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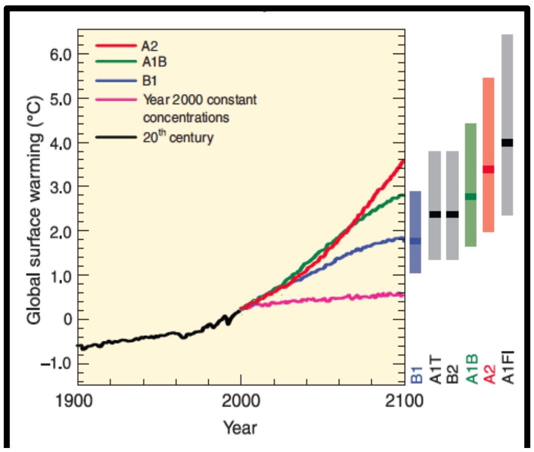
Natural Resource Stewardship and Science

A Collaborative Science Agenda on Climate Change for Southern California Coastal National Parks

Natural Resource Report NPS/MEDN/NRR—2012/583



UCLA Institute of the Environment and Sustainability

UCLA La Kretz Center for California Conservation Science

MEDN mediterranean coast network inventory & monitoring program

ON THE COVER

Clockwise from top left: Atmosphere-Ocean General Circulation Model projections of surface warming (IPCC Synthesis Report, 2007); Red-legged frog (NPS); California Brown Pelican (US Fish and Wildlife Service); Mussels at a tidepool at Cabrillo National Monument.

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Fort Collins, Colorado

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

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

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

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available at the MEDN website (http://www.mednscience.org/events/2011_Climate_Change_Workshop) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Contents

Page

Contents (continued)

Page

Figures

Tables

Executive Summary

This report documents the objectives, approach and findings of a collaborative process to develop a science agenda related to the effects of climate change on Southern California (SoCA) coastal National Park Service (NPS) lands: Santa Monica Mountains National Recreation Area, Channel Islands National Park and Cabrillo National Monument. The focus of the approach was a workshop held on April 27-28, 2011 on the University of California, Los Angeles (UCLA) campus. The workshop was a cooperative effort between the Mediterranean Coast Network (MEDN) of the National Park Service Inventory & Monitoring (I&M) Program, and two centers within the Institute of the Environment and Sustainability: the UCLA La Kretz Center for California Conservation Science and the UCLA Center for Climate Change Solutions. The objectives of the workshop were to:

- Update National Park staff and managers regarding the latest research on climate change in SoCA,
- Familiarize UCLA faculty and graduate students with research needs, ongoing monitoring, and operational constraints of national park managers,
- Identify and prioritize research and monitoring activities related to understanding and managing for climate change, and
- Help form collaborative research relationships between park managers and research scientists.

The first day of the workshop consisted of presentations by researchers on climate change science. The second day began with a focus on educating academics about park research and monitoring activities, available datasets, and management concerns, and was followed by breakout group discussions that generated recommendations for research and monitoring on five topic areas: Climate Data; Marine Organisms; Terrestrial Vegetation; Terrestrial Wildlife; and Watershed Processes (Fire, Hydrology and Sediment). A core team was convened to review workshop results, continue communication with participants, prioritize research and monitoring recommendations, and draft a climate change science agenda.

This report includes summaries of the collaborative approach, workshop findings, and priority recommendations for research and monitoring. The following themes are the highest priorities for research and monitoring for the MEDN parks:

Fog and Microclimate – Further research is required to improve our understanding of the impact of climate change on fog, the role of fog and microclimates in the distribution and abundance of vegetation within the parks, and improve our ability to model fog and microclimates.

Ocean Acidification and Warming – Specific priority research goals include: improving our ability to model pH and temperature in the near-shore environment though increased data collection; better understanding of spatial and temporal variation in pH and temperature at different scales to inform field data collection; performing literature reviews or lab studies to

determine key species that should be targeted for impact analyses; performing modeling studies to assess species responses under future climate scenarios.

Conduct Periodic, Repeated Inventories and Monitor Phenology – Expand park inventories and monitor the abundance, distribution and phenology of species most likely to be impacted by climate change.

Vulnerability Assessments – Assess the vulnerability of various species and habitats to climate change using downscaled climate models for SoCA and appropriate ecological models, to facilitate the prioritization and development of adaptation plans. Research on the genotypic and phenotypical adaptive responses of various organisms is needed to better understand and predict responses to climate change.

Fire and Climate Change – Although the primary drivers of wildland fire in SoCA are fairly well understood, a nuanced understanding of the impacts of climate change on the relationships and feedbacks among these drivers is important, including: drought, frequency and intensity of Santa Ana winds, vegetation die-back, post-fire vegetation recovery, and vegetation type conversion.

Acknowledgments

The authors would like to acknowledge and thank peer reviewers Glen MacDonald from UCLA and John Gross and Marti Witter from NPS.

Introduction

This report documents the objectives, approach and findings of a collaborative process to develop a science agenda related to the effects of climate change on Southern California (SoCA) coastal parks. The focus of the approach was a workshop held on April 27-28, 2011 on the University of California, Los Angeles (UCLA) campus. The workshop was a cooperative effort between the Mediterranean Coast Network of the National Park Service (NPS) Inventory & Monitoring (I&M) Program, and two centers within the Institute of the Environment and Sustainability: the UCLA La Kretz Center for California Conservation Science and the UCLA Center for Climate Change Solutions. The objectives of the workshop were to update National Park staff and managers regarding the latest research on climate change in SoCA, to familiarize UCLA faculty and graduate students with research needs, ongoing monitoring, and operational constraints of national park managers, to identify and prioritize research and monitoring activities related to understanding and managing for climate change, and to help form collaborative research relationships between park managers and research scientists.

The Mediterranean Coast Inventory and Monitoring Network (MEDN) is one of 32 networks that conduct natural resource inventories and monitoring for the NPS. The MEDN includes three national parks within Southern California: Channel Islands National Park (CHIS), Santa Monica Mountains National Recreation Area (SAMO), and Cabrillo National Monument (CABR); see Figure 1.

Figure 1. The Mediterranean Coast Network of the National Park Service includes three park units along the coast of Southern California: Channel Islands National Park (CHIS), Santa Monica Mountains National Recreation Area (SAMO), and Cabrillo National Monument (CABR).

The primary goal of the Inventory & Monitoring Program is to provide information on condition and trends of park resources to inform management decisions. This overarching goal is achieved by: (1) conducting long-term monitoring programs to determine the status and trends of key components ("vital signs") of park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments; and (2) sharing NPS information with other natural resource organizations and form partnerships for attaining common goals and objectives. Systematic and repeated assessments of park natural resources through 15 long-term monitoring programs are managed centrally for these three parks through MEDN. MEDN was allocated additional funds for FY2010-2011 to enhance monitoring in light of climate change issues through additional monitoring programs, or expansion of existing monitoring. Revision to data collection and analysis protocols for nearly all of the vital signs programs is planned over the coming 5 years, providing an ideal opportunity to incorporate new methods to document and quantify ecological responses to climate change.

The UCLA La Kretz Center for California Conservation Science (LKC) is housed within the UCLA Institute of the Environment and Sustainability, and was established as a partnership with the natural resources agencies in the Santa Monica Mountains. Its mission is to conserve the biodiversity and unique ecosystems of California through research, education and public outreach, with a focus on Southern California and the Santa Monica Mountains. As specified within the Memorandum of Understanding between UCLA and the NPS, the LKC has undertaken the development of a Cooperative Research Plan that will guide research to increase understanding and management capability within SAMO. Park staff clearly articulated needs across many topic areas (e.g., invasive species, fire management, impacts of fragmentation) due to their active involvement in these research areas; however, expertise on climate change science was far less prevalent. The need was identified for a significant academic role to update park staff and assist with development of climate change research priorities.

The UCLA Center for Climate Change Solutions (CCCS) is also within the UCLA Institute of the Environment and Sustainability. CCCS is dedicated to catalyzing solutions to the threats and consequences of global climate change by serving as a locus for translating science into policy and policy into science. The CCCS works to bridge the gap between science and policy by promoting better-informed and more effective policies to adapt to the challenges posed by climate change and to conduct cross-disciplinary research on technological and science-based solutions to the causes and consequences of climate change.

Approach

Following scoping discussions between NPS and UCLA, a joint meeting was planned to bring two key audiences together (park staff and academics) to discuss the research and monitoring needs in SoCA. A two-day workshop was designed to achieve the following objectives:

a) Update NPS staff and others regarding the latest research on climate change in SoCA and the observed and predicted ecological responses to climate change.

b) Provide background on park management research interests and operational constraints to academic research scientists interested in partnering with agency scientists.

c) Identify the top priority research needs related to climate change for SoCA coastal national parks, and help form collaborative research relationships to pursuing these topics.

d) Identify the top priority monitoring needs to enable detection and documentation of ecological responses to climate change in SoCA coastal national parks.

