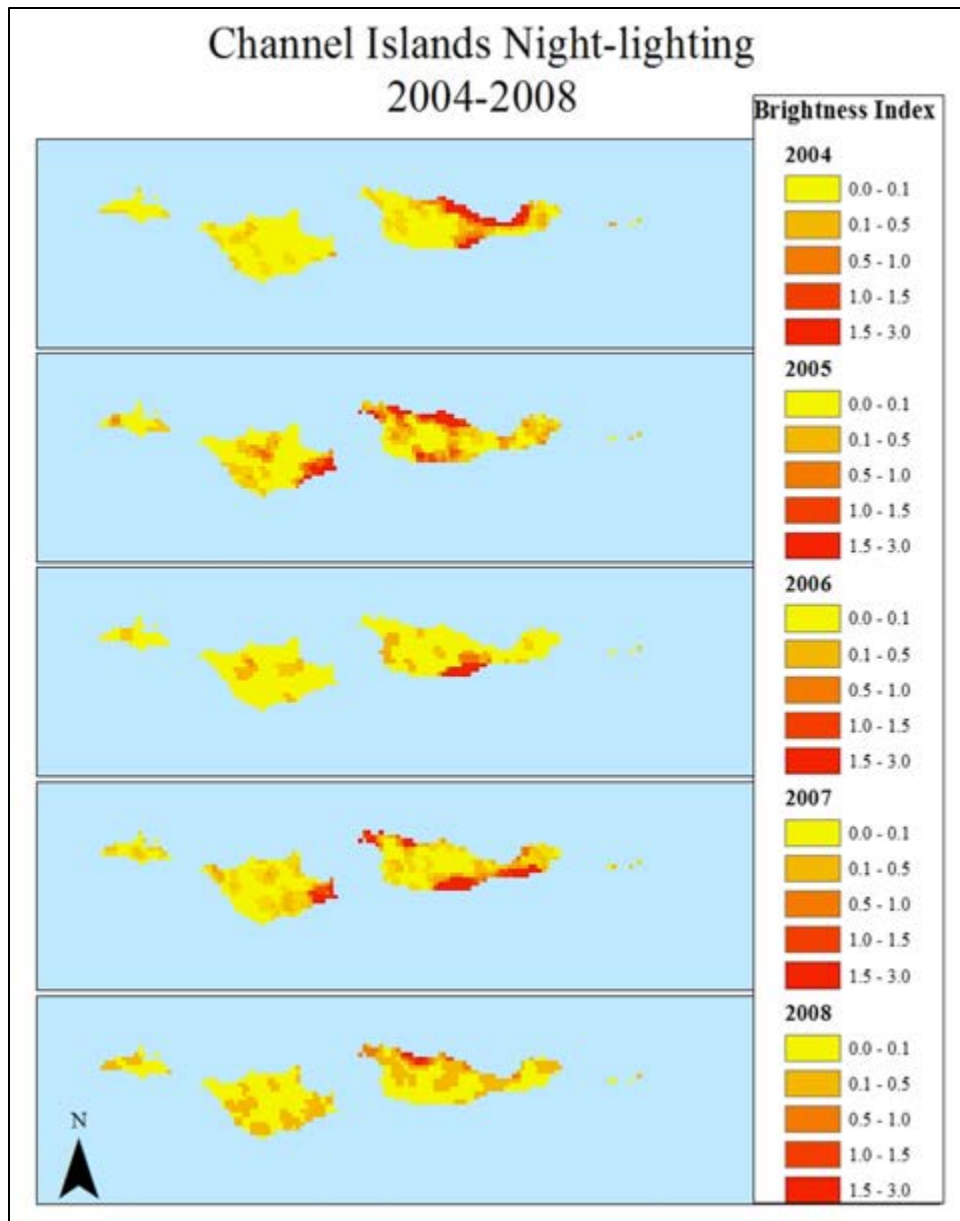


Figure 33. Map shows raw nighttime brightness values averaged over CHIS northern four islands, 2004 – 2008 from F16 DMSP Satellite. Many of these shifts represent squid fishing boats present off-shore.

Overall light pollution can be quantified as percent change between two time periods (Figure 34). Light pollution was stable in SAMO with some areas of increase in light pollution near the park boundaries. This can provide natural resource managers information about regions that have experienced a 5 percent increase in light pollution over time and identify areas where light abatement should be focused.

Detailed methods for data analysis are further described in SOP 3.

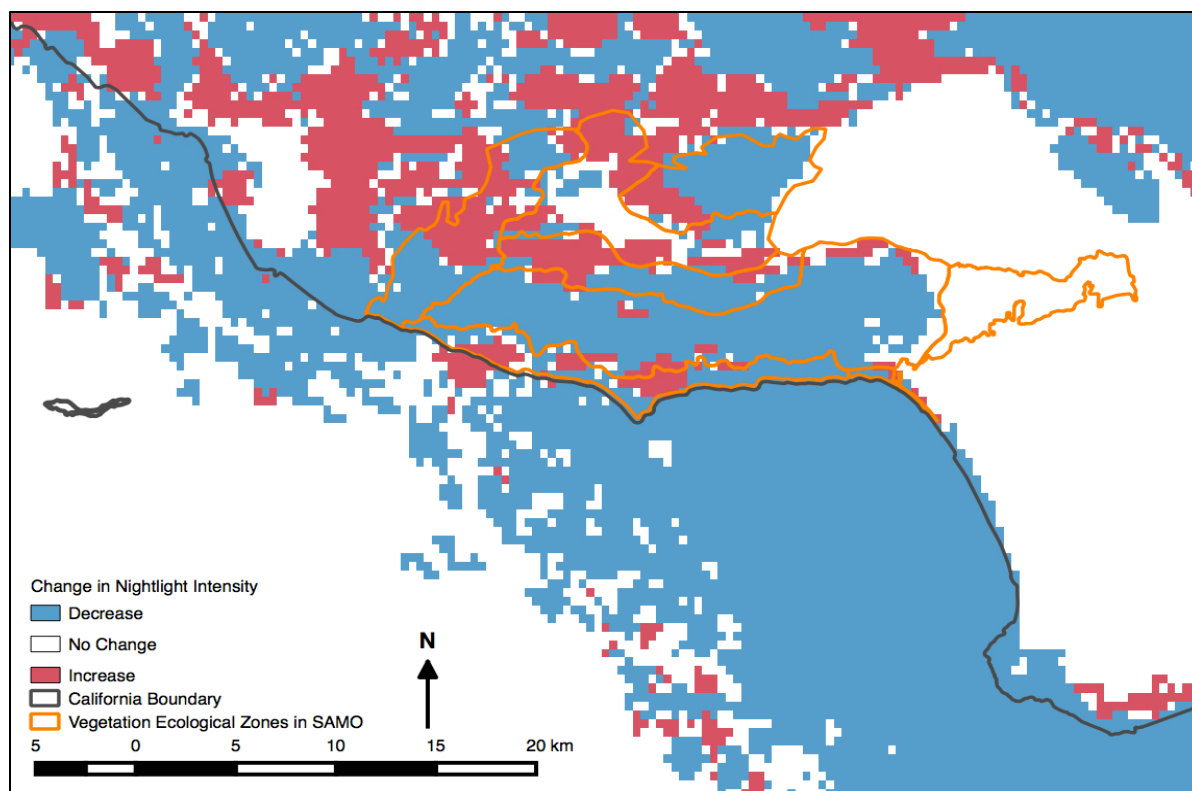


Figure 34. Changes in nighttime light pollution in Santa Monica Mountains National Recreation Area from 1992 to 2012.

