National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Pinnacles National Monument

Natural Resource Report NPS/PINN/NRR—2013/709

ON THE COVER
Prairie falcon fledgling flaring wings, Pinnacles National Monument.
Photograph by: Gavin Emmons © 2011

Natural Resource Condition Assessment

Pinnacles National Monument

Natural Resource Report NPS/PINN/NRR—2013/709

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This report was prepared under Task Agreement J8C07080005 of the Californian Cooperative Ecosystem Studies Unit (Cooperative and Joint Venture Agreement between the National Park Service and University of California Santa Barbara H8C07080001).

September 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
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 These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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 from the San Francisco Bay Area Network Inventory and Monitoring Program (http://science.nature.nps.gov/im/units/sfan/index.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Davis, F. W., D. M. Stoms, and P. A. Jantz. 2013. Natural resource condition assessment: Pinnacles National Monument. Natural Resource Report NPS/PINN/NRR—2013/709. National Park Service, Fort Collins, Colorado.

NPS 114/122356, September 2013

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Executive Summary

This report is an assessment of condition of the natural resources of Pinnacles National Monument (PINN) and an evaluation of the threats and stressors that act on these resources. An improved understanding of the state of knowledge regarding the condition of PINN's natural resources and the threats acting on these resources is needed to guide data collection and broader natural resource management efforts. This condition assessment was undertaken to provide National Park Service (NPS) managers, interpreters, and planners with a synthesis of the most current information on the natural resources in and around PINN. The assessment is divided into five chapters: (1) **NRCA Background Information** describes the purpose and use of the assessment; (2) **Park Resource Setting/Resource Stewardship Context** provides an overview of the natural resources of the monument and the planning and science perspectives about their management; (3) **Study Approach** outlines the process used to identify priority indicators, the assessment framework, and the analytical methods in the assessment; (4) **Natural Resource Conditions** contains the heart of the report with the assessment of status and trends of the stressors and resources of concern; and (5) **Discussion and Conclusions** synthesizes major themes of the assessment, highlights the emerging threats and data gaps identified, and makes recommendations for future study.

PINN is a gem of volcanic rock formations and talus caves in a relatively intact Mediterranean climatic ecosystem dominated by chaparral vegetation. Visitors come to Pinnacles for many reasons including hiking, rock climbing, viewing condors, wildflowers and other life forms in their natural environment, and immersing themselves in wilderness. The surrounding landscape is primarily privately owned ranchlands, providing both an ecological buffer for the natural resources protected within the monument and a cushion of wide open spaces and scenery to ease visitors through the transition from highly developed areas. Working cooperatively with neighboring landowners and communities is considered a critical element for successfully managing Pinnacles into the future.

PINN was decreed a National Monument in 1908 to protect its unique geologic features. Through the years many other significant natural and cultural values have been recognized. PINN is a biological refuge for many Californian species, preserving a high species richness of many taxa. Recent efforts to manage culturally important plant species are bringing traditional ecological knowledge back to the landscape. Approximately 65% of Pinnacles' 27,000 acres are congressionally designated Wilderness, with additional areas remaining undeveloped. As California's human population continues to expand, the value of Pinnacles as a refuge for humans and other species will only increase.

The assessment followed an iterative process between NPS staff and the authors to identify the ultimate set of indicators of stressors and resources of greatest concern. Indicators are grouped hierarchically according to the NPS Ecological Monitoring Framework used by the NPS Inventory and Monitoring (I&M) Program. Prior to compiling spatial data and conducting the assessment, conceptual models were developed that characterize the natural and anthropogenic

drivers of environmental stressors that affect resource endpoints through ecological pathways. These conceptual models are valuable tools for communication of the cause and effect relationships and about what information is actually available about these ecological processes. The assessments of each stressor or resource were conducted by either spatial or statistical analysis. In some cases the assessment could model endpoints directly from environmental data to gain an understanding of the strength of hypothesized relationships. In many cases, however, where endpoint data were not available, the assessment was done on a midpoint indicator such as on stressors or ecological pathways. I&M or vital signs data were used as much as possible. Ecological processes operate at different spatial scales. Often a process such as a stressor beyond the park unit boundary has distinct consequences for the resources in the park. Therefore three reference scales were designated and the individual resources and stressors were characterized at one or more scales as appropriate. The "local" scale or reference region is the PINN boundary itself. For the "landscape" scale processes such as wildfire, a reference region extending 10 kilometers beyond the boundary was used. For "regional" drivers and stressors such as housing development, a grouping of "hydroecoregions" was used that encompasses most of Monterey and San Benito Counties and the southern part of Santa Clara County.

Table i. Summary of status, trends, and data confidence for indicators used in the condition assessment report. Confidence in data sources used in the assessment was rated High for primary (direct observation) data and Medium for modeled results.

INDICATORS	STATUS	REFERENCE CONDITIONS	TREND	DATA
STRESSORS				
Housing development	In 2000, average housing density in the region was 15 units/ km^2, which can be considered exurban. Average housing density at the park-and-buffer scale was 3 units/ km^2 but the number of units increased 53% from 1999 to-2000.	NA		High confidence
Road distance and accessibility	32% of PINN is within 1 km of a paved road. Riparian cover and invasive plant sections tend to occur much closer to roads than the average. Accessibility or travel time from the park entrances averages just under an hour.	NA		Medium confidence
Pesticides affecting amphibians	Application rates in the Salinas Valley of pesticides known to have adverse effects on amphibians are similar in magnitude to those of California's Central Valley where studies have attributed amphibian population declines in Yosemite and Sequoia/Kings Canyon National Parks to regional pesticide use. The amphibian chytrid fungus, a major factor in declines of California anuran populations, is potentially exacerbated by immunosuppressant effects of pesticides.	NA		High confidence
Rodenticides	Thousands of individual rodenticide applications are possibly being applied near PINN every year. The more lethal second generation rodenticides were applied infrequently. Rodenticides were applied within the foraging range of Prairie falcons (*Falco mexicanus*) and California condors (*Gymnogyps californianus*) that nest at PINN.	NA		High confidence