In addition to staff from the NPS, the audience included participants from a variety of other land management and research agencies and non-profit organizations including California State Parks, the Santa Monica Mountains Resource Conservation District, the USGS, the Natural History Museum of Los Angeles, and the USA National Phenology Network. Attendees from academia and research institutions included UCLA faculty, post-docs and graduate students, as well as faculty/scientists from the Scripps Institute, University of California, San Diego; University of California, Berkeley; and the Desert Research Institute. Approximately 80 individuals attended the workshop (Appendix A).

The workshop was designed to promote a two-way exchange of information between academic researchers and natural resource managers and staff. Day one of the workshop featured presentations by faculty on climate change science, progressing from global mechanisms of change to climate modeling and predictions for Southern California. Both ocean and atmospheric processes were addressed. Observed and predicted ecological changes were discussed for terrestrial vegetation and wildlife, marine organisms, and watershed processes including fire, hydrology and sediment. An overview of key analysis tools was presented, including remote sensing data, vulnerability assessment models and phenology monitoring.

Day two of the workshop began with a focus on educating academics about park activities and concerns, starting with the park agency perspective on climate change. An overview of the MEDN I&M Program was presented, as well as information on available services to facilitate scientific research on park property. This was followed by breakout group discussions that generated priority recommendations for research and monitoring on five topic areas:

1. Climate Data
2. Marine Organisms
3. Terrestrial Vegetation
4. Terrestrial Wildlife
5. Watershed Processes (Fire, Hydrology, Sediment)

Breakout groups consisted of approximately 8 to 14 members, and each was assigned a facilitator and two note takers. Reports from each breakout session were provided back to the larger group, with an opportunity for questions and discussion. The workshop concluded with a panel discussion by four representatives from NPS, UCLA, and USGS, to assist with synthesis, context and initial ideas for next steps.

Based on the panel recommendations, a core team (Table 1) was convened to review the workshop results, continue communication with workshop participants and faculty presenters, prioritize research and monitoring recommendations, and draft this climate change research agenda.

Table 1. Core team members and affiliations

Name	Organization	Title
Stacey Ostermann-Kelm	NPS	MEDN I&M Program Manager
Felicia Federico	UCLA	LKC Executive Director
Christy Brigham	NPS	Chief of Planning, Science, and Resource Management, SAMO
Paul Bunje	UCLA	CCC Executive Director

Evaluation of the workshop suggestions was conducted based on the following factors:

- Urgency of knowledge to conservation and resource management
- Applicability to conservation decision-making
- Increased understanding of ecological responses to climate change
- Particular relevance to Southern California (for research)
- Generality of understanding (for research)
- Integration with existing program (for monitoring)
- Feasibility of additional data collection (for monitoring)
- Additional attributes – early response / charismatic species (for monitoring)
- Availability of partnership/matching funds

Although the core team made initial attempts to quantitatively prioritize workshop recommendations using a matrix rating process, there were insufficient data to establish objective rankings. Instead, the team qualitatively applied the evaluation factors to the workshop recommendations. This was done with a strong tendency toward inclusiveness for several reasons: research topics that might be considered “medium” priority may have an champion ready to start work immediately, providing more benefit than a “high” priority project with no current academic support. Furthermore, high priority monitoring recommendations that may not be feasibly or economically integrated into current I&M protocols may find alternate funding sources for implementation. The core team will schedule follow-up meetings over the next 2 years to review progress, re-assess priorities and gather additional suggestions.

Findings – Overview of Workshop Presentations

This section provides a high-level summary of the information presented at the workshop by subject-matter experts (Table 2). It is not intended to be a comprehensive or complete review of the information available on these topics. Copies of presentations from the workshop can be found at: http://science.nature.nps.gov/im/units/medn/climatechange/

Table 2. Workshop presentation topics and subject-matter experts

Topic	Presenter	Affiliation
1. Introductory Remarks on Climate Change	Prof. Glen MacDonald	UCLA
2. Observed and Expected Climate Change in the Western US	Dr. Dan Cayan	USGS / Scripps
3. Projected Climate Change in Southern California	Prof. Alex Hall	UCLA
4. Ocean Processes and Climate Change	Prof. Curtis Deutsch	UCLA
5. Tools for Planning for Climate Change	Dr. Wolfgang Buermann	UCLA
6. Climate Monitoring in the MEDN	Dr. Kelly Redmond	Desert Research Inst./ Western Region Climate Center
7. Plant Responses to Climate Change	Prof. Victoria Sork	UCLA
8. Changes in Hydrologic Response and Fire Recovery	Prof. Terri Hogue	UCLA
9. Terrestrial Wildlife Response to Climate Change	Prof. Steve Beissinger	UC Berkeley
10. Marine Responses to Climate Change	Prof. Rich Ambrose	UCLA
11. Phenology Monitoring	Dr. Jake Weltzin	US National Phenology Network
12. The NPS Perspective on Climate Change	Dr. Christy Brigham	NPS, SAMO
13. Vital Signs Monitoring in the MEDN	Dr. Stacey Ostermann-Kelm	NPS I&M Program
14. Conducting Research in National Parks: the Southern California Research Learning Center	Susan Teel	So. CA Research Learning Center

State of Climate Knowledge for Southern California

Temperature

Since 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, and climate model projections suggest that warming may be greater in summer than other seasons (Cayan et al. 2010).

Precipitation

Southern California's hydrology is prone to dry spells whose impacts could be exacerbated in a warmer climate. Since 2001, large portions of the arid Southwest have experienced prolonged drought. Particularly widespread drought occurred in 2002, 2003, 2007, and 2009 (National Drought Mitigation Center).

During these years, the region's precipitation averaged as much as 22–25% below the 20th-century mean, with local deficits being greater. The majority of global climate models (GCMs) predict decreasing precipitation in the Southwest, with estimates of up to 10-15% less precipitation than the historical average (1951-1999) by the end of the century (Cayan et al. 2010; Figure 2).

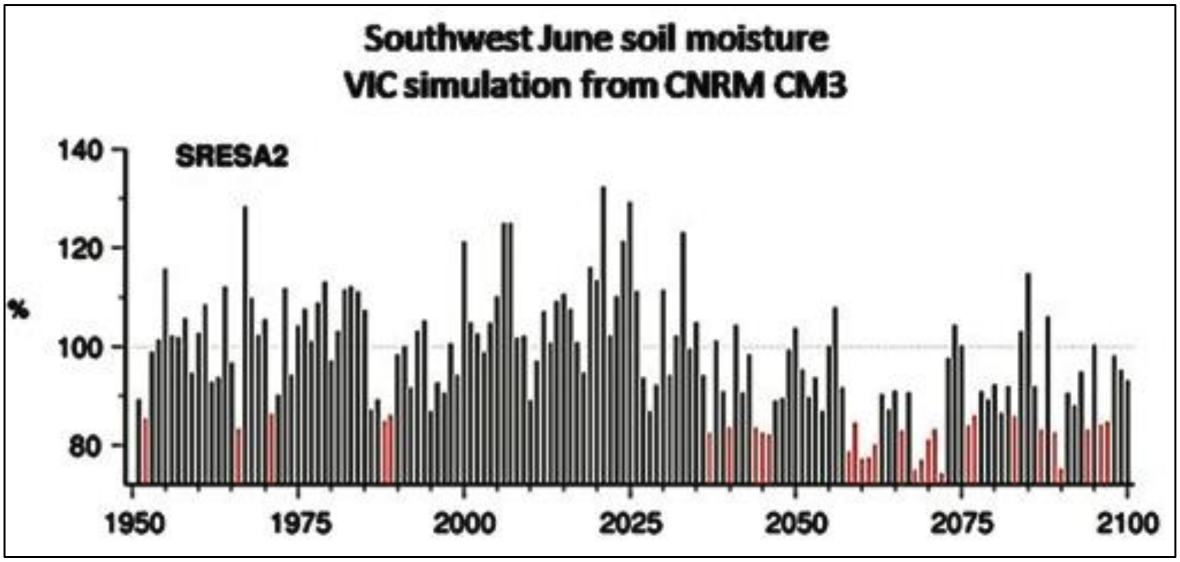

Figure 2. Soil moisture historically and under future climate change, from Cayan et al. (2010). The increasing number of red bars indicates more frequent drought conditions than experienced historically. Southwest region June soil moisture (% of 1951–1999 average annual values) from simulation of the CNRM CM3 Global Climate Model for 1950 to 2100. Climate change period (2000–2100) from GHG emissions scenario SRES A2. Extremely dry years are indicated by red bars that mark years when June soil moisture is lower than the 10th percentile of the historical (1951–1999) period (18.0 mm).