4. Periodic Trend Reports

Given the limited funding available for this monitoring program and the relatively slow rate of change in landscape dynamics metrics, trend reports will be produced approximately every 3-5 years. If additional funding becomes available or the importance and urgency of these data increase, annual reports or more frequent trend reports may be added in the future. The periodic trend reports will build upon and provide comparisons to the data presented in the baseline reports (Gillespie et al. 2016; Willis et al. 2018a; Willis et al. 2018b). Here we provide a basic overview of the contents of future trend reports to inform and guide collaborators in producing reports for the MEDN.

At this time, we expect that a separate report will be written to address each of the three major monitoring objectives. Each trend report should include data from and build upon the respective original baseline report, and include the following sections:

- 1) Introduction
- 2) Methods of data acquisition and processing
- 3) Results and discussion, including comparison to baseline data
- 4) Conclusions and management recommendations, including changes to the protocol
- 5) Literature cited.

Data will be summarized and interpreted with the aim of providing usable information to park managers. Readers should be able to quickly view and interpret changes. Additionally, these reports will ideally facilitate more in-depth analyses of vegetation or habitats for particular species in collaboration with topical experts.

The resulting deliverables (i.e. report, GIS database, imagery, maps) of these analyses, including all the raw and processed datasets, will be stored with MEDN for archiving and future analyses. Additional information regarding data archiving is provided in SOP 4.

Trend reports will be published as Natural Resources Reports (template available at <http://www.nature.nps.gov/publications/nrpm/>), or in a peer-reviewed journal. We will aim to present results from each trend analysis at a scientific conference when feasible, or at a minimum, to the park staff during at an annual MEDN Science Symposium.

The MEDN Data Manager will be responsible for making the products and reports available to the public on the MEDN website as well as the NPS Integrated Resources Management Application (IRMA) portal (<https://irma.nps.gov/App/Portal/Home>).

5. Data Management

The following section outlines general procedures for data checking, analysis, and report development. This section is required reading for anyone involved in the collection or processing of data for this program. Proper data management ensures that data will be reliable, relatively free of errors, and ready for analysis.

Specific data management procedures are described in the MEDN Data Management Plan (Lee 2005) and SOP 4. The MEDN Vital Signs Monitoring Plan (Cameron et al. 2005) provides an overview of the network's information management and reporting plan. All project personnel must know and understand their responsibilities in data management.

Data management is critical to the success of all long-term monitoring and resulting datasets, and especially long-term remote sensing projects. Acquisition of Landsat satellite images as well as other mediums of high resolution aerial imagery used for validation entail large volumes of digital data and may require more than one terabyte of data storage, depending on the size of the park and pixel resolution of the imagery. In addition to the large volume of data and multiple versions of processed data, management of geospatial data is an ever-changing field as users are continually trying to keep pace with new spatial database models. In this section, we provide a brief overview of the data management considerations. Metadata procedures and requirements are detailed in SOP 4.

5.1. Data Management Overview

The stages of the data management life cycle are summarized below and in Figure 35. Quality assurance and documentation are not limited to any particular stage, but rather occur throughout the life cycle.

- Preparation – Contracting, training, planning
- Data acquisition – Dataset download
- Data entry and processing – Image classification, export of change detection datasets
- Quality review – Program Lead(s) oversee data verification and validation (reviewed for completeness and logical consistency using queries within the database). Data verification and validation constitute the quality review.
- Metadata – Documentation of the year's data collection (e.g., version of protocol followed) and results of the quality review
- Data certification – The collaborator/Program Lead in consultation with the Data Manager certifies the data have been verified and validated. The data are certified as complete for the period of record.
- Data analysis – Data summarized and analyzed.
- Product development – Reports, maps, and other products are developed.
- Product delivery – Deliver reports and other products for posting and archiving
- Posting and distribution – Distribute products as planned and/or post to NPS websites.

- Archiving and records management – Review analog and digital files for retention (or destruction) according to NPS Director’s Order 19. Retained files are renamed and stored as needed.
- Season closeout – Review and document improvements needed to the database, procedures or infrastructure.

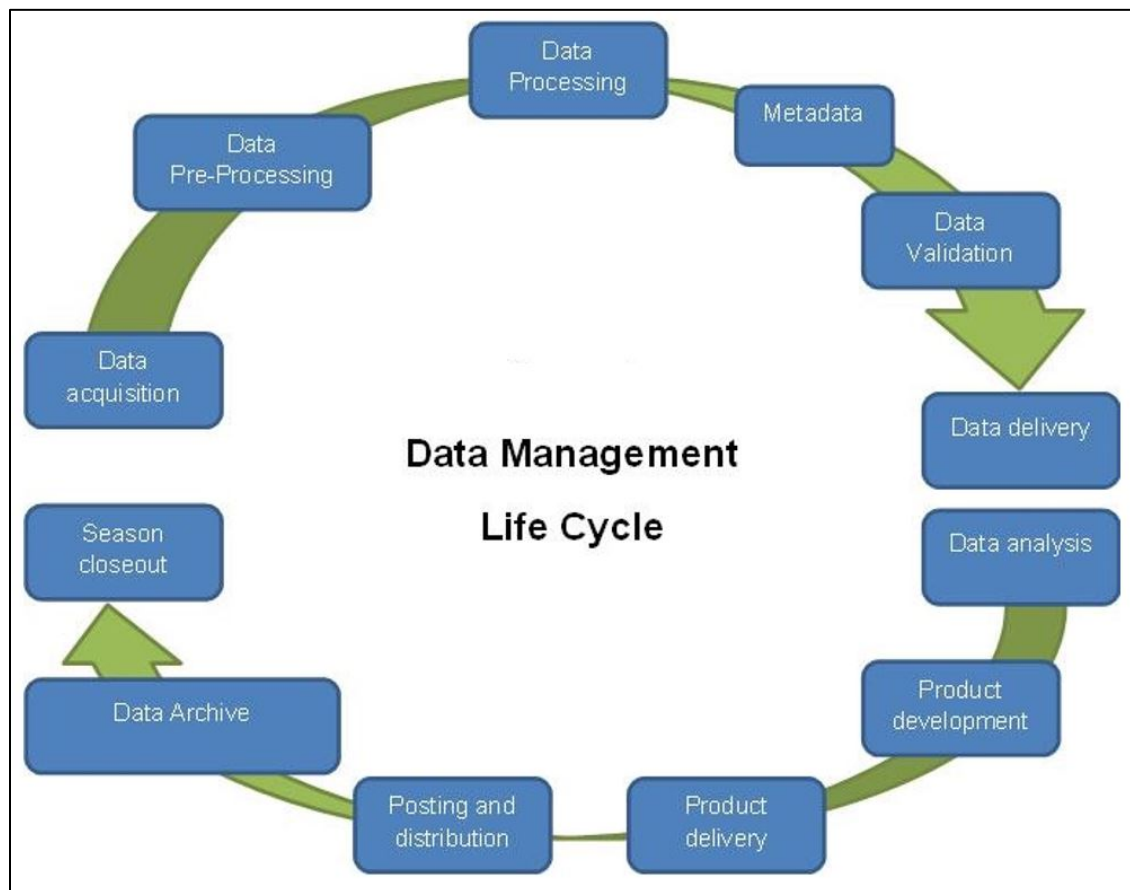


Figure 35. Recommended flow diagram of the stages of data management from pre-season preparation to season closeout. Quality review includes data verification (checking paper datasheets against the electronic data) and validation (queries for logical consistency and completeness) that require input from the Program Leads.