INDICATORS	STATUS	REFERENCE CONDITIONS	TREND	DATA
Human footprint	The footprint is generally low to medium intensity within the PINN boundary due to the absence of development or agriculture in or near the park unit. At the park-and-buffer scale, the intensity tends to increase. The larger region is more complex, ranging from high intensity in the urban Monterey Bay area and Silicon Valley to the west and north to low intensity further east in the inner coast ranges and near the Big Sur coastline.	NA		Medium confidence
AIR AND CLIMATE				
Air quality	Recent ozone concentrations are near the EPA non-attainment standard. Nitrogen and sulfur deposition rates are relatively low. However, chronic low level nitrogen loading could result in changes in lichen species over time.	75 ppb (EPA); <= 60 ppb is "good condition" (NPS) 0.25 kg/ha/yr is natural background; <1.0 kg/ha/yr is "good condition" (NPS standards); 5.5 kg/ha/yr is considered the critical load for lichen communities in California chaparral. 0.25 kg/ha/yr is natural background; <1.0 kg/ha/yr is "good condition" (NPS standards) 8 deciviews (5 year average deciview values minus estimated deciview values in the absence of human caused degradation)		High confidence
Climate	There were no directional trends in climate factors at PINN from 1948 to 2001. Minimum winter temperatures are projected to increase by 2.0–2.7ºC while maximum summer temperatures are projected to increase by 3.7–4.0ºC. Seasonality, a measure of temperature variability, is projected to	15ºC (mean annual temperature of past 50 years) 432 mm (average of past		Medium confidence

INDICATORS	STATUS	REFERENCE CONDITIONS	TREND	DATA
	increase by 7–16%. Precipitation projections are variable, either increasing or decreasing depending on the global climate model.	50 years)		
WATER				
Water quality	Water quality ranks among the most important indicators of ecosystem health. A large number of water quality indicators were sampled at eight sites in PINN in 2007 and 2008. In general, water quality indicators met regional standards, but there were occasional exceedances at some sites such as for E. coli bacteria. Emerging issues include aerial drift of agricultural pesticides, nitrogen deposition from expanding human activities, and the effects of climate change.	7.0–8.5 (CCRWQB) > 5.0 mg/L <log mean of 200 (minimum of not less than five samples for any 30 day period), nor shall more than ten percent of total samples during any 30 day period exceed 400/100 ml)		High confidence
BIOLOGICAL INTEGRITY				
Invasive plants	About 140 of approximately 675 plant species are nonnative. Several of these species are invasive, with the potential for creating serious ecological damage. Areas of highest exposure to invasions in weed control zones coincide substantially with land cover types that are most sensitive to invasion that occur along roads and trails.	None.		Medium confidence
Feral pigs	Relative pig abundance is relatively low or eradicated at the park scale. Habitat within the PINN boundary is moderately suitable for feral pigs, but they have been exterminated inside the pig fence. Lands within PINN that are outside the pig fence are also suitable habitat and may therefore harbor dense populations of pigs.	No pigs.		High confidence
Prairie falcon	Since 1989 there has been no statistically significant trend in the number of territorial pairs, nesting pairs, successful nests, or fecundity. Overall the prairie falcon population at PINN appears to be relatively stable.	Given the lack of trend and relative stability of the population, the mean occupancy rate and mean nest fecundity since 1989 is a reasonable reference condition.		High confidence
LANDSCAPES				

INDICATORS	STATUS	REFERENCE CONDITIONS	TREND	DATA
Fire regime	The fire rotation period is 265 years. Fire regimes are similar inside PINN and the surrounding landscape. Fire-size distributions suggest a small decrease in fire sizes for the period 1980–2008 compared to 1950–1979.	Chaparral vegetation is maintained by moderate fire return frequency of 20–80 years. Grassland and oak woodland community types may have experienced shorter return periods (10–25 years) historically). Burning typically occurred between June and October. California Indian peoples likely set intentional fires in this region.		High confidence
Future fire regime	Wildfire is sensitive to climate change and urban growth. Modeling predicts a marked increase in burned area by the end of this century in all scenarios at all three scales of analysis. Countering the potentially significant impact of increased fire on ecosystems may require substantial increases in fire management resources.	NA		Medium confidence
Habitat connectivity	PINN is contained within a Natural Landscape Block identified by the California Essential Habitat Connectivity Project, which is linked by an Essential Connectivity Area to another block at Pancho Rico Valley.	NA		Medium confidence
Habitat connectivity —badgers	Most of the highest suitability (grassland) habitat for badgers occurs outside PINN. Depending on traffic volume and effects on badger behavior, roads could represent a significant influence on badger distribution in portions of PINN.	NA		Medium confidence
Dark night sky	Skyglow as modeled from 1990 population data was relatively minor at PINN. Skyglow was less than Point Reyes and Santa Monica Mountains, but more than remote park units such as Death Valley and Yosemite. Local light sources such as campgrounds may have localized impacts on behavior of nocturnal predators and prey.	7 (no artificial light)		Medium confidence

 = baseline only  = no significant trend = increasing trend

The condition assessment identified a number of emerging issues that may become of greater management concern in the future. The most obvious of these is climate change from anthropogenic emissions of greenhouse gases. Modeling predicts that PINN will become similar to current conditions in the southern San Joaquin Valley in terms of growing degree days and temperature. Minimum winter temperatures in particular are forecasted to increase. Models are less consistent in forecasting precipitation changes. Most ecological resources in PINN would be affected by these changes in climate. The assessment found that the frequency of wildfire and the area burned annually would almost certainly increase, with consequent impacts on invasive plants and wildlife habitats. Climate change is likely to have direct effects on other resources or processes such as plant-pollinator phenology, range shifts of plant and animal species, and added stress on amphibians with changing precipitation and runoff patterns.