Santa Ana Winds

A reduction in both the local and continental-scale mechanisms generating Santa Ana winds is predicted; however, this has ambiguous consequences for fire because it is also accompanied by a decrease in relative humidity (Hughes et al. 2011).

Fog

Little is known about the current frequency and distribution of fog along Southern California as compared to early 20th-century levels. Existing climate models rarely resolve climate at a sufficiently fine level to capture coastal fog processes, and regular measurements of coastal fog are spotty and do not extend into the past more than a few of decades in most locations. Fog is a critical climate component for MEDN park ecosystems; fog drip is a crucial water source for many plants in this ecosystem and the shade from persistent low clouds near the coast reduces drought stress (Fischer et al. 2009). Detailed mechanisms of fog formation at the local level are not well understood (but see Tseng et al. 2012, Vasey et al. 2012).

Ocean Warming and Sea Level Rise

As climate changes in the Eastern Pacific, oceans are warming and sea level is rising due to thermal expansion of sea water and melting of sea ice. Surface density is decreasing relative to deeper waters, which increases the stratification and inhibits vertical exchange. Long-term warming has been observed in Southern California surface waters, although it is not evident in recent decades due to natural decadal variability (Kim and Miller 2007). Sea level rise could pose enormous challenges to California's ecosystems and society. To date, sea level rise off California has been modulated by alongshore winds (NOAA 2009). However, the rate of sea level rise (~20 cm since the late 1800s) is expected to accelerate and may reach 0.5 – 1m by 2100 (IPCC 2007; NRC 2010).

Ocean Chemistry and Productivity

As oceans absorb anthropogenic carbon dioxide (CO_2) from the atmosphere, the CO_2 dissolves and forms carbonic acid, making oceans more acidic and fundamentally altering their chemical balance (Caldeira and Wickett 2003, Doney et al. 2009). Sea-surface pH is estimated to have dropped by 0.1 pH units since the preindustrial era, which is a 26% increase in acidity over 150 years. Declines of an addition 0.2-0.3 pH units over this century are predicted (Freely et al. 2009). Another oceanic abnormality that has been linked to climate change is the increase in hypoxia or the expanding oxygen-depleted "dead zones" in many areas of the open ocean in recent decades (Keeling et al. 2010). Oxygen concentrations appear to have declined in the Southern California Current since the mid-1980's (Bograd et al. 2008). The most direct consequences to the marine environment of increasing CO_2 are the reduction of pH and the saturation state of CaCO3 (Orr et al. 2005, IPCC 2007; Figure 3). Coastal upwelling regions may be particularly vulnerable to acidification (Feely et al. 2008).

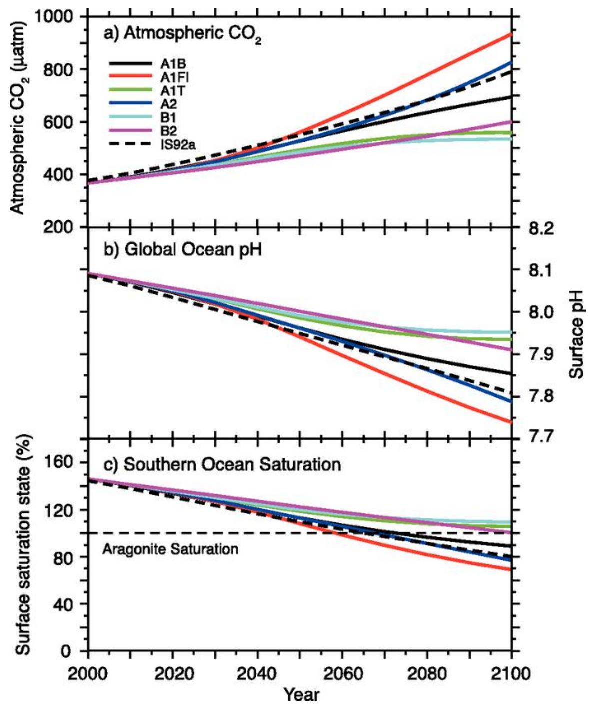

Figure 3. Changes in global average surface pH and saturation state with respect to aragonite in the Southern Ocean under various emissions scenarios from the IPCC Synthesis Report (2007). Time series of (a) atmospheric CO2 for the six illustrative SRES scenarios, (b) projected global average surface pH and (c) projected average saturation state in the Southern Ocean from the BERN2.5D EMIC (Plattner et al., 2001). The results for the SRES scenarios A1T and A2 are similar to those for the non-SRES scenarios S650 and IS92a, respectively. Modified from Orr et al. (2005).

Climate Impacts

Impacts on Marine Organisms

Marine organisms are affected by changes in both water and air temperature. There has been a poleward shift in species ranges, with the range and abundance of warm-water species increasing, while those of coldwater species are diminishing (Hoegh-Gulberg and Bruno 2010). Evidence from invertebrate species in Monterey Bay over the last 60 years indicate that species' ranges are shifting northwards (Barry et al 1995,; Sagarin et al. 1999). However, distributional changes may not be simply poleward, due to the complex mosaic of thermal environments created by the timing of low tides. These local processes may result in localized extinctions at "hot spots" (Helmuth et al. 2002).

Rising temperatures have been shown to cause declines in intertidal invertebrates and kelp ecosystems (Hoegh-Gulberg and Bruno 2010). The Multi-Agency Rocky Intertidal Network (MARINe) conducts monitoring at sites along the entire west coast of the United States, as well as into Canada and Mexico (http://www.marine.gov/). Recent data shows mussel beds have declined 70% on the Channel Islands and 59% on the Southern California mainland (Smith et al. 2006); although the cause of this decline could not be pinpointed to climate change, more recent studies at CABR have found declines in mussel size and all potential causes except climate change have been ruled out (Pister, personal communication). Biomass of zooplankton in the Southern California Bight has decreased by 80% between 1951-1993, believed to be due to ocean surface layer warming and resulting changes to inorganic nutrient upwelling (Roemmich and McGowan 1995).

There is some evidence that harmful algal blooms increase with warmer water (Peperzak 2003, Edwards et al. 2006, Gilbert et al. 2005). An increase in disease is expected due to changing distributions of pathogens and vectors, as well as increased susceptibility due to environmental stress. The progression of black abalone "withering syndrome" up the west coast was documented by MARINe monitoring and is related to warming water (Raimondi et al. 2002). Ocean acidification has direct impacts on organisms that form a $CaCO_3$ shell or skeleton, as well as indirect impacts through the marine food web through loss of organisms at the bottom of the food web and loss of important ecosystem engineers (e.g. mussels and oysters). Expansion of ocean hypoxia can cause mass die-offs of fish and invertebrates (Grantham et al. 2004). Marshes may be able to keep up with sea level rise if there is sufficient sediment, but urbanization has reduced sediment supply to many southern California wetlands. Furthermore, the opportunity for landward migration of wetland or rocky intertidal species in Southern California is highly challenged due to urbanization (CEC 2009).

Marine systems are understudied with respect to climate change impacts (Richardson and Poloczanska 2008, Hoegh-Guldberg and Bruno 2010), and therefore climate change effects are poorly understood compared to terrestrial ecosystems. Like terrestrial ecosystems, marine species will respond to climate change with changes in their phenology, distribution and abundance, and novel community compositions are expected. However, in contrast to terrestrial ecosystems, fundamental changes in primary production are expected (due to acidification and changes in stratification and upwelling) with widespread ramifications.

Impacts on Terrestrial Vegetation

Possible plant responses to climate change include: tolerating new climate conditions, adaptation in place, migration to a more suitable environment, or extirpation. Plant populations that are most likely to tolerate climate change are those that have experienced historical climate change that is similar in magnitude and direction to that predicted for under global climate. One advantage that many California plant species may have is their experience with wide fluctuations in climate within recent history due to the highly variable nature of the California climate as a whole. Populations that can adapt will likely be those with extensive existing genetic variation with respect to climate tolerances. Restricted migration may be another critical factor in the ability of many plant species to migrate to new climates. The severity and speed of climate change will be critical factors (Loarie et al. 2009) in determining how species respond. Many plant species may be extirpated in their current locations and as a result of individual species responses, we are likely to see novel communities arise. The change in species composition will be shaped by climate tolerances, seed production and dispersal capabilities of species. Conditions may favor non-native invasive plant species due to their typically wide climate tolerances, high reproductive output, and excellent dispersal capabilities.

Current modeling targeted at predicting plant species or community response to climate change focuses on modeling correlations between existing distributions and current climate and then using these to predict future distributions (e.g., Loarie et al. 2008). Studies using this type of modeling approach indicate that many of California's endemic plant species may experience significant range contractions (Loarie et al. 2008) and that southern California may lose its most charismatic, keystone oak species, valley oak (Kueppers et al. 2005), see Figure 4. Shortfalls of this approach are that it does not consider biotic interactions, which may currently limit distributions or may act in the future to limit distributions; soil type, which drives the occurrence of many of California's rare flora; and phenotypic or genotypic potential for adaptation to new environmental conditions (Iverson et al. 2011).