5.2. Metadata Procedures

Many of the reporting products from this protocol will be the result of a series of image or spatially-driven processing steps. Data documentation or the creation of metadata is a critical step toward ensuring that datasets are usable for their intended purposes well into the future. The development of metadata is defined as structured information about the content, quality, and condition of data. Additionally, metadata provide the means to catalog datasets within intranet and internet systems, making data more accessible to a broad range of potential users. Metadata for all MEDN monitoring data will conform to Federal Geographic Data Committee (FGDC 1998) and NPS guidelines (NPS 2011b) and will contain all components of supporting information such that the data may be

confidently analyzed and synthesized. For long-term projects such as this one, metadata creation is most time consuming the first time it is developed – after which most information remains static from one year to the next (see SOP 4 for a list of metadata requirements). Metadata records in subsequent years then only need to be updated to reflect current publications, references, taxonomic conventions, contact information, data disposition and quality, and to describe any changes in collection methods, analysis approaches, or quality assurance for the project.

Specific procedures for metadata development and posting are outlined in the MEDN Data Management Plan (Lee 2005). In general, the collaborator or Project Lead and MEDN Data Manager will work together to create and update an FGDC- and NPS-compliant metadata record in XML format. The collaborator/Program Lead(s) should update the metadata content as changes to the protocol are made, and each year as additional data are accumulated. Edits within the document should be tracked so that any changes are obvious to those who will use it to update the XML metadata file. The MEDN Data Manager will post edited metadata records to the NPS IRMA (Integrated Resource Management Applications) data system, where they will be available to the public.

5.3. Sensitive Information

Metadata development includes determining whether or not the data include any sensitive information. For example, the location of an endangered species population could be considered sensitive data. Prior to completing metadata, the collaborator/Program Lead should identify any sensitive information in the data. The collaborator's or Program Lead's findings should be documented and communicated to the MEDN Data Manager. At this time, we do not anticipate that sensitive information will be present in the Landscape Dynamics monitoring program.

5.4. Data Certification and Delivery

Data certification is a benchmark in the project information management process indicating that (1) the data are complete for the period of record, (2) they have undergone and passed the quality assurance checks, and (3) they are appropriately documented and in a condition for archiving, posting, and distribution. Certification is not intended to imply that the data are completely free of errors or inconsistencies that may not have been detected during quality assurance reviews.

To ensure that only data of the highest quality are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Program Lead is primarily responsible for completing certification, in consultation with the MEDN Data Manager.

5.5. Data Storage and Archival Procedures

Final output datasets, as well as some raw and intermediate datasets used to derive final datasets, will be stored on the MEDN server at SAMO. Files will adhere to the file structure outlined in SOPs 1, 2, and 3 with a hierarchical directory structure beginning with park unit, data type (i.e. imagery, GIS), and separate directories for raw and final datasets. For image storage and handling, consistency of file naming is central to this effort. Procedures that force compliance with file naming conventions and that produce standardized filenames for outputs will greatly reduce the possibility for ambiguity in data handling.

Because of the potential of large sizes of the data used for processing, archiving of data will be necessary when processing steps are completed. Final products, as defined in SOPs 1, 2, and 3, will be retained in their original format, while original and intermediate products will be compressed and archived, with the exception of large satellite raster datasets, such as Landsat, MODIS or DMSP, which are publically available and downloadable. By archiving, rather than deleting, the data can be later reanalyzed or reprocessed.

Details regarding the storage structure and documentation can be found in SOP 4: Data Management. File structure, version control, and regular backups are carefully controlled to preserve the integrity of MEDN datasets. After all data have been imported, verified, validated, and certified by the Collaborator/Program Lead, the database will be sent to the MEDN Data Manager for archiving and distribution on the NPS IRMA (Integrated Resource Management Applications) data system. The archived database will be stored on a secure server with regularly scheduled back-ups and will be read-only accessible to the network parks. A complete copy of the database also will be archived and stored on the MEDN network server prior to any database version changes.

Once the data have been archived, any changes made to data values must be documented in the edit log document. Any editing of archived datasets will be accomplished jointly by the Program Lead and MEDN Data Manager.

Certified and archived non-sensitive data, along with any associated metadata, will be made available through the NPS IRMA (Integrated Resource Management Applications) data system. The MEDN Data Manager will post certified datasets to IRMA, where they may be downloaded for research and management applications. Other datasets, including those containing sensitive data, may be requested in writing from the Program Lead and MEDN Program Manager. Sensitive data will be released only with a signed confidentiality agreement.

6. Personnel, Budgeting, and Scheduling

Implementation of this protocol involves a wide range of detailed work with geographic information systems, remote-sensing, programming, and image processing. Carrying out pre-processing is particularly challenging for non-specialists, as it requires multiple software programs (ENVI and IDL, ArcGIS) as well as proficiency in IDL coding language, ENVI, and GIS methods. The protocol is written with sufficient detail in the SOPs so that personnel with moderate familiarity with GIS and remote sensing can undertake most steps; this protocol requires that someone with expertise in GIS and remote sensing will perform the data acquisition, processing, and analysis. Given the limited staff of the MEDN, we plan to implement this protocol every five years via an agreement with UCLA or another similarly equipped university or cooperator.

The MEDN Program Manager will take the lead in identifying a collaborator to produce trend reports every five years, ideally using a Cooperative Ecosystems Study Unit (CESU) agreement. The cooperator must have licenses for all software required in analyses (ENVI and IDL, ArcGIS) as well as the skills listed above. Each of the three baseline reports (LULC, Phenology, and Night Lighting) will need to be updated and results interpreted for a lay audience.

Initial baseline reports for all three MEDN parks have been completed (Gillespie et al. 2016; Willis et al. 2018a; Willis et al. 2018b) and will serve as the basis for subsequent analyses. It is estimated that a graduate student with experience in GIS and remote sensing would be able produce an updated trend report within two months. Therefore, MEDN is tentatively budgeting \$27,000 (FY17) plus NPS staff time to update the landscape dynamics trend reports (Tables 13 and 14).

Table 13. Estimated fiscal year 2017 costs for professional assistance (professor and graduate student) to update the three Landscape Dynamics trend reports, assuming a 17.5% overhead rate through the CESU. Note these costs do not include purchasing imagery, as may be needed for future analyses.

Position	Cost	Units	Total
Principal Investigator	\$7,000/mo. plus benefits (39.1%)	0.5 months	\$4,869
Graduate Student Research Assistant 1	\$1,000/week plus benefits (21%)	14 weeks	\$16,940
Lodging for presentation	\$135/night	2 nights	\$270
Per diem at presentation	\$73/day	2	\$146
Airfare to conference	\$500	1 round-trip	\$500
Misc. office supplies	\$200	1	\$200
Total direct cost	–	–	\$22,925
Overhead	17.5%	–	\$4,012
Total cost	–	–	\$26,937

Table 14. Estimated time contribution of MEDN staff to protocol oversight and data management.

Position	Units	Cost
MEDN Data Manager	0.06 FTE*	\$6,040
MEDN Program Manager	0.04 FTE	\$4,830
Total	0.10 FTE	\$10,870

*FTE = full-time equivalent

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Appendix A. Land Cover Classification

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Overview

This appendix provides a brief description of each land cover classification used in this protocol and shows graphics of its Landsat spectral signature, the Shuttle Radar Topography Mission (SRTM) elevation data associated with it, and a sample aerial image of the land cover type from Google Earth. Table A-1 summarizes the land cover classifications and their abbreviations.