Other emerging issues are related to chemical contaminants, potential loss of connectivity in the larger landscape, and skyglow from regional metropolitan areas. The biological resources of PINN are exposed to a variety of contaminants. Fuel combustion in the region leads to nitrogen deposition, with current deposition levels at PINN equivalent to levels known to cause negative effects on lichens elsewhere in California. Pesticides known to have negative effects on amphibians are being increasingly applied to farmland in the region encompassing PINN. It is unknown how much of these chemicals are migrating (particularly from aerial drift) into the habitats of amphibians in the monument. Anticoagulant rodenticides are also being applied near development in the region to control rodents such as ground squirrels. Predators and scavengers who consume dead rodents then accumulate this toxin, which combined with other stressors, can have lethal effects. Raptors such as prairie falcons that nest in PINN forage far enough from the monument to be exposed. As development expands in the region, this issue may become more pronounced. Because of the low intensity of use of the landscape surrounding PINN, habitat connectivity remains relatively high. Park managers should be proactive in planning with neighboring land owners and agencies to ensure that such connectivity is not degraded from new activities. Metropolitan areas that have been growing also tend to emit more skyglow that brightens the nighttime sky. Although not devastating in itself, increasing skyglow can contribute to the cumulative stresses on some organisms. Local light sources such as at campgrounds are suspected of increasing the effectiveness of predation on California red-legged frog, which is a federally threatened species. Amphibians themselves are an emerging issue because of global and regional declines in many populations.

The report identifies data gaps that, if filled, would improve the usefulness of the stressor or resource condition indicators assessed in this report. These data would either improve the accuracy of the indicator value or in many cases provide trend information where only baseline values are currently known. Key data gaps include:

- Pesticides—the volumes applied on agricultural lands are known but the amounts transported into PINN such as by aerial drift and the levels in aquatic habitats have not been inventoried or monitored.

- Rodenticides— the volumes applied on agricultural lands are known, but the main use is around structures, which is not reported to the California Department of Pesticide Regulation. Moreover the levels accumulating in PINN predators foraging beyond the boundary is unknown.

- Air quality—the effects of low but chronic levels of nitrogen deposition on the diverse assemblage of lichens and other plant communities are not well-understood.

- Invasive plants—trend data are still too short and too geographically limited to determine whether non-native plants are expanding or whether recent control activities have had much impact on invasions.

- Feral pigs—pigs were exterminated within the pig fence, but the abundance and density of pigs in high suitability habitat in the unfenced portions of PINN are not known. The extent to which the pig fence may also be a barrier to some native wildlife (e.g., American badger) and a facilitator for human access into the backcountry and its associated impacts (e.g., invasive plants) is unknown.

- Without data on nest disturbance by rock climbers, it is not possible to test the effect of the raptor advisory system on prairie falcon fecundity in core areas. Compilation of regional data sets on prairie falcon trends would also be valuable for evaluating potential larger-scale environmental controls on prairie falcon abundance as well as the possible influence of immigration on population dynamics in PINN.

- Statewide connectivity modeling needs to be supplemented with species-specific modeling that accounts for their individual habitat affinities. Knowledge of these affinities needs to be compiled through literature review and expert consultation.

The assessment makes a number of recommendations for future analyses that were beyond the scope of this initial effort.

- Conceptual models developed for the assessment have highlighted the complex interactions of stressors on resource indicators plus the effects of changes in one indicator on another. Most of the analyses in the assessment are either simple GIS models of suitability or statistical models of time-series data that do not capture these synergies among stressors. The Human Footprint attempts to perform this synthesis by aggregating models of multiple stressors into an overall spatially-explicit representation of degree of human impact. The assessment also extracts data for PINN from a statewide model of the response of fire regime to climate (another resource indicator) and urban growth (a stressor). This level of synthesis is challenging both in the structure of the model and in quantifying the parameters of the interactions. Therefore the choice to extend modeling to this level must be made judiciously where the resources are high priority and the potential management actions are likely to be controversial.

- Habitat connectivity has been identified as important at multiple scales. A couple of studies have shown PINN to be a core area of a regional set of linkages or corridors. We recommend that park managers be engaged cooperatively with adjoining land owners to maintain viable and healthy working landscapes outside the monument.

Acknowledgments

We thank M. Koenen, former Inventory & Monitoring Program Manager of the San Francisco Bay Area Network, and P. Johnson, Wildlife Biologist at Pinnacles National Monument, for their assistance in preparing this report. Their help with data sources, contacts with resource staff, and prioritizing of resource issues was indispensable to this project. D. Kamradt from Santa Monica Mountains National Recreation Area provided additional guidance throughout the assessment process. The report benefited immensely from reviews by J. Albright, D. Graber, M. Davis, B. Johnson, R. Steers, and G. Emmons of the National Park Service. J. Kreitler assisted with GIS data management and analysis. A number of colleagues graciously provided data or advice about their area of expertise. We are very grateful to A. Westerling from the University of California-Merced who made his data available on response of wildfire to climate change and urban growth scenarios. A. Flint from USGS supplied downscaled data of climate change forecasts. D. Theobald and C. Davidson generously gave advice.

Prologue

Publisher’s Note: This was one of several projects used to demonstrate a variety of study approaches and reporting products for a new series of natural resource condition assessments in national park units. Projects such as this one, undertaken during initial development phases for the new series, contributed to revised project standards and guidelines issued in 2009 and 2010 (applicable to projects started in 2009 or later years). Some or all of the work done for this project preceded those revisions. Consequently, aspects of this project’s study approach and some report format and/or content details may not be consistent with the revised guidance, and may differ in comparison to what is found in more recently published reports from this series.

Commonly Used Abbreviations

Acronym	Definition
ARD	Air Resources Division (NPS)
BLM	Bureau of Land Management
CARB	California Air Resources Board
CEHC	California Essential Habitat Connectivity Project
CWHR	California Wildlife Habitat Relationships System
DDE	Dichloroethenylidene
DTR	Distance to roads
ECA	Essential Connectivity Area
ECI	Ecological condition index
EPA	Environmental Protection Agency (US)
GCM	Global climate model
GFDL	Geophysical Fluid Dynamics Laboratory
GDD	Growing degree days
GHG	Greenhouse gas
GIS	Geographic Information System
HCB	Hexachlorobenzene
IPCC	Intergovernmental Panel on Climate Change
I&M	Inventory & Monitoring (NPS)
MCB	Modified census block
NHD	National Hydrography Dataset
NLB	Natural Landscape Block
NLCD	National Land Cover Dataset
NPS	National Park Service
PAD	Protected Areas Database
PBG	Partial block group
PCB	Polychlorinated biphenyls
PCM	Parallel Climate Model
PINN	Pinnacles National Monument
PLSS	Public Land Survey System
UCSB	University of California Santa Barbara
USGS	United States Geological Survey
WY	Water year

Publisher's Note: Some or all of the work done for this project preceded the revised guidance issued for this project series in 2009/2010. See Prologue (p. xxi) for more information.