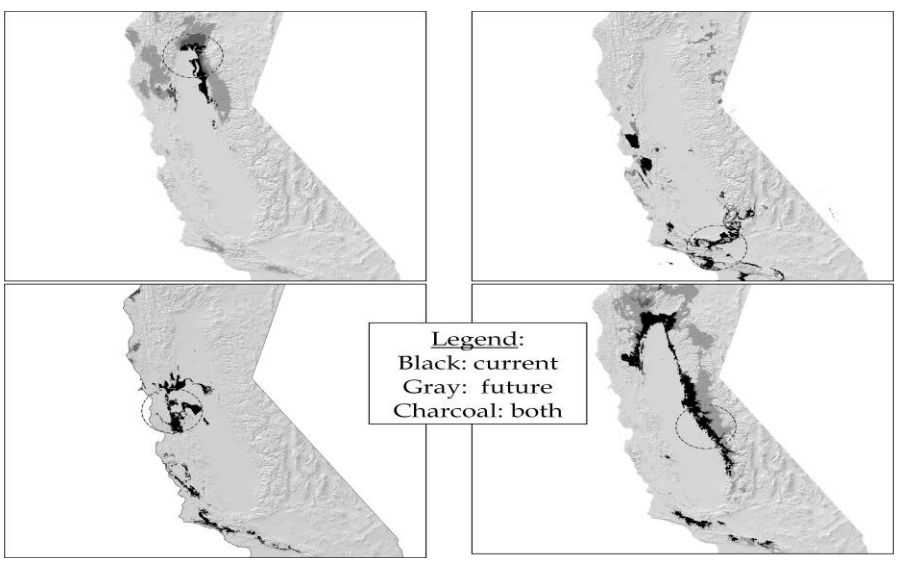

Figure 4. Predicted changes in distribution for the four sub-groups of California Valley Oak under the A2 scenario of GHG emissions for climate change by 2100. Source: Sork et al., unpublished.

Impacts on Terrestrial Wildlife

The documented or anticipated responses of terrestrial wildlife to climate change include changes in their phenology (the timing of annual life cycle events such as hibernation, migration, or breeding), geographical distribution, and exposure to pathogens (Harvell et al. 2002, Parmesan and Yohe 2003, Parmesan 2006). Documented phenological changes include the advancement of the average first spring flight of 23 butterfly species in California's Central Valley over the past 31 years, many up to 24 days or more, with climatic conditions explaining a large part of this change (Forister and Shapiro 2003). Variation in phenological responses has also resulted in asynchrony in predator-prey and insect-plant systems (Both et al. 2006). Combined with geographic range shifts, these responses create the potential for novel community compositions and new species interactions.

As temperatures change, many species are moving northward in latitude and upward in elevation. Similar to study in Great Britain, Hitch and Leberg (2008) found that the northern limit of 26 bird species having a southern distribution within North America showed a significant shift northward at an average rate of 2.35 km/year. The Grinnell Resurvey Project (Museum of Vertebrate Zoology 2011) is attempting to determine historic and future impacts of climate change on small mammal and bird communities in California over the last century, using data collected by the Museum of Vertebrate Zoology (founded in 1908) under its first Director, Joseph Grinnell. Grinnell resurvey data showed that 91% of bird species studied tracked their climate niches in response to climate change; the five species that did not track their niche were urban colonists (Tingley and Beissinger 2009). While the Grinnell resurvey data are valuable in understanding responses to climate change, there are several significant challenges when comparing historical data and contemporary data on wildlife. Data quality issues (use of non-standardized survey protocols and uncertain historical locations) and the availability of detection and non-detection only, or a focus on detection only, limit the ability to develop models or understand data quality.

Attempts to predict wildlife responses to a warmer and potentially dryer environment in SoCa would ideally incorporate the evolutionary adaptation potential of these species (Hoffman and Sgro 2011), in addition to more common habitat niche modeling efforts (Phillips et al. 2006).

Impacts on Watershed Processes (Fire, Hydrology and Sediment)

Increasing temperatures are expected to reduce runoff and recharge in Southern California; increasing temperatures coupled with increased variability in precipitation are expected to result in more uncertainty in discharge/ flood events (Lopez et al, 2011). Modeling of future climate scenarios indicates a strong potential for increases in wildfire occurrence and burned area in coastal southern California[1]. (CEC, 2009). Post-fire hydrologic consequences include decreased infiltration, lower water quality, and increased erosion, overland flow, flooding and debris flow occurrence due to acute loss of vegetation and hydrophobic soil layer formation. Post-fire recovery patterns (coupled vegetation-hydrologic response) was shown to be highly related to post-fire precipitation and temperatures, in addition to burn-severity and aspect (Kinoshita and Hogue, 2011). These relationships between fire recovery and post-fire precipitation may result in slower rates of post-fire recovery under global climate change.

Status of Monitoring, Modeling and Analysis Tools for Southern California Coast Parks

Climate Monitoring

Sustained monitoring of climate and climate-affected systems is critical to detect and understand changes and to plan for the future. The Western Regional Climate Center was contracted by the NPS I&M Program to complete climate data inventories for all National Parks with significant natural resources. The comprehensive climate report for MEDN parks includes detailed information on the location of weather stations within or near the parks (Davey et al. 2007). The report is available from
http://www.wrcc.dri.edu/nps/reports/2007_04_24_medninventory_final.pdf

Climate Modeling

The Regional Earth System Model developed by UCLA and partners contains three interacting components: atmosphere, land surface and ocean. Dynamical downscaling of climate models to 18km, 6km, and 2km resolutions is currently being conducted as part of the Los Angeles Regional Climate Action Plan (http://www.atmos.ucla.edu/csrl/RegionalDynamics.html).

Whereas the Los Angeles region comprises merely a pixel in the highest resolution global climate model, this level of downscaling accounts for the topographic detail that defines the variety of climates across the region (http://c-change.la/la-climate-studies/). All three MEDN parks are completely represented in the 18 and 6km models (see Figure 5). The 2km model includes SAMO and Anacapa and Santa Cruz Islands from CHIS; however the western side of Santa Cruz Island is up against the boundary of that domain, making some results of greater uncertainty in that area.

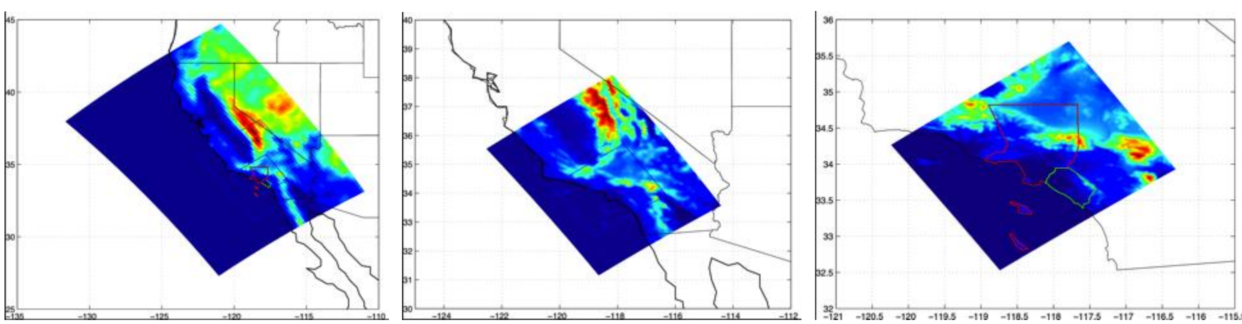

Figure 5. Geographic domains for simulating climate change at high resolution for Southern California, left is 18km resolution, middle is 6km resolution, right is 2km resolution. Color variation represents topography, showing how higher resolution models improve the ability to capture California's diverse terrain and topographical diversity – both drivers of local climate dynamics. Dynamically downscaled simulation centered in the Los Angeles region using WRF + Noah land surface model. Figure courtesy of Alex Hall.