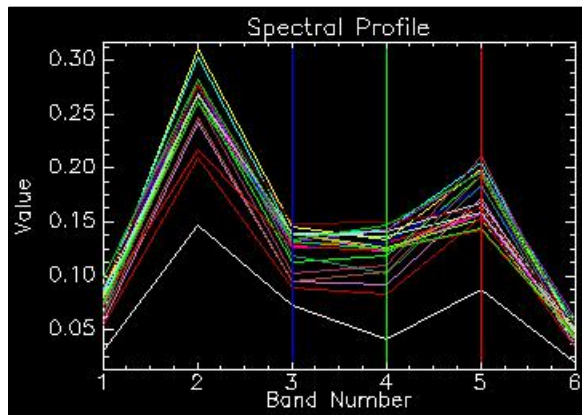
Table A-1. Land cover classifications and abbreviations used for this protocol.

Class	Abbreviation
Agriculture	AGRI
Beach, Shore, Sand	SAND
Chaparral	CHAP
Cliff, Canyon, and Talus	CLFF
Conifer Dominated Forest Woodland (Mesic-Wet)	CONF
Conifer Dominated Forest Woodland (Xeric-Mesic)	CONF
Deciduous Dominated Savanna Glade	DSAV
Developed – High Intensity	DVHI
Developed – Medium Intensity	DVMD
Developed – Low Intensity	DVLO
Developed – Open Space	DVOP
Floodplain Riparian	RIPE
Freshwater Herbaceous Marsh, Swamp, or Baygall	MRSH
Mixed Deciduous / Coniferous Forest and Woodland (Mesic-Wet)	CONF
Open Water	WATR
Sand Prairie, Coastal Grassland, and Lomas	CGRS
Scrub Shrubland	SCRB

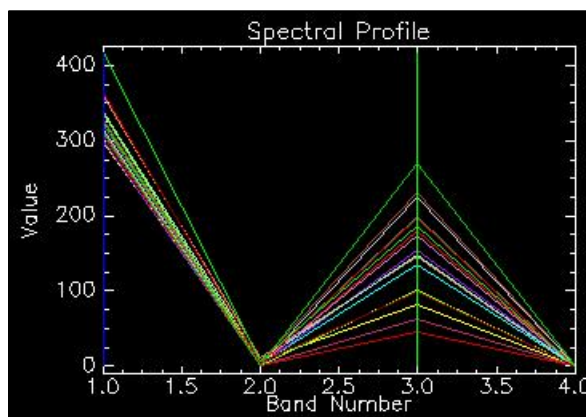
Note: Each color curve in the graphs below represents the spectral signature of one particular pixel of the given land cover class.

Agriculture

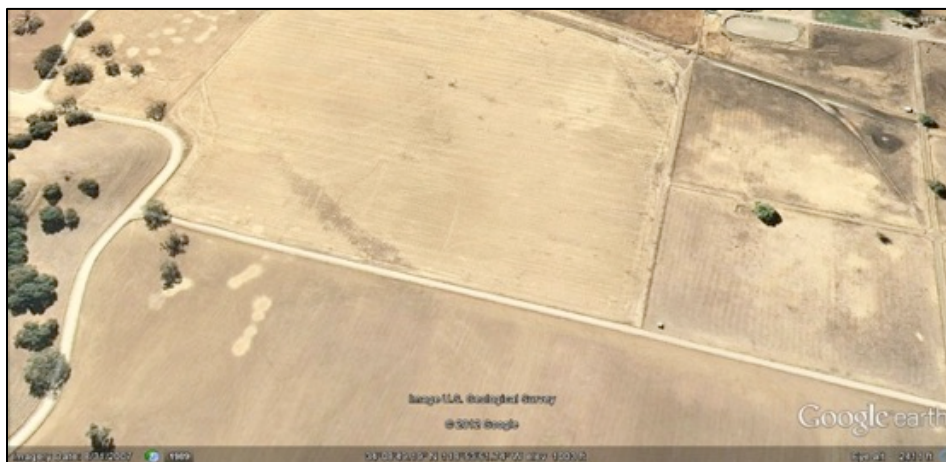
Classified under Level 2 – Human Land Use
Includes cultivated cropland, pasture, and hay.



Landsat spectral information for Agriculture (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for Agriculture (elevation, slope, aspect, relief)

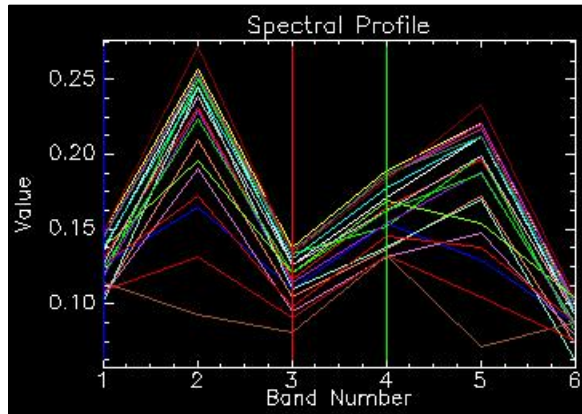


Aerial image of Agriculture (from GoogleEarth)

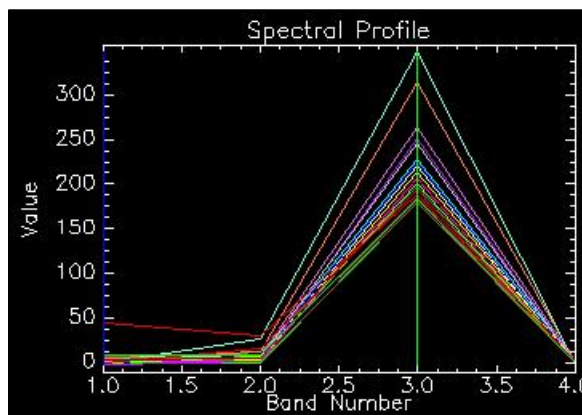
Beach, Shore, and Sand

Classified under Level 2 - sparse and barren systems.

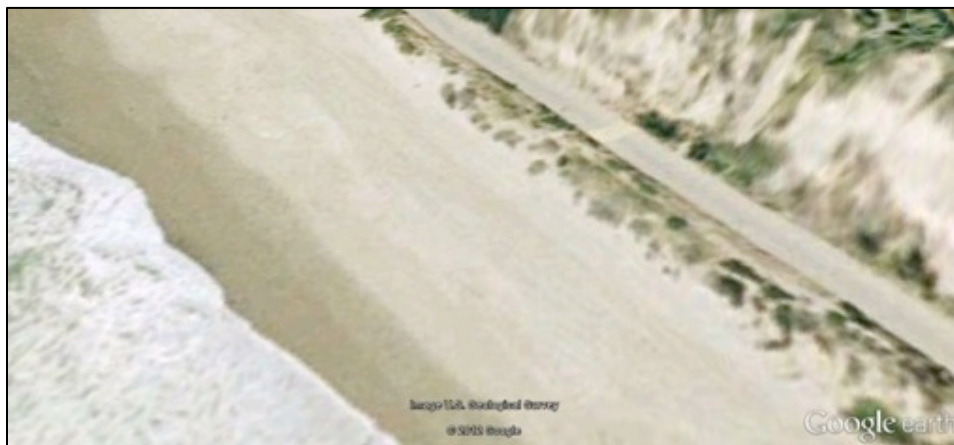
Defined as including Mediterranean California southern coastal dune.