Chapter 1. NRCA Background Information

NRCAs Strive to Provide…

Credible condition reporting for a subset of important park natural resources and indicators

Useful condition summaries by broader resource categories or topics, and by park areas

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks". For these condition analyses they also report on trends (as possible), critical data gaps, and general level of confidence for study findings. The resources and indicators emphasized in the project work depend on a park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators for that park, and availability of data and expertise to assess current conditions for the things identified on a list of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement, not replace, traditional issue and threat-based resource assessments. As distinguishing characteristics, NRCAs:

- are multi-disciplinary in scope[1]
- employ hierarchical indicator frameworks[2]
- identify/develop reference conditions/values to compare current condition data against[3,4]
- emphasize spatial evaluation of conditions and GIS (map) products[5]
- summarize key findings by park areas[6]
- follow national NRCA guidelines and standards for study design and reporting products

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[1] However, the breadth of natural resources and number/type of indicators evaluated will vary by park

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition reporting by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions

[4] Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers")

[5] As possible and appropriate, NRCAs describe condition gradients or differences across the park for important natural resources and study indicators through a set of GIS coverages and map products

[6] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on a area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested

NRCAs also report on trends for any study indicators where the underlying data and methods support it. Resource condition influences are also addressed. This can include past activities or conditions that provide a helpful context for understanding current park resource conditions. It also includes present-day condition influences (threats and stressors) that are best interpreted at park, landscape, or regional scales, though NRCAs do not judge or report on condition status per se for land areas and natural resources beyond the park's boundaries. Intensive cause and effect analyses of threats and stressors or development of detailed treatment options are outside the project scope.

Credibility for study findings derives from the data, methods, and reference values used in the project work—are they appropriate for the stated purpose and adequately documented? For each study indicator where current condition or trend is reported it is important to identify critical data gaps and describe level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject matter experts at critical points during the project timeline is also important: 1) to assist selection of study indicators; 2) to recommend study data sets, methods, and reference conditions and values to use; and 3) to help provide a multi-disciplinary review of draft study findings and products.

Important NRCA Success Factors …

Obtaining good input from park and other NPS subject matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

NRCAs provide a useful complement to more rigorous NPS science support programs such as the NPS Inventory and Monitoring Program. For example, NRCAs can provide current condition estimates and help establish reference conditions or baseline values for some of a park's "vital signs" monitoring indicators. They can also bring in relevant non-NPS data to help evaluate current conditions for those same vital signs. In some cases, NPS inventory data sets are also incorporated into NRCA analyses and reporting products.

In-depth analysis of climate change effects on park natural resources is outside the project scope. However, existing condition analyses and data sets developed by a NRCA will be useful for subsequent park-level climate change studies and planning efforts.

NRCAs do not establish management targets for study indicators. Decisions about management targets must be made through sanctioned park planning and management processes. NRCAs do provide science-based information that will help park managers with an ongoing, longer term effort to describe and quantify their park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[7] and help parks report to government accountability measures[8].

NRCA Reporting Products…

Provide a credible snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

Due to their modest funding, relatively quick timeframe for completion and reliance on existing data and information, NRCAs are not intended to be exhaustive. Study methods typically involve an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in our present data and knowledge bases across these varied study components.

NRCAs can yield new insights about current park resource conditions but in many cases their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is credible <u>and</u> has practical uses for a variety of park decision making, planning, and partnership activities.

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[7] NRCAs are an especially useful lead-in to working on a park Resource Stewardship Strategy (RSS) but study scope can be tailored to also work well as a post-RSS project

[8] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget

Over the next several years, the NPS plans to fund a NRCA project for each of the ~270 parks served by the NPS Inventory and Monitoring Program. Additional NRCA Program information is posted at: http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm

Chapter 2. Park Resource Setting / Resource Stewardship Context

Introduction

PINN is a gem of volcanic rock formations and talus caves in a relatively intact Mediterranean climatic ecosystem dominated by chaparral vegetation. Visitors come to Pinnacles for many reasons including hiking, rock climbing, viewing condors, wildflowers and other life forms in their natural environment, and immersing themselves in wilderness. The surrounding landscape is primarily privately owned ranchlands, providing both an ecological buffer for the natural resources protected within the monument and a cushion of wide open spaces and scenery to ease visitors through the transition from highly developed areas. Cooperation with neighboring landowners and communities is considered a critical element for successfully managing Pinnacles into the future.

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Enabling Legislation

PINN was established by Presidential Proclamation in 1908, stating that "the natural formations, known as Pinnacles Rocks, with a series of caves underlying them…are of scientific interest, and it appears that the public interests would be promoted by reserving these formations and caves as a National Monument, with as much land as may be necessary for the proper protection thereof." Incorporated into the park were portions of the Pinnacles Forest Reserve, which was established by Presidential Proclamation in 1906.

After its establishment, a series of seven Presidential Proclamations between 1923 and 2000 led to land additions that increased the monument's acreage to near its current size. The most recent of these delineated additional features of significance, including streams and biological resources. In 2011 a minor boundary adjustment added another 115 acres and the historic Bear Valley School Hall.

Geographic Setting

PINN is located in the Inner Coast Ranges of Central California at the southern end of the Gabilan Mountains. It is nestled between the Salinas Valley and the Great Central Valley approximately 40 miles inland from Monterey Bay and about 100 miles south of the San Francisco Bay Area (Figure 1). The monument lies primarily within San Benito County, with extreme western portions in Monterey County. Areas adjacent to the monument are primarily agricultural; all but two of the towns or cities within 30 miles have fewer than 15,000 inhabitants. The exceptions are Salinas, 26 miles to the northwest with a population of 151,000; and Hollister, 23 miles north with a population of 35,000.