Phenology Monitoring

"Phenology…is perhaps the simplest process in which to track changes in the ecology of species in response to climate change" (IPCC, 2007). It is relatively easy to observe, sensitive to environmental variation, occurs at a wide range of scales, and is linked to most aspects of ecosystems. The phenotypic flexibility of species appears to be associated with their ability to adapt to rapid climate change, and species that don't adapt phenologically may experience a decline in performance (Cleland et al, 2012). Information on phenology is relevant to planning for and implementing climate adaptation. The USA National Phenology Network (NPN - www.usanpn.org) is a national network of integrated phenological observations across space and time; its key goal is to understand how plants, animals and landscapes respond to environmental variation and climate change. Nature's Notebook is a project of the NPN that facilitates tracking of status and abundance of hundreds of plant and animal species using established protocols. It provides real-time downloadable data and visualization tools that can be integrated with climatological data, and allow species-specific queries and animations. The California Phenology Project (CPP - http://www.usanpn.org/cpp/) applies these tools to support long-term phenological monitoring and public education activities across California National Parks. The project is initially focusing on plants in seven pilot national parks, including SAMO, but products and infrastructure are being designed to expand to 19 national parks throughout the state. template

Climate Change Impact Analysis Tools

Glick et al (2011) provides a comprehensive guide to climate change vulnerability assessments for resource managers. The following is a brief comparison of two common approaches to vegetation distribution modeling to assess potential impacts of climate change: bioclimate envelope models and dynamic vegetation models. Bioclimate envelope models assume that current species distribution is determined by, and in equilibrium with, current climate. The availability of presence/absence data allows for a wider variety of modeling options. If only presence data is available, standard regression models cannot be used. MaxEnt models, based on a "maximum entropy" analysis approach, can be run with presence-only point data (Phillips et al., 2005), although inference from presence only methods is limited. Dynamic vegetation models mechanistically represent the physiological limits of a species' climatic tolerance, with no assumptions of equilibrium. Both model approaches, however, are severely limited in dealing with biotic influences such as species interactions, adaptation and dispersal ability. Furthermore, when applied to future projections, these models assume that rates of species adaptation are slower than extinction rates (ecological niche conservatism).

One New Approach to Conservation Planning

One of the recent developments in conservation planning is a shift from the classical approach of maximizing species diversity (focus on patterns), to one of maximizing adaptive genetic variation to ensure conservation of the evolutionary processes that generate and maintain biodiversity (focus on process). The intent is to maximize the potential for species to respond to land use and climate changes, known as adaptive capacity. One approach to analyses to support such conservation planning goals involves a suite of tools, starting with a MaxEnt species distribution model, followed by genetic diversity modeling that provide correlations between environmental variables and both genetic and morphological traits, to predict patterns across the landscape (Thomassen et al. 2011). Mapping regions of high genetic and morphological variation will allow these areas to preferentially protected. A project to identify just such adaptive hotspots in the Santa Monica Mountains region is currently underway in Dr. Tom Smith's lab (UCLA), focusing on areas to conserve in the face of climate change. The next steps required to support this approach include improving the accessibility and efficiency of biodiversity monitoring data; quantifying the main determinants of the sensitivity of species to climate change; incorporating community dynamics into projections of biodiversity responses;

and accounting for the influence of evolutionary processes on the response of species to climate change (McMahon et al., 2011]).

Land Managers' Perspectives

Land managers are deeply concerned about climate change and the potential impacts of altered and novel climates on the organisms and ecosystems they are mandated to protect. Unfortunately the new impacts from climate change will be overlaid on top of, and interact with, a suite of challenges already facing native plant and animal communities including invasive species, fragmentation, urbanization and disease. Given the complexity of ecological communities and limited resources for management, land managers often feel overwhelmed by all of the potential interactions and possible problems that might occur under climate change.

Academic researchers and students are needed to work collaboratively with land managers to:

- Develop research projects to identify species and communities most at risk due to climate change
- Help adapt current monitoring practices to more accurately detect climate signals
- Analyze long term monitoring data in conjunction with climate data to better understand climate contributions to resource conditions and trends
- Provide updates to managers on what the current state of knowledge is in their particular fields with respect to climate change and climate change impacts

The type of interactions fostered by this workshop are exactly the kinds of information exchanges needed to develop collaborative partnerships between scientists and land managers that will both push forward our climate change science and maximize the effectiveness of future management efforts given the wide range of threats facing our species and ecosystems.

Existing mechanisms that are in place within the Southern California network of parks to help facilitate these research collaborations include the La Kretz Center for California Conservation Science and the Southern California Research Learning Center. Both of these entities can assist researchers in finding land managers to work with and can help land managers find needed research expertise. The Research Learning Center (http://www.mednscience.org/research) also supports students and faculty with logistical issues including obtaining permits for work within the park.

Long-term Natural Resource Monitoring: MEDN I&M Program

Long-term ecological monitoring data are necessary to understand the dynamic nature of ecosystems, to evaluate responses to human disturbance or large scale drivers disturbances such as climate change, and to inform management decision-making aimed to maintain, enhance, or restore the ecological integrity of parks (Fancy et al. 2009, Lindenmayer and Likens 2009). The MEDN I&M Program includes 15 long-term monitoring programs (Table 3) that address a variety of organisms or processes at the three network parks, with each program monitoring anywhere from one (e.g., Island Fox, Deer Mouse) to many (e.g. Terrestrial Vegetation, Kelp Forest Monitoring) species. Monitoring programs at CHIS began in the late 1980s and were formalized in 1993, when the Park was designated as a Prototype Park for the NPS I&M Program (Davis et al. 1994). Monitoring programs at CABR and SAMO were not generally started until approximately 2001, and a few programs (e.g., riparian systems/fresh water quality and landscape dynamics) have not yet been developed or implemented.

For each Vital Sign program, a detailed protocol is developed according to guidance provided by Oakley et al. (2003) to ensure consistent data collection through time, a statistically-rigorous sampling design, and to provide guidance on data analysis and reporting. Once the peer-reviewed protocol for a program is implemented, data are entered on a routine basis and checked to assure their accuracy, annual summary reports are prepared (if data are collected annually), and trend analyses are performed every 3-6 years. Data collected through this program are frequently analyzed and published in collaboration with academic partners. Within the next 5-10 years, nearly all MEDN protocols will be developed for the first time, or reviewed and revised. Therefore, this is a critical time to incorporate changes to long-term monitoring programs that will allow a better understanding of ecological responses to climate change.

Table 3. Overview of MEDN long-term "Vital Signs" monitoring programs.

	Parks where implemented		
VITAL SIGN	**CHIS**	**CABR**	**SAMO**
Aquatic Herpetofauna			x
Beaches & Lagoons	x		
Climate and Weather^	x	x	x
Deer mouse*	x		
Nonnative Invasive Plant Species	x	x	x
Island Fox*	x		
Kelp Forest Communities*	x		
Landbirds*	x		
Landscape Dynamics Using GIS & Remote Sensing Data^	x	x	x
Pinnipeds	x		
Riparian Integrity and Fresh Water Quality^	x		x
Rocky Intertidal Communities*	x	x	
Seabirds*	x		
Terrestrial Reptiles & Amphibians*	x	x	x
Terrestrial Vegetation* (CHIS) ^ (CABR, SAMO)	x	x	x

*Program with > 10 years of data

^Program that is newly or not yet implemented

Recommendations

Recommendations are presented below in two different ways. First, we discuss broad themes that have emerged as priorities; these themes may cut across the individual breakout group topics, or may be focused on a specific issue within a single topic. These themes represent the highest priorities for climate change research and monitoring within the SoCA coastal national parks. Second, we present details of the priority recommendations within each breakout group topic area.

Priority Themes for Research and Monitoring

The following research and monitoring themes are the highest priorities for the MEDN parks.

Fog and Microclimate

Fog plays a critical role in the marine/coastal climates of the MEDN parks, but remains poorly characterized within current climate models. Diurnal and annual variability of fog, now and under future climate scenarios, should be elucidated further, and studies of vegetation-fog interactions should be pursued. More broadly, further research is required to improve our ability to estimate the current and projected geographical distributions of ecologically important microclimates, and improve our ability to model microclimates using downscaled models.

Ocean Acidification and Warming

Changes in ocean pH and temperature due to climate change may have profound direct and indirect effects on a range of marine organisms. Specific priority research goals include: improving our ability to model pH and temperature in the near-shore environment though increased data collection; better understanding of spatial and temporal variation in pH and temperature at different scales to inform field data collection; performing literature reviews or lab studies to determine key species that should be targeted for impact analyses; performing modeling studies to assess species responses under future climate scenarios.

Enhanced monitoring: Conduct Periodic, Repeated Inventories and Monitor Phenology

Expand park inventories and conduct experiments to monitor abundance, distribution and phenology of species likely to be impacted by climate change.

Vulnerability Assessments

Assess vulnerability of various species and habitats to climate change. Data and tools to assess the vulnerability of various species and habitats (such as downscaled climate models for SoCA) are critically needed to aid natural resource managers in the development of adaptation plans.

Fire and Climate Change

Although the drivers of wildland fire in southern California, including climate, vegetation, and topography, are fairly well understood (Peterson et al. 2011, Keeley and Zedler 2009, Keeley and Fotheringham 2001), given the large impact that wildland fires have on southern California, a refined understanding of the effects of climate change on the relationships and feedbacks among the primary drivers of wildfire in SoCA is important. Research in this area should include the effects of changes in and inter-relationships between: drought, frequency and intensity of Santa Ana winds, vegetation die-back, post-fire vegetation recovery, and vegetation type conversion.