Landsat spectral information for beach, shore, sand (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for beach, shore, sand (elevation, slope, aspect, relief)

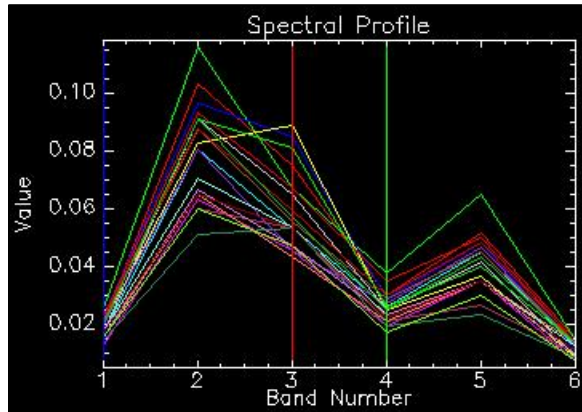


Aerial image of beach, shore, sand (from GoogleEarth)

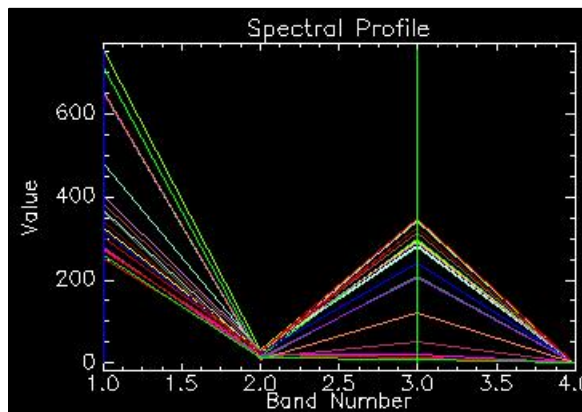
Chaparral

Classified under Level 2 – Shrubland, steppe and savanna systems.

Includes California maritime chaparral, California mesic chaparral, and southern California dry-mesic chaparral.



Landsat spectral information for chaparral (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for chaparral (elevation, slope, aspect, relief)

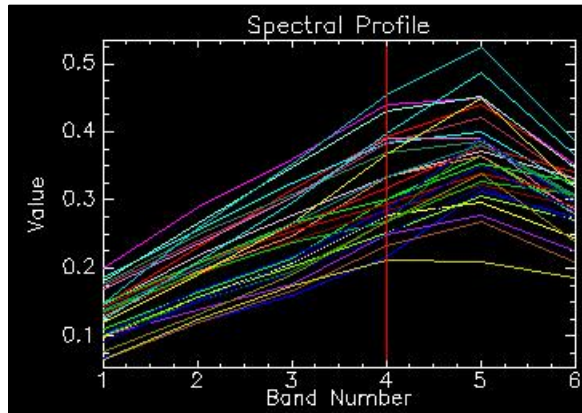


Aerial image of chaparral (from GoogleEarth)

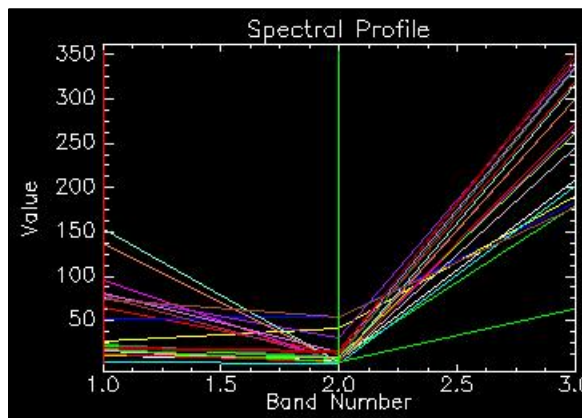
Cliff, Canyon, and Talus

Classified under Level 2 – sparse and barren systems

Includes southern California Coast Ranges cliff and canyon.



Landsat spectral information for Cliff, Canyon, and Talus (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for Cliff, Canyon, and Talus (elevation, slope, aspect)

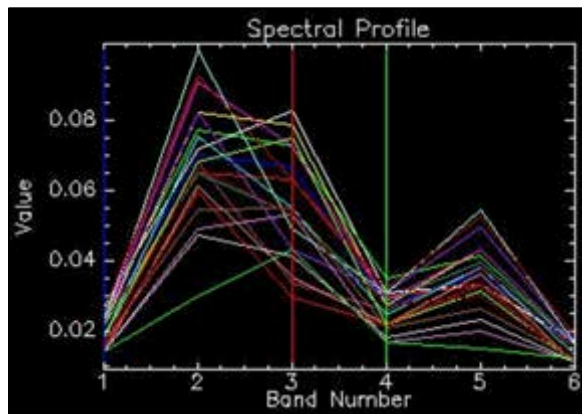


Aerial image of Cliff, Canyon, and Talus (from GoogleEarth)

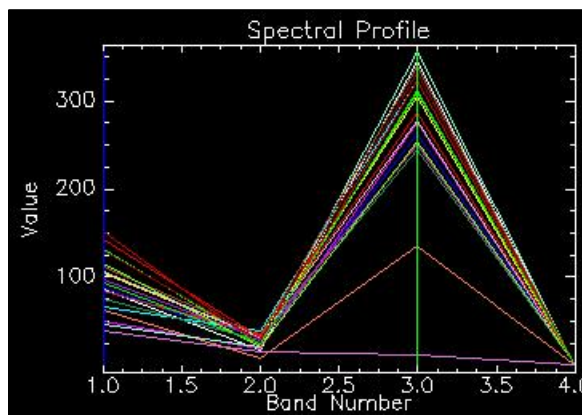
Conifer: Conifer-dominated woodland (xeric-mesic)/ Conifer-dominated woodland (mesic-wet) / Mixed Deciduous/Coniferous Forest and Woodland (mesic-wet)

Classified under Level 2 – forest and woodland systems.

Includes great pinyon-juniper woodland, Mediterranean California dry-mesic mixed conifer forest and woodland, Mediterranean California mesic serpentine woodland and chaparral, and California coastal closed-cone conifer forest and woodland.



Landsat spectral information for Conifer (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for Conifer (elevation, slope, aspect, relief)

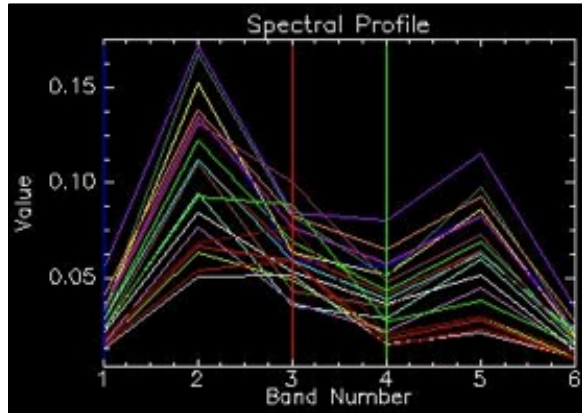


Aerial image of Conifer (xeric-mesic) (from GoogleEarth)

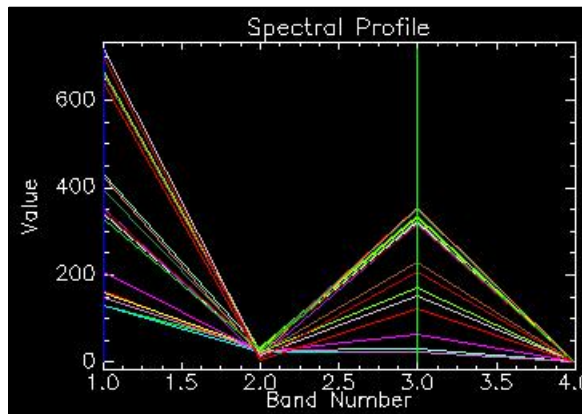
Deciduous Dominated Savanna and Glade

Classified under Level 2 – shrubland, steppe and savanna systems.