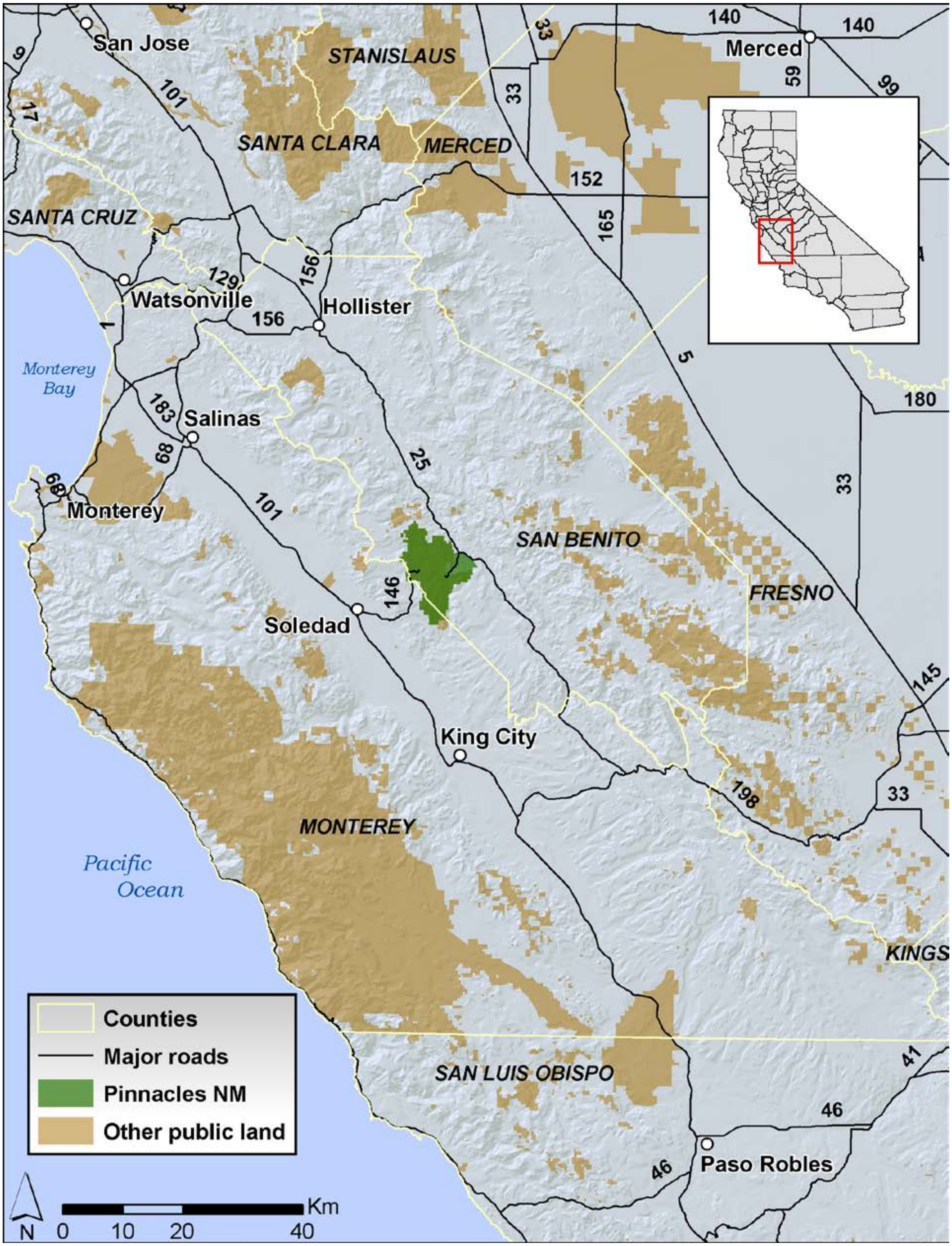

Figure 1. Location map of PINN.

PINN has a Mediterranean climate which varies considerably with the seasons and time of day. Typically, summers are hot and dry and winters are cool with moderate rainfall. Although the monument is 40 miles from the Pacific Ocean, the Santa Lucia Range mediates the ocean's influence. Consequently, summer temperatures of over 100°F with a daily temperature swing of 50°F are not uncommon, while high temperatures at the coast and even the nearby Salinas Valley may be 60°F. A reverse effect holds true in winter. The absence of the ocean's warming effect pushes the range below freezing inland while the coast remains relatively warm.

Annual average precipitation is approximately 16 inches per year. Nearly all of the precipitation is in the form of rainfall, with the vast majority occurring from October to April. Snow occurs in small amounts on the higher elevations infrequently between December and March. Thunderstorms also occur infrequently. There is moderate to severe lack of moisture during the summer months, though it is not uncommon for morning and evening fog to encroach upon the West Side of the monument and down through the valley of Chalone Creek.

PINN’s topography ranges from flat valley bottoms to rolling hills to rock spires to crags and cliffs. Although the terrain is mountainous with locally steep topography, the area is of generally low relief. Elevations in the monument range from less than 800 feet along Chalone Creek to 3,304 feet at the summit of North Chalone Peak. Hawkins Peak, at over 2,700 feet, is the tallest member of the centrally located group of pinnacles known as the High Peaks. The mean elevation of the monument is about 2,000 feet above sea level.

PINN is situated among resources well suited to public use. The region is famed for its scenic coastline and numerous recreational opportunities. The area within a 100-mile radius has a total of 427,600 acres of public lands. These lands are administered by Federal, State and local agencies and they provide for a diversity of recreational experiences. Commercial activities on lands adjacent to the monument are primarily cattle ranching, viticulture with some agriculture and tourism. The Salinas Valley to the west is one of the agriculturally richest zones in the world, as is the Great Central Valley farther to the east. Although the immediate area is sparsely populated, the monument is influenced by an expanding adjacent urban concentration, increasing the role of tourism in the local economy.

Visitation Statistics

PINN can be reached from the west by U.S. Route 101 and from the east by California State Route 25. Nearly six million people live within a 100-mile radius of the monument and about 20 million within a 200-mile radius (NPS 1999). About 85% of Pinnacles' visitors are from the San Francisco Bay Area.

The cool temperatures, abundant wildflowers and opportunities to view wildlife attract a large percentage of visitors in late winter and spring, with a small increase during the cooler months of fall.