Priority Recommendations by Topic Area

The following specific recommendations (summarized in Table 4) were identified as priority research and monitoring activities within each topic area.

Table 4. Summary of priority recommendations

CLIMATE	MARINE	VEGETATION	WILDLIFE	WATERSHED
Research: • Fog • Microclimates and the accuracy of downscaled climate models • Hydrologic variability • Soil moisture • Extreme events	***Research:*** • Ocean acidification – determine key MEDN species • Ocean acidification – pH measurements • Integrate monitoring data with oceanographic models	***Research:*** • Understanding relationships between plant distributions and climate • Detecting changes in phenology and phenological mismatches • Understanding the role of phenological plasticity • Fog, now and in the future • Predictors of plant species response • Non-native grasses and climate change • Nitrogen enrichment and climate change	***Research:*** • Vulnerability assessments • Understanding mechanisms of response: phenology, circadian rhythms, and physiology • Changing wildlife disease interactions • Habitat connectivity at risk	***Research:*** • Hydrologic changes • Inter-relationships between fire, climate and vegetation
Monitoring: • Expand climate station networks • Enhance manual / direct observations • Curate long-term climate data sets • Improve communication of climate data	***Monitoring:*** • Rocky intertidal -- include additional measurements • Phenology • Kelp forests – include additional measurements • Monitor shoreline erosion • Track settlement and recruitment of marine species	***Monitoring:*** • Phenology monitoring • Co-location of climate and vegetation data stations • Remote sensing • Monitoring of moss and lichen populations	***Monitoring:*** • Genetic and morphometric monitoring • Phenology monitoring • Monitor for range shifts • Community monitoring • Arthropods • Mule deer • Butterflies • Landbird phenology and population dynamics • Combined phenology monitoring at focal sites	***Monitoring:*** • Vegetation change monitoring including postfire • Hydrology and sediment monitoring

Climate

Climatic patterns and processes underlie many of the identified research and monitoring priorities identified for the other topic areas. As such, high priorities for climate may also have additional research and/or monitoring applications in other topic areas.

Priority **research** areas related to climate:

Fog

Better characterization of the existing and projected fog (and other cloud) patterns in the coastal zone is of particularly high priority. Specific subjects for research are vegetation-fog interaction, diurnal and annual variability of fog now and under climate change, and clarification of the sensitivity of climate models to fog characterization in the coastal Southern California (the Channel Islands in particular).

Microclimates and the accuracy of downscaled climate models

Of particular relevance to climate change research in coastal Southern California is the influence of complex topography, distance from the coast, and fog input on microclimate, and the accuracy of regional climate model outputs given these complexities. The ability of different climate model downscaling techniques (dynamical and statistical) and interpolation techniques (e.g. PRISM) to represent microclimates in the MEDN area should be evaluated. Since ecological processes are often determined by microclimate, it is necessary to understand how, and under what circumstances, regional climate models accurately capture microclimates. One possible technique to gather data to address this research question is the relatively short-term deployment of a large number of inexpensive data loggers along perceived climate gradients. An additional research priority is the assessment of whether or not changes in microclimates are correlated with or predict ecological distributions.

Hydrologic Variability

Hydrologic variability under future climate conditions, expected impacts on streamflow, and better understanding of the climate feedbacks between vegetation and hydrologic processes, are high priorities for research.

Soil Moisture

Soil moisture is not currently being monitored but may respond to climate change in unexpected ways. Further understanding of soil moisture patterns and processes in integrated climate models will highlight potential areas of concern and further research. This has been identified as a research effort rather than a long-term monitoring recommendation.

Extreme Events

Research related to characterizing changes in extreme events and shifts in seasonal weather patterns under future climate scenarios is a priority research area.

Priority **monitoring** activities related to climate

Expand Climate Station Networks

The highest priority for additional monitoring is to increase the number and distribution of weather stations in key locations within the MEDN area. Data collected by these stations are relevant to a number of other research and monitoring priorities for the parks. In situ observations are also key to validating regional models. To obtain climate data at spatial scales that are more relevant to many types of ecological monitoring, it is recommended that weather data loggers be co-located with a spatially-balanced subset of vegetation monitoring transects and at wildlife monitoring sites. The areas most in need of long-term weather stations (e.g., RAWS or COOP) are San Miguel Island and SAMO. There is not currently an active station with long-term data within SAMO. San Miguel Island is the westernmost of the islands that comprise CHIS and is the only island within the park that does not have a RAWS station. If additional monitoring stations are deployed, precipitation and temperature are the most important variables, followed by dew point, winds, soil moisture, and visibility. High-resolution monitoring of temporal patters of fog is also critical, but there is the need for more affordable instrumentation for these data.

Enhance Manual / Direct Observations

Manual observations are still valuable and are used for evaluating/validating automated monitoring stations. However, quality control needs to be improved for RAWS and ranger station data. All monitoring data should adhere to minimum quality standards and be appropriate for comparison with other observations.

Curate Long-Term Climate Data Sets

Long-term data sets are critical for use by park staff and collaborators; through coordinated effort, these data can inform ongoing management practices. Currently these data sets are uncoordinated and of variable quality. Compiling these into a single, high quality, accessible resource would prove immensely valuable to researchers and managers. This could also include developing correlations between station data to help fill gaps.

Improve Communication of Climate Data

More extensive dissemination of climate research and monitoring data to other researchers and resource managers should occur. A particularly high priority under this category is the production of an Annual Report for the MEDN (plus its Southern California neighborhood). In addition to Park observations, this report should include larger scale fields (e.g. clouds, atmospheric circulation, temperature, precipitation), as well as interpretive discussion in a climate change context. Potential collaborators include members of the Southwest Climate Science Center, NOAA (Regional Integrated Sciences and Assessments) and the USGS.

Marine

Priority **research** areas related to marine organisms:

Ocean Acidification – Determine Key MEDN Species

Fundamental research questions are: What are the key species within the MEDN parks that should be targeted in order to assess the impacts of ocean acidification? What are the expected responses? This research could be conducted in the form of a literature review or a lab study. Potential species include those that form shells or skeletons from $CaCO3$ and highly abundant species at the base of the food chain. Specific candidates may include shellfish, larval fishes, calcareous algae, and zooplankton.

Ocean Acidification – pH Measurements

In order to model and predict changes in ocean acidification in response to climate change, it is critical to have an accurate understanding of current pH conditions, including the temporal and spatial variation. It is also important to understand the spatial and temporal variation of ocean pH at different timescales, including daily. CABR and CHIS (Santa Barbara Is.) are potential locations for conducting repeated measurements of pH throughout the day. However, the precision of hand-held pH units should be assessed to determine if this is a suitable measurement method; a pilot study could be conducted to assess accuracy, precision and repeatability of manual pH measurements.

Integrate Monitoring Data with Oceanographic Models

Apply existing data or obtain new data to test and validate oceanographic models, and to assess and predict species responses to changing ocean conditions. Possible species data include rocky intertidal organisms, marine mammals, kelp, and seabirds (there is legacy data on seabird phenology and abundance that could be converted into a digital database). Conduct research to understand and predict marine species distributions/abundances under climate change scenarios. Consider also accounting for climate change responses in conjunction with fishing, trampling, and other direct impacts.

Priority **monitoring** activities relating to marine organisms

Rocky Intertidal -- Include Additional Measurements

Although the physiology of rocky intertidal organisms is not well understood, the following additional monitoring is believed to be critical to understanding and forecasting these species' responses to climate change:

- Add plots above existing rocky intertidal plots (above "barnacle" plots) to detect organisms moving into these areas as a result of sea level rise.
- Measure elevations of the fixed rocky intertidal plots to better understand how they might be impacted by sea level rise. This has been done at CABR, but had not yet been done at CHIS, and would involve working with USGS or BLM to install benchmark sites.
- Collect more spatially comprehensive temperature data. Further understanding is needed regarding the necessary spatial density for temperature loggers; changes in temperature monitoring protocols should be standardized across monitoring sites to permit comparisons.

- Measure relative humidity, as this influences the potential for organisms to become desiccated.
- Consider locating a weather station near the intertidal zone, for continuous comprehensive weather data.
- Measure wave motions, including wave height magnitude and wave force magnitude.
- Collect ocean salinity data (this is already being done by The California Cooperative Oceanic Fisheries Investigations - CalCOFI).
- Collect pH measurements to understand ocean acidification. Models currently in development (Deutsch, UCLA) make predictions of pH, so this data would allow for verification and ground truthing of the models. However, because of uncertainties regarding pH variation on daily and annual timescales, this has been identified as a research project (see above section).
- Consider adding oxygen measurements as a "cheap backdoor" to pH information. This relationship is tight in deep water, but not currently known for the nearshore environment.
- Monitor species' range adjustments to see how communities are changing by performing biological inventories every 5-years for all MARINe sites to collect data on species that are not routinely monitored. Many species are too difficult to identify in the field and require collection for later identification in the lab. Collect vouchers and take photos during inventories.