Includes California central valley mixed oak savanna, California coastal live oak woodland and savanna, California lower montane blue oak-foothill pine woodland and savanna, and southern California oak woodland and savanna.



Landsat spectral information for Deciduous dominated savanna and glade (Landsat bands order 1,2,3,4,5,7)



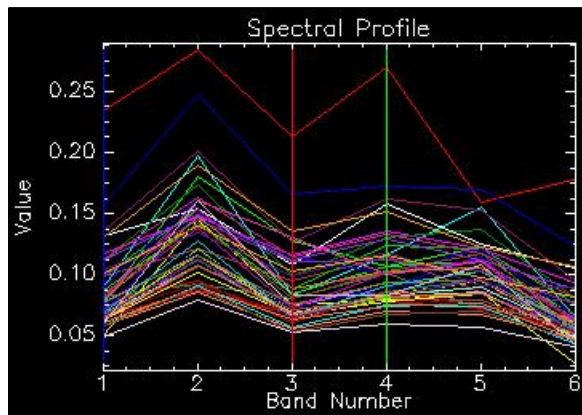
SRTM elevation data for Deciduous dominated savanna and glade (elevation, slope, aspect, relief)



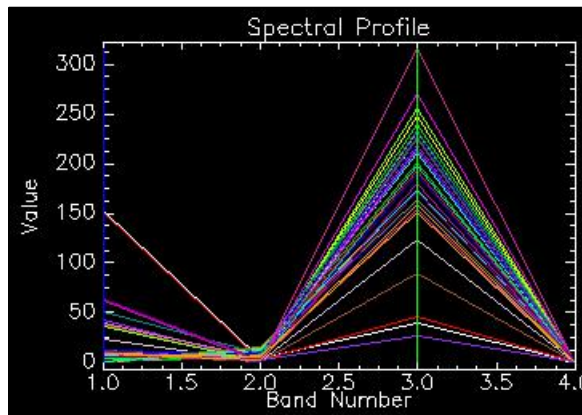
Aerial image of Deciduous dominated savanna and glade (from GoogleEarth)

Developed – High Intensity

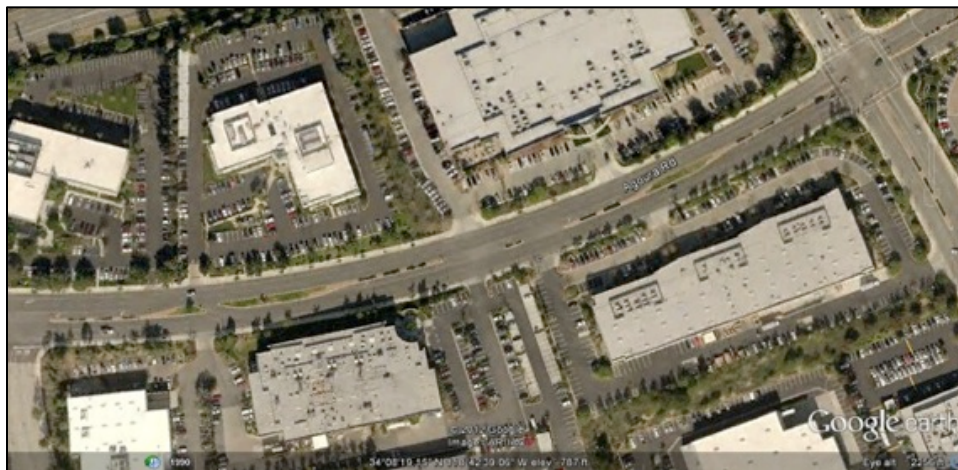
Classified under Level 3 – human land use.



Landsat spectral information for Developed – High Intensity (Landsat bands order 1,2,3,4,5,7)



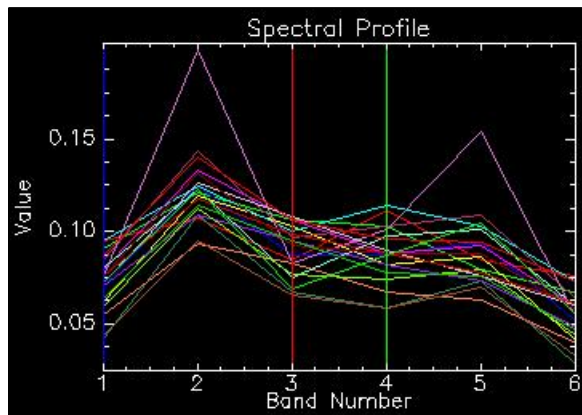
SRTM elevation data for Developed – High Intensity (elevation, slope, aspect, relief)



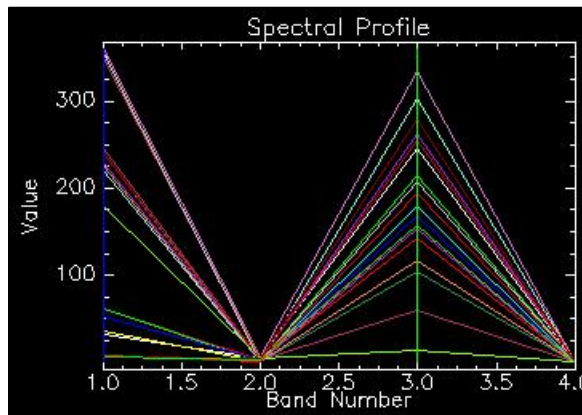
Aerial image of Developed – High Intensity (from GoogleEarth)

Developed – Medium Intensity

Classified under Level 3 – human land use.



Landsat spectral information for Developed – Medium Intensity (Landsat bands order 1,2,3,4,5,7)



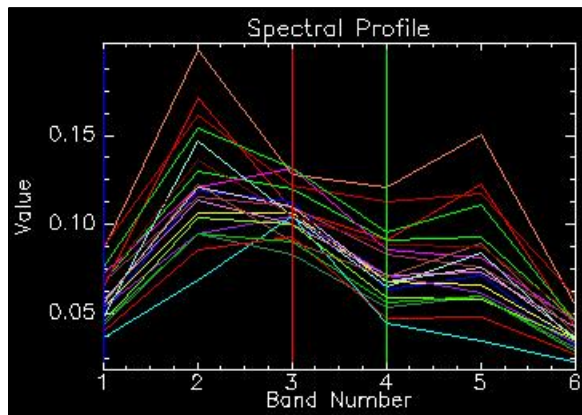
SRTM elevation data for Developed – Medium Intensity (elevation, slope, aspect, relief)



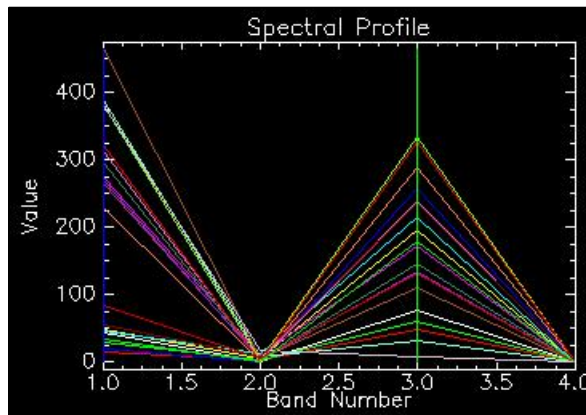
Aerial image of Developed – Medium Intensity (from GoogleEarth)