Overall, annual visitation has remained fairly stable since the 1970s, averaging 170,000 people annually over the past 20 years and 154,000 over the past decade, with a peak of 194,755 visitors in 1993. Approximate visitation in 2008 was 166,988. Factors likely to affect visitation rates in any particular year include the weather, the economy, school schedules, and the price of gasoline. However, based on the long-term trends and the more important consideration of the surrounding region's population growth, it is likely that visitation will hold steady or slightly increase during the next 25 years. Cities in Monterey and San Benito Counties are expected to grow substantially during that time frame. Because PINN is visited heavily by the local and regional population, increasing population growth will likely affect visitation rates.

Natural Resources

Our understanding of natural resources at PINN has evolved over the years as we have learned more about the resources and how they interact with the ecosystem and our actions. The following summary is a snapshot of our current understanding of the important natural resources at PINN.

Ecological Units and Watersheds

PINN lies almost entirely within the Chalone Creek watershed which flows into the Salinas River and then empties into the Monterey Bay. Sandy Creek is the largest tributary of the Chalone Creek watershed, and more than half of Sandy Creek's drainage lies outside of the monument. The only substantial subwatersheds (drainage area > $1 km^2$) contained entirely within the monument are Frog Canyon, McCabe Canyon, and North Wilderness, though Bear Gulch, Lost Canyon, and West Fork Chalone are nearly so (Figure 2).

PINN is within one of only five regions in the world with a Mediterranean climate, characterized by warm, dry summers and cool, wet winters. In a study of reptiles and amphibians, Morafka and Banta (1976) described PINN as having five seasons, with spring divided into a cold, wet portion (March-April) and a warm, dry portion (May-June). They also noted that autumn is quite spring-like, with temperature and rainfall in October closely matching conditions in May.

PINN is located in a transitional zone between northern and southern as well as coastal and interior systems. Coastal fog influences the western portions of the monument and occasionally creeps along Chalone Creek and Bear Creek to reach the east side. Soil types interacting with other factors such as slope and aspect create desert-like conditions in some areas and much more mesic conditions in others.

The Pinnacles ecosystem is relatively intact. Vast expanses of chaparral cover much of the monument. Many areas are characterized by varied vegetation patches, creating a rich network of habitat edges. Most of the landscape has either not been grazed, or grazed only intermittently and at low intensity. Only portions of valley bottoms have been significantly altered by modern agriculture. Although exotic annual grasses and other non-natives are abundant in some vegetation types such as grasslands and oak woodlands, much of the monument has little to no presence of exotic plant species. And although the California grizzly and perhaps some other large mammals have been extirpated, the historic complement of wildlife species seems to be fairly intact. Thus, many of the intricate interspecies connections are still functioning.

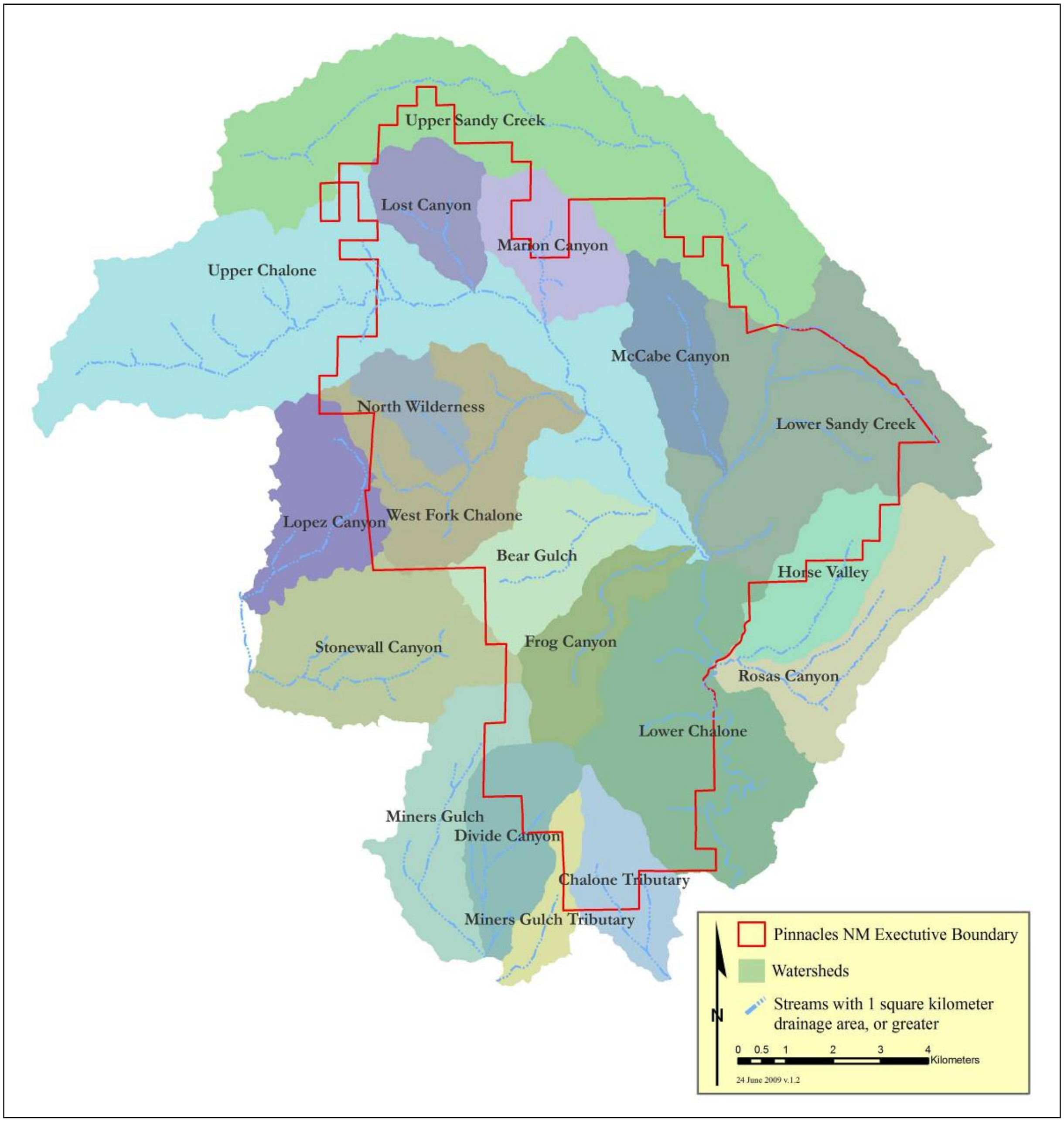

Figure 2. Map of watersheds of PINN larger than 1 km^2 (source: Denn and Ryan 2010).