Phenology

Monitor phenology (flowering, recruitment) of selected species at CABR, potentially including: surfgrass, rockweed, and sargassum. This work might be done using volunteers / citizen scientists. Also, work with NMFS to monitor marine mammal pupping timing.

Kelp Forests - Include Additional Measurements

Include the following additional measurements for kelp forest monitoring at CHIS:

- Incorporate more temperature loggers (there is currently only one per site). Temperature is believed to be a strong proxy for kelp distribution.
- Add nutrient sensors to understand the relationship between temperature and nitrogen. However, nutrient monitors (ISIS) are only recently available and cost approximately $20K. The maintenance needs of these sensors would also be a consideration.
- Use remote sensing imagery to look at nutrients/ productivity and kelp distribution / abundance.
- Collect data on kelp canopy extent. This might provide clues to temperature, nutrients, etc. (Ed Parnell at Scripps may be a resource)

Monitor Shoreline Erosion

Institute periodic LIDAR flights to detect shoreline erosion due to sea level rise. This has been done at CHIS and was shown to be effective in tracking cliff erosion.

Track Settlement and Recruitment of Marine Species
Look for a climate change signature by tracking settlement and recruitment of marine species. Consider teaming up with California State University Channel Islands and California Cooperative Oceanic Fisheries Investigation (CalCOFI) for this work. The challenge will be obtaining resources for labor and sorting of samples.

Vegetation

Priority **research** areas related to vegetation

Understanding Relationships between Plant Distributions and Climate
Some modeling of species distributions and future climate provide cause for concern, indicating that many of California's endemic plant species and some of its keystone plant species may be lost from southern California under climate change (Loarie et al. 2009, Kueppers et al. 2005). However, it is not yet clear whether climate refugia may exist within the Santa Monica Mountains or whether keystone plant species already contain sufficient adaptive potential to persist in place given anticipated future climate changes. To what extent are species distribution and abundance related to microclimatic factors, and can these relationships be used to create fine scale species distribution models under future climate scenarios? Further research is also needed to understand the role of habitat fragmentation and soil characteristics in limiting the potential future distributions of plant species. Much of the current research suggests that differential response of species to climate change may result in the formation of novel communities. In order to better understand and manage these future communities we need to understand what species are likely to move, how species function within their communities and assess the functionality of these new communities when they arise.

Detecting Changes in Phenology and Phenological Mismatches
The timing of seasonal biological events can be important both ecologically and socioeconomically. Recent research suggests that the failure of an organism to adapt its phenology as climate changes may be an early warning of future extirpation (Willis et al. 2010). In addition, other research has shown that phenological mismatches between plants and their pollinators, dispersers, and even herbivores, can have serious consequences for ecological functioning (e.g. Post and Forchhammer 2008). Finding predictors or early warning signs of impending phenological mismatches or changes in phenology would be very useful to managers as they try to predict which species will persist and which will be lost under climate change. An example of a specific project for a keystone species, valley oak, would be a provenance study to examine variation in phenology of budburst. This would help to understand how variation for climate change response related traits are distributed, and whether some populations are better adapted to meet anticipated changes. Such information would inform future restoration efforts.

Understanding the Role of Phenological Plasticity
Preliminary work in other areas (and currently under review by an NCEAS working group headed by Elsa Cleland) has shown that phenological plasticity can be a predictor of future abundance under climate change. Species that show large plasticity in flowering, fruiting or other phenological events were able to maintain population numbers in the face of a changing climate while those whose phenological traits were

fixed were locally extirpated as climate changed. Does this same relationship hold in our three parks? Does phenological plasticity correlate with current abundance levels? Can we examine phenological plasticity by monitoring plants across an environmental gradient?

Fog, Now and in the Future
The role of fog in determining plant species abundances has been understudied in southern California systems. Fog both provides an additional input of moisture over normal precipitation events as well as reduces the evapotranspiration draw on plants. Understanding the role of fog in plant species distribution as well as what causes fog to occur where it does currently are key factors in understanding future fog distributions and future plant distributions.

Predictors of Plant Species Response
Being able to predict how plant species will respond to environmental changes, including climate change, N deposition, increased ozone, and other human-caused environmental alterations would be very helpful in formulating management responses to these stressors. Until we know what species are likely to decline under climate change, what role they play within a community, and whether they are likely to be replaced by another species that is thriving under altered conditions, it is difficult to formulate management alternatives. Managers may need to consider assisted migration for some species but the effectiveness of such actions may be reduced if we do not know sufficiently early that a species is likely to decline.

Non-Native Grasses and Climate Change
What are the impacts of non-native annual grasses on native diversity and how might this relationship change under climate change? Do we have clear evidence for our three parks on the impacts of non-native grasses on native plants? Are they superior competitors for light, water, resources? Do they impact seed/seedling and adult stages of native species? How might these relationships change as climate changes?

Nitrogen Enrichment and Climate Change
Acquire baseline information on nitrogen enrichment and examine the interactions between nitrogen enrichment and climate on plant communities. Many studies have shown impacts of nitrogen levels on native plant communities. Assess the baseline levels of nitrogen throughout the three parks and understand nitrogen, climate, and plant dynamics to predict future impacts of nitrogen deposition on plant communities.

Priority **monitoring** activities related to vegetation

Phenology Monitoring
Shifts in the timing of fruiting, flowering, bud burst, etc. can be early indicators of climate change and have been linked to changes in abundance and distribution. Additionally, if phenology tracking also monitors the actual amount of flowers, fruits, and seeds produced, these data can provide early indications of future population failures. Web cameras focused on key plant species, used in combination with visual analysis tools, may be an effective technique to track phenology. Related research would involve investigating what phenological events could be detected via remote cameras, and

developing a systematic method for collecting and analyzing this data (possible events include flowering of chamise and ceanothus, and leaf out of valley oaks, walnuts, sycamores).

Co-location of Climate and Vegetation Data Stations
The topography of the Santa Monica Mountains and Channel Islands results in large changes in climate over short distances and in a proliferation of microclimates throughout the mountains. Understanding vegetation response to climate change necessitates understanding fine-scale responses of vegetation communities to the climate they are experiencing. Due to the heterogeneity of climate throughout the region and at fine-scales, developing this detailed understanding of vegetation response to climate may require co-location of temperature and moisture sensors with vegetation monitoring stations or deployment of a large number of sensors for a short-time period in order to generate accurate, small-scale climate models to match to vegetation monitoring transect data.

Remote Sensing
Use of LandSat, MODIS, or other remote imagery may be helpful in examining large-scale, long-term trends in vegetation that could be analyzed in conjunction with climate data to look for relationships between climate changes and vegetation change. This approach may be constrained by the resolution of the imagery and the confounding influence of other large scale changes other than climate such as development. A Landscape Dynamics Monitoring Protocol that applies remote sensing imagery is under development (Willis et al, in prep)

Monitoring of Moss and Lichen Populations
Moss and lichens have been shown to be sensitive to climate changes (as well as many other environmental factors) and may function as an early indicator that the climate in a particular area is changing in a biologically meaningful way.

Wildlife

Priority **research** areas related to wildlife

Vulnerability Assessments
Assessing the relative vulnerability of species within this region to climate change is necessary to determine where to focus planning and management actions. Results from such analyses will inform management and funding decisions related to climate change adaptation plans. Assessments should address, if possible, all three components of vulnerability: exposure, sensitivity and adaptive capacity (Dawson et al. 2011; Glick et al. 2011; see Klausmeyer et al. 2011 for a solid, recent CA application).

Understanding Mechanisms of Response: Phenology, Circadian Rhythms, and Physiology
Research is needed to understand the mechanisms by which species respond to climate changes, to assess the extent of species' flexibility to shift daily or seasonal activity patterns, and to determine their physiological limits. These elements are key to assessments of sensitivity and adaptive capacity, which along with exposure, comprise the components of a species' vulnerability to changing climate.

Changing Wildlife Disease Interactions
Given that warmer temperatures generally increase pathogen transmission and reproductive rates, how will host-pathogen interactions in our region change with climate warming? Which wildlife species will be most vulnerable and which diseases or parasites can be anticipated and possibly managed (e.g. mange, mites, ticks, West Nile Virus)?

Habitat Connectivity at Risk
Research is needed to determine where habitat connectivity for wildlife (e.g. South Coast Wildlands, 2008) is at risk as a result of anticipated climate-induced vegetation changes. Which critical linkages in Southern CA will be reduced or eliminated by shifts in vegetation? How will this combine with habitat destruction and fragmentation?

Priority **monitoring** activities related to wildlife

Genetic and Morphometric Monitoring
Develop protocols for systematic and opportunistic collection and storage of geo-referenced samples, including whole carcasses, for baseline genetic and morphometric analysis. Changes in animal morphology related to climate change have already been documented. Are there additional data we can begin to collect opportunistically, to better document and understand how wildlife are responding to climate change?