Developed – Low Intensity

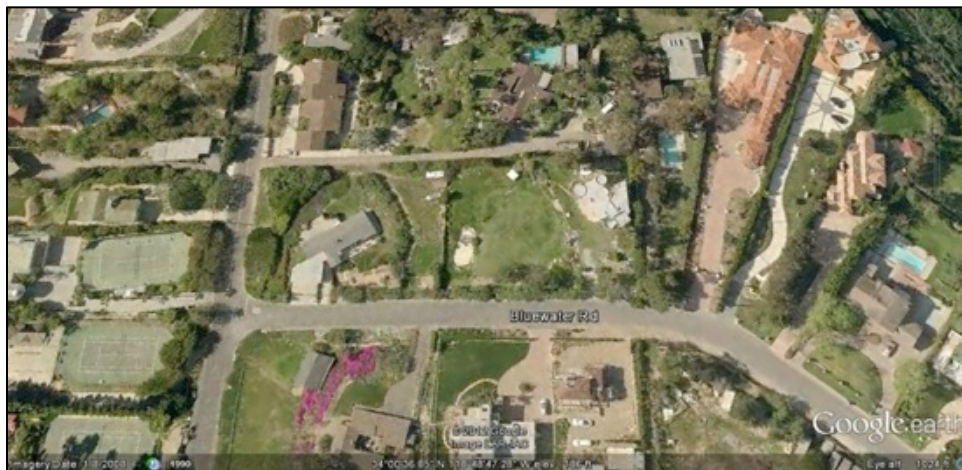
Classified under Level 3 – human land use.



Landsat spectral information for Developed – Low Intensity (Landsat bands order 1,2,3,4,5,7)



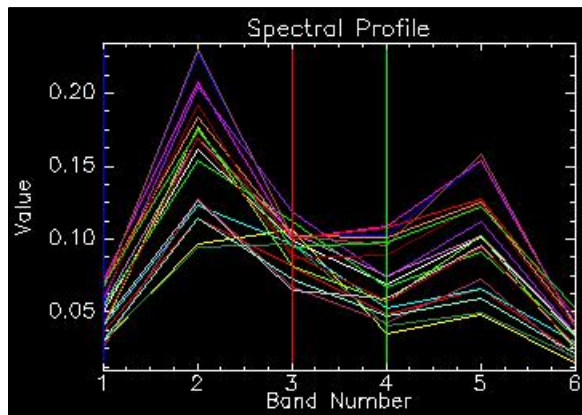
SRTM elevation data for Developed – Low Intensity (elevation, slope, aspect, relief)



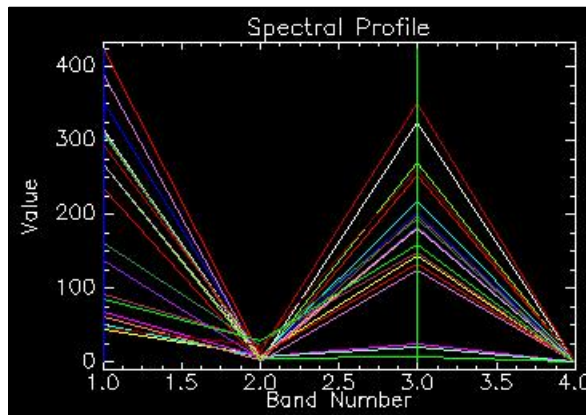
Aerial image of Developed – Low Intensity (from GoogleEarth)

Developed – Open Space

Classified under Level 3 – human land use.



Landsat spectral information for Developed – Open Space (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for Developed – Open Space (elevation, slope, aspect, relief)

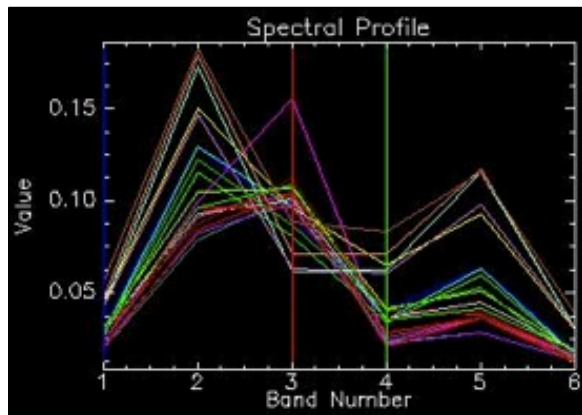


Aerial image of Developed – Open Space (from GoogleEarth)

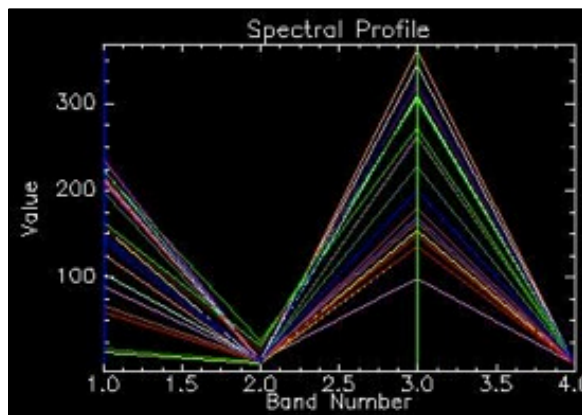
Floodplain/Riparian

Classified under Level 2 – riparian and wetland systems.

Includes California central valley riparian woodland and shrubland, North American warm desert riparian woodland and shrubland, and Mediterranean California foothill and lower montane riparian woodland.



Landsat spectral information for floodplain/riparian (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for floodplain/riparian (elevation, slope, aspect, relief)

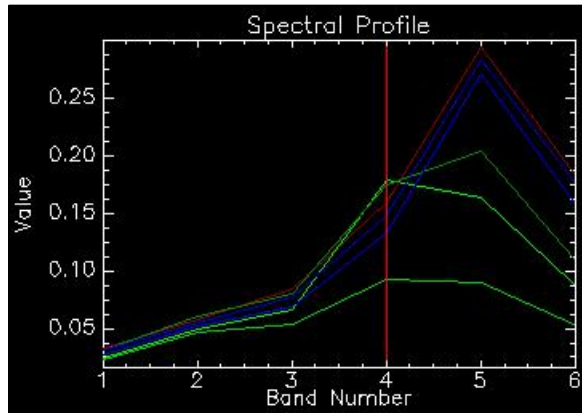


Aerial image of floodplain/riparian (from GoogleEarth)

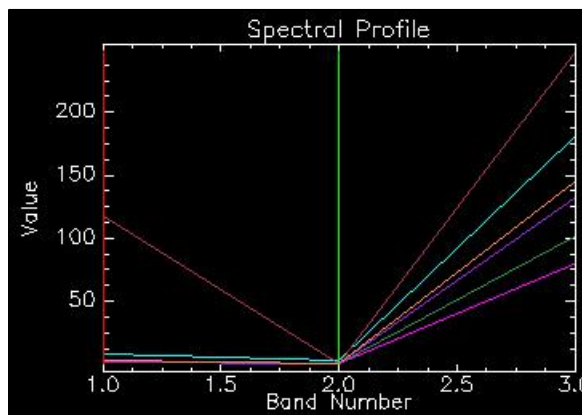
Freshwater Herbaceous Marsh, Swamp, or Baygall

Classified under Level 2 – Riparian and Wetland Systems

Includes Temperate Pacific Freshwater Emergent Marsh.