Resource Descriptions

Geological Resources

PINN's volcanic formations are nationally exceptional and comprise the core of the monument. The volcanics are bordered on the east and west by faults, beyond which are granitic rocks typical of the rest of the Gabilan Mountain Range and marine sedimentary rocks formed in an inland basin as volcanic and granitic rocks were eroded away. A few marble outcrops occur on the West Side, remains of a much earlier time when the land was submerged beneath tropical seas.

Volcanic Spires

PINN derives its name from rock spires and crags that are eroded remnants of Oligocene-Miocene volcanic layers. These outstanding landscape characteristics, the “Pinnacle Rocks,” inspired the first conservation movement in the area and eventually led to Theodore Roosevelt’s declaration of Pinnacles National Monument in 1908. The Pinnacles themselves are formed from tilted, fractured, and deeply eroded layers of volcanic rock. The volcanic layers originated approximately 23 million years ago when quartz-rich lavas were forced to the surface through fissures in a basement of quartz diorite and granite and flowed out across a broad area to form a volcanic field. Later volcanic activity built up pyroclastics above the earlier lava flows. The western half of this volcanic field was eventually torn by the San Andreas Fault from its origin approximately 195 miles south (near Lancaster, California) and tilted and eroded over millions of years as it moved northward to its present position at PINN. Slowly, the erosive work of water and wind on the rhyolitic tuff and other pyroclastics, as well as other volcanic, sedimentary, and granitic rocks, gave rise to exceptional geologic forms and highly variable topography for which PINN is famous. These formations are significant for their scenic values; present an outstanding example of plate tectonics; and provide important habitat, particularly for nesting California condors, vultures, and birds of prey.

Caves

Erosion of the Pinnacles has produced talus cave formations unlike the more commonly occurring limestone caves or lava tube caves of the continent. Large boulders break from spires and cliffs, tumbling into steep gorges and forming talus jumbles on a grand scale. Caves occur where the largest interstitial spaces in these heaps of variable sized boulders remain relatively insulated from daily temperature extremes. The largest and most persistent caves have formed in places where huge boulders cap a section of narrow canyon. Intermittent stream erosion beneath the boulder ceiling keeps the cave floor open. The 520-foot-long Balconies Cave is an example of this type of geologic formation. The most outstanding cave in the monument, the 1700-foot-long Bear Gulch Cave, also originated in this fashion when volcanic tuff boulders capped the gorge.

The talus caves at PINN have multiple entrances and therefore greater air exchange and more light than most lava tube or limestone cave systems. However, the darkness and reduced air flow of the monument’s talus caves do form moderately stable microclimates in an area with widely varying temperatures. The caves are relatively cool and moist during hot and dry summer days, but also can be relatively warmer and drier during cold and rainy winter days. Because of their relatively moderate microclimates, the caves provide important habitat for bats, amphibians, invertebrates, and other wildlife. Their moderate level of air exchange creates conditions that allow Townsend's big-eared bats to use them to raise their young in the summer and to enter torpor in the winter. It is rare for this species to use the same cave in both winter and summer. Listed as a Species of Special Concern by the state of California, monument staff regulate visitation in order to prevent impacts to breeding or overwintering bats. Federally threatened California red-legged frogs (*Rana aurora draytonii*) also use Bear Gulch Cave during much of the year, though they are not known to breed there.

Rocks and Minerals

Because of its complex geologic history, including large offset along the San Andreas Fault, PINN harbors a diverse group of rocks and minerals. The Pinnacles themselves are primarily tuff, breccia, and ash of rhyolite, dacite, and andesite composition. Strata of contrasting texture or color are readily visible in several areas. Because of the rapid eruptions that formed the breccias, fragments of a diverse group of older rocks are also embedded within these volcanic rocks. The heat and compression of volcanic deposition also metamorphosed some inclusions. Among the rocks and minerals captured or formed in the strata are feldspars, pumice, and natural glass. Calcite deposits are also found within fractures of the volcanic rocks.

While the most visible of the monument rock types is volcanic, granitic outcrops are prevalent in western and southeastern portions of the monument. These granitic rocks were formed in Cretaceous time by slower cooling of magma deep below the Earth's surface and include quartz monzonite, quartz diorite, and granodiorite. The less abundant Gabilan limestone, a white coarse-grained marble with some gneiss, quartzite and schist, is found in thin, isolated bodies within the granitic rocks on the west side of the monument. These are the metamorphic remnants of Paleozoic reefs and coastal deposition that were intruded by the Cretaceous granitic magma. Widespread marine sedimentary rocks, consisting of eroded material (decomposed granite, volcanics, and some marine deposits) from adjacent areas, and in places forming unconsolidated sandstone cliffs make up the northern and eastern portions of the monument. Fragments of other rocks from historically eroded strata also occur in alluvium within the monument. This diversity of rocks has been an invaluable resource to regional geologists investigating the ancient history of the continent, and likely contributes to the biodiversity found within the monument.

Fossils

Fossils are not generally associated with volcanic rocks, but they can occur in some ash fall deposits or even as tree molds in lavas. Vince Matthews described an interesting fossil occurrence within the park. Ostracod fossils (small bivalved crustaceans) are rare to abundant in some of the tuff (consolidated volcanic ash) deposits northwest of Bear Gulch Headquarters. While many ostracod families are marine, some are found in freshwater or even damp leaf litter or soils. The discovery of ostracods, graded bedding, rip-up and flame structures suggest underwater deposition for the tuff yet it is still unknown whether these ostrocods are marine or freshwater derived. Additional fossil-like fragments, visible in thin sections, are found in the breccia in the northern area of the park (Elder et al. 2007). Further research into these occurrences will likely yield additional information.