Phenology Monitoring
Changes in phenological events are among the most sensitive biological indicator of climate change; therefore, it is suggested that phenology monitoring be added to existing wildlife monitoring protocols.

Range Shifts
Range shifts have already been detected for a number of taxa across the US. Adding monitoring sites outside of the current range of monitored species may facilitate detection of range shifts; however, this type of monitoring must be done near the edge of a species' current range.

Community Monitoring
Where possible, institute community-level monitoring of wildlife and vegetation. This would involve co-location and simultaneous monitoring of multiple measurements such as climate, reptiles and amphibians, and vegetation.

Arthropods
The lifecycle of most arthropods (insects, spiders and mites), is highly dependent on temperature, and in many cases precipitation. Their close ties to the environment, relatively short life span, importance to human health and food supplies, and position at the bottom of the food chain make them an ideal taxon to monitor for ecological responses to climate changes. Emphasis should be on important pollinators such as bees and butterflies, as they are subject to phenological mismatch with their host plants as a result of climate change. Monitoring is inexpensive if done with Malaise traps set out by field crews and experts identifying groups of species at a later time. Specific research

questions include: What are community changes in species distribution and richness? Are new invasive species being detected?

Mule Deer
Deer are the largest herbivore at SAMO and the primary prey for mountain lions. Climate change is anticipated to increase grasslands, which may cause deer population increases, which may in turn have feedback effects on vegetation. To what extent do deer use urban areas? This may lead to safety concerns for both people and deer (e.g. car accidents, disease vectors). Mule deer have stricter road-undercrossing requirements than carnivores. Their populations may be more likely to become isolated with fragmentation and habitat change, and fragmented deer populations may have a reduced capacity to adapt to climate change.

Butterflies
Several published studies have documented butterflies responding to climate changes by shifting ranges and emergence times. Because of their close ties to host plants and their temperature-dependent larval stages, butterflies are sensitive indicators of climate change. Butterflies are good candidates for physiological, behavioral, and phenological studies, and they are also relatively easy to find, capture and mark. Citizen scientists and the NPS Southern California Research Learning Center could potentially play a strong role in this work. UCLA Postdoc T. Bonebrake is doing some monitoring of butterfly phenology in SAMO.

Landbird Phenology and Population Dynamics
Many bird species have responded to climate change by altering their distribution or phenology. Are land birds across the southern CA coastal region altering arrival dates and local distributions? Are these changes affecting species richness? Several potential collaborators exist for this work, including Professor Tom Smith's group at UCLA (MAPS stations). Additional lines of research include monitoring genetic diversity, monitoring circadian patterns of singing and other behaviors in different habitats.

Combined Phenological Monitoring at Focal Sites: Birds, Bees, Butterflies and Plant Phenology
This proposed monitoring project focuses on taxa that are of known concern having already shown effects of climate change by changes in distribution, emergence time, or phenology., They would provide insights into the impacts of these responses on interactions across three tropic levels. This project could co-locate monitoring sites for multiple species and add phenology trails placed according to a sampling design rather than accessibility. Potential partners include but are not limited to: Tim Bonebrake (UCLA), Brian Brown (LA County Natural History Museum), Walk Sakai (Santa Monica College), Tom Smith (UCLA), Institute for Bird Populations (MAPs stations), California Phenology Network, and the NPS Southern California Research Learning Center bee project.

Watershed Processes (Fire, Hydrology and Sediment)

Priority **research** needs related to watershed processes

Hydrologic Changes

There is currently poor agreement among climate models regarding predicted changes in SoCA rainfall; future climates may be warmer and dryer or warmer and wetter. Understanding the impacts of variability in future precipitation regimes on streamflow and sediment dynamics in the MEDN parks is an important research area. The interrelationship between changes in precipitation, fire and vegetation (discussed below) also need to be considered. Predictive models are needed to guide management actions where excess sediment accumulation could altere stream pool habitats for aquatic amphibians and reptiles. Other research priorities include understanding the combined effects of increased population, emerging efforts to increase stormwater infiltration, and increasing reliance on local water supplies to reduce the amount of imported water.

- How will these changes combine to alter stream flows within SAMO under future climate scenarios?
- What are the relationships between urbanization, imported water, and riparian habitats in the parks and how might these change under new hydrologic regimes?
- How might watershed restoration approaches need to be modified under the hydrologic regimes anticipated with climate change?

Inter-Relationships between Fire, Climate and Vegetation

This is a complex area of research, as it involves teasing out the relationships and feedback processes among multiple aspects of the fire regime, climate and vegetation. Research emphasis is on drought, frequency and intensity of Santa Ana winds, vegetation die-back, stressors on post-fire vegetation recovery, and vegetation type conversion from high fire frequency. Specific research questions include:

- How will climate change affect wildfire frequency and intensity in the Santa Monica Mountains? Research has shown that large wildfire events in southern California are primarily driven by increased human ignition sources, low seasonal plant tissue moisture levels (live fuel moisture and the frequency and severity of Santa Ana wind conditions. How will these three primary controls on major wildfires change overall and seasonally under climate change?
- How will climate change affect the interrelationship between drought, die-back, fire frequency and post-fire recovery? Will increased fire frequency shift vegetation types from evergreen chaparral to scrub or herbaceous communities with less intense wildfires?
- What is influence of climate change on frequency and severity of drought?
- What is the impact of drought on post-fire vegetation recovery?
- What is the impact of drought on die-back/subsequent fire regimes?
- How can drought-induced die-back be incorporated into fire prediction for So Cal?
- What will be the likely impacts of changes in fire regimes on type conversion?

- How will changes in climate regime and fire affect silt/scour potential after fire?
- What are the anticipated impacts of a changed fire regime on animal populations?
- Are CABR and CHIS likely to experience increased fire under climate change and what would the impacts be?

Priority **monitoring** activities related to watershed processes

Vegetation Change Monitoring

- Develop and implement optimum monitoring methods for post-fire vegetation recovery.

- Incorporate remote sensing technology to monitor vegetation changes such as die-back and implement under the Landscape Dynamics Protocol currently under development

Hydrology and Sediment Monitoring

Develop and implement a post-fire hydrology and sediment monitoring protocol including post-fire water quality monitoring (i.e. turbidity, DO, TDS, nutrients). This will support the development of sediment and hydrology models to simulate and predict post-fire system recovery and support management planning under climate change scenarios. There is also a need to increase soil moisture and streamflow measurements to track climate change impacts on watershed processes.

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Appendix A - List Of Workshop Participants

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Neil	Berg	UCLA	Keith	Lombardo	NPS – CABR
Timothy	Bonebrake	UCLA	Kaye	London	NPS – CABR
Erin	Boydston	USGS	Travis	Longcore	UCLA
Christy	Brigham	NPS- SAMO	Sonya	Lopez	UCLA
Brian	Brown	Nat’l History Museum LA	Glen	MacDonald	UCLA
Wolfgang	Buermann	UCLA	David	Mazurkiewicz	NPS - CHIS
Paul	Bunje	UCLA	Kathryn	McEachern	USGS
Dave	Busch	USGS	Carolyn	Mini	UCLA
Dan	Cayan	USGS / Scripps Institute	Cully	Nordby	UCLA
Jay	Chamberlin	CA State Parks	Stacey	Ostermann-Kelm	NPS - MEDN I&M
Jaime	Chaves	UCLA	Katherine	Pease	UCLA
Liz	Chornesky	Resources Legacy Fund	Tom	Philippi	NPS - I&M FT Collins
Tim	Coonan	NPS - CHIS	Benjamin	Pister	NPS – CABR
Rosi	Dagit	RCD-SMM	Paula	Power	NPS - CHIS
Nick	De Roulhac	NPS – SoCA RLC	Kelly	Redmond	DRI / WRCC
Katy	Delaney	NPS- SAMO	Dan	Richards	NPS - CHIS
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Kate	Elgin	UCLA	Erin	Riordan	UCLA
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Kate	Faulkner	NPS - CHIS	Rocky	Rudolph	NPS
Felicia	Federico	UCLA	Tarja	Sagar	NPS- SAMO
Carol	Felixson	UCLA	Kevin	Schallert	NPS
Aaron	Ferrel	UCLA	Sara	Scozolino	UCLA
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Devaughn	Fraser	UCLA	Clark	Stevens	RCD-SMM
Hartmut	Frenzel	UCLA	Robert	Taylor	NPS- SAMO
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Terri	Hogue	UCLA	Steve	Whitaker	NPS - CHIS
Irina	Irvine	NPS- SAMO	Marti	Witter	NPS- SAMO
Denise	Kamradt	NPS- SAMO	Tom	Workman	NPS - CABR
Jon	Keeley	USGS	Tiffany	Yap	UCLA
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