Landsat spectral information for freshwater herbaceous marsh, swamp, or baygall (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for herbaceous marsh, swamp, or baygall (elevation, slope, aspect)

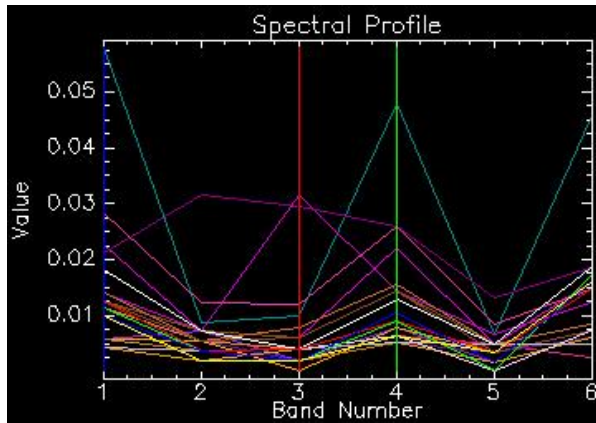


Aerial image of herbaceous marsh, swamp, or baygall (from GoogleEarth)

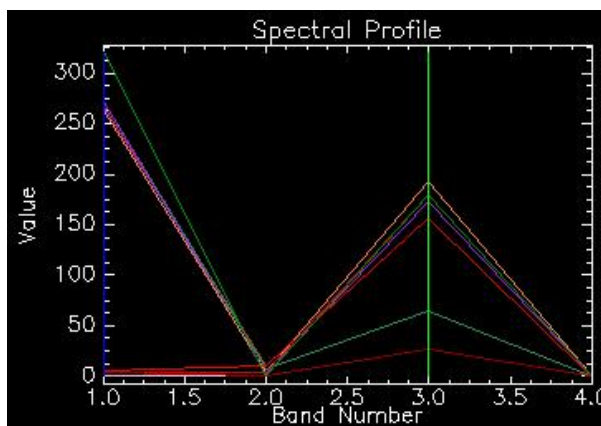
Open Water

Classified under Level 2 – aquatic.

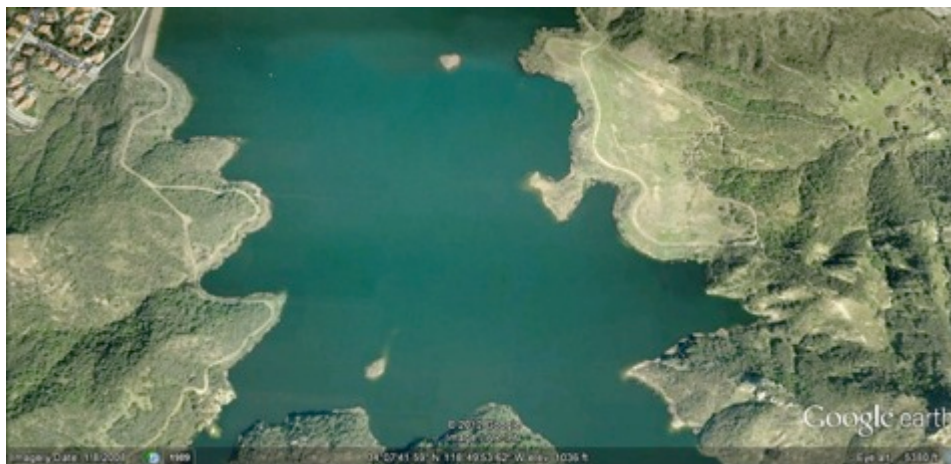
Includes open water (fresh) and open water (brackish/salt).



Landsat spectral information for open water (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for open water (elevation, slope, aspect, relief)

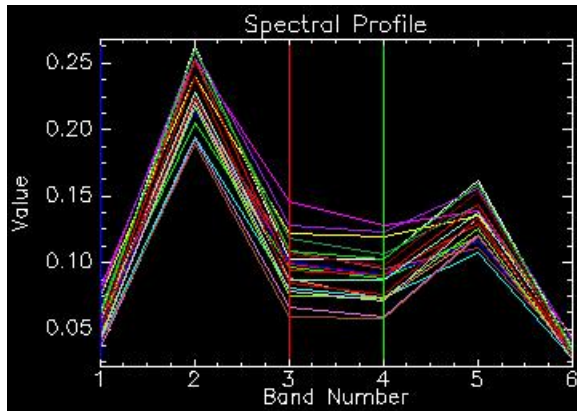


Aerial image of open water (from GoogleEarth)

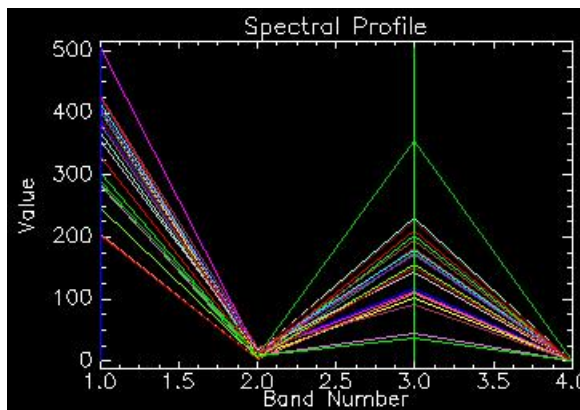
Sand Prairie, Coastal Grasslands and Lomas

Classified in Level 2 – grassland systems.

Includes California central valley and southern coastal grassland.



Landsat spectral information for Sand prairie, coastal grasslands and lomas (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for Sand prairie, coastal grasslands and lomas (elevation, slope, aspect, relief)

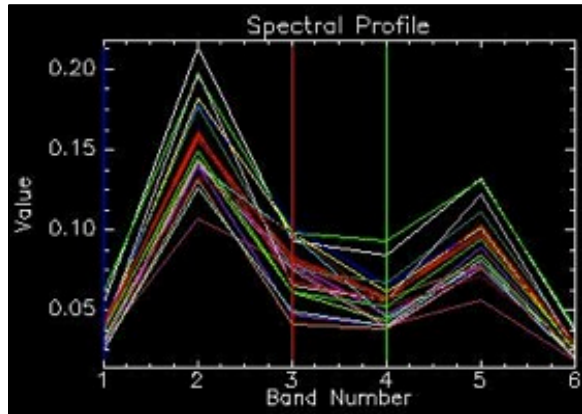


Aerial image of Sand prairie, coastal grasslands and lomas (from GoogleEarth)

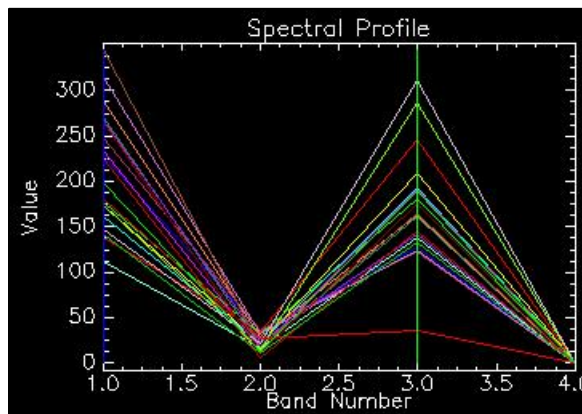
Scrub Shrubland

Classified under Level 2 – shrubland, steppe and savanna systems.

Includes inter-mountain basins mixed salt desert scrub, Mojave mid-elevation mixed desert scrub, Sonora-Mojave creosotebush-white bursage desert scrub, and southern California coastal scrub.



Landsat spectral information for scrub shrubland (Landsat bands order 1,2,3,4,5,7)



SRTM elevation data for scrub shrubland (elevation, slope, aspect, relief)



Aerial image of scrub shrubland (from GoogleEarth)

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 925/149714, November 2018

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

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