Sedimentary rocks on the eastern edge of the monument contain diatomaceous mudstone, composed of fossilized diatom skeletons. Fossilized remains of plants, fish scales and fish bones have been found in these rocks (Ken Finger, pers. comm.) Similar fossils have been found in Sandy Creek, presumably washed in from outside the monument or brought in as road fill. Boulders of sandstone containing many mollusk and gastropod fossils are found in Needlegrass Canyon. These boulders are also washed into the park from Miocene sandstones to the east. A single cobble containing a mollusk fossil was found at the junction of Marion Canyon and Chalone Creek, probably washed into the monument along Marion Canyon from a known mollusk locality north of the monument.

Faults

PINN is located along the boundary of the Pacific and North American Plates, an area of significant tectonic activity. This movement of the Earth's crust has formed many faults—geologic fractures where masses of rock and earth slip past one another. Three large faults occur within the area of the monument: Chalone Creek, Pinnacles, and Miner's Gulch. The Chalone Creek Fault is believed to have been an ancestral strand of the San Andreas Fault, which is now located about a mile east of the monument's eastern boundary. Faulting and related forces have tilted major strata, and preferred erosion of rocks crushed by fault motion formed deep, narrow gorges in the monument.

Small to moderate earthquakes are frequently felt within the monument and seismic activity continues to be monitored by the United States Geological Survey (USGS). There is a seismometer along the Chalone Creek Fault and a corresponding seismograph in the Bear Gulch Nature Center that provides a continuous record of seismic activity.

Soils

Soil is the loose mineral and organic material that supports plant growth and performs many critical biotic and abiotic functions. The bedrock has been transformed into diverse soils, many endemic to the monument. Soil types are categorized according to several factors including parent material (alluvium, granite, sedimentary rock, or volcanic rock), landform (flood plains, stream terraces, valley floors, and toe slopes, back slopes, and summits of hills), and aspect. A recent soil survey mapped 38 different soils here (USDA 2007). The steepness of slope, acreage, and percentage of the monument covered by each soil type is given in Table 1.

The upland PINN soils are typically thin, undeveloped sandy loams with large amounts of gravel and little ability to retain nutrients and water. Nutrient supply is low but well balanced. Much of the monument's soil is derived from coarse-grained granites and is highly erodible because it contains very little binding material. Less erodible areas of soil rich in humus lie within the base of some canyons and in the bottomlands, but typically average only two feet in depth. The soils offer little resistance to root growth, thus allowing extensive root development. These properties tend to increase moisture loss from the soil, causing less water to be available for plant cover. When plant cover is disturbed, soils become acutely susceptible to erosion during periods of intense rainfall. All soils in the monument are described as well- to excessively-drained.

Table 1. Acreage and extent of soils at PINN.

Soil Name	Acres	Percentage of park
Ordeal-Passion-Badlands association, 50 to 100 percent slopes	3,171	11.7
Knuckle-Burgundy-Argixerolls complex, 20 to 70 percent slopes	1,573	5.8
Chalone-Firstsister-Highpeaks complex, 50 to 70 percent slopes	1,207	4.5
Casino-Argixerolls complex, 50 to 70 percent slopes	436	1.6
Casino sandy clay loam, 20 to 35 percent slopes	114	0.4
Rock outcrop-Highpeaks-Burgundy complex, 35 to 100 percent slopes	1,498	5.5
Knuckle-Chalone-Burgundy complex, 35 to 70 percent slopes	149	0.5
Backdoor-Tuborcio complex, 20 to 70 percent slopes	3,768	13.9
Rimtrail sandy loam, 0 to 5 percent slopes	60	0.2
Elder-Oxyaquic Haploxerolls complex, 2 to 5 percent slopes	32	0.1
Ordeal-Tuborcio-Passion complex, 20 to 50 percent slopes	2,094	7.7
Tuborcio loam, 2 to 20 percent slopes	185	0.7
Elder gravelly sandy loam, 0 to 1 percent slopes	154	0.6
Still clay, 0 to 2 percent slopes	46	0.2
Elder coarse sandy loam, 1 to 3 percent slopes	69	0.3
Tuborcio sandy loam, 35 to 50 percent slopes	790	2.9
Teapot-Rock outcrop complex, 35 to 50 percent slopes	191	0.7
Argixerolls-Rock outcrop-Chalone complex, 35 to 50 percent slopes	623	2.3
Still-Riverwash complex, 0 to 2 percent slopes	98	0.4
Firstsister-Oxyaquic Haploxerolls-Rock outcrop complex, 0 to 50 percent	21	0.1
Toags-Oxyaquic Haploxerolls-Riverwash complex, 0 to 2 percent slopes	254	0.9
Toags-Pinncamp complex, 0 to 5 percent slopes	80	0.3
Toags gravelly coarse sand, 2 to 9 percent slopes	59	0.2
Toags-Riverwash complex, 0 to 9 percent slopes	109	0.4
Oxyaquic Haploxerolls, 0 to 1 percent slopes	20	0.1
Rock outcrop-Highpeaks-Chalone complex, 35 to 50 percent slopes	730	2.7
Highpeaks-Rock outcrop complex, 35 to 50 percent slopes	282	1.0
Ordeal-Longsfolly-Passion complex, 9 to 50 percent slopes	3,803	14.0
Badlands	59	0.2
Backdoor-Tuborcio complex, 35 to 50 percent slopes	2,143	7.9
Backdoor sandy loam, 9 to 20 percent slopes	163	0.6
Chalone-Knuckle-Rock outcrop complex, 35 to 50 percent slopes	651	2.4
Chalone-Knuckle-Firstsister complex, 50 to 70 percent slopes	1,716	6.3
Pinnacles coarse sandy loam, 5 to 30 percent slopes	175	0.6
Pinnacles stony sandy loam, 30 to 75 percent slopes	29	0.1
Pinnacles coarse sandy loam, 15 to 30 percent slopes	164	0.6
Pinnacles coarse sandy loam, 30 to 75 percent slopes	240	0.9
Santa Lucia channery loam, 30 to 75 percent slopes	139	0.5
Total	27,095	100.0

Air Quality

High air quality is a defining feature of the monument and an important resource. Plants such as blue elderberry (*Sambucus mexicana*) and mugwort (*Artemisia douglasiana*), as well as many lichens, are more sensitive to air quality degradation. Clean air directly enhances visitor enjoyment, and good visibility of landscape features enhances visitor understanding and appreciation of natural systems. The designation of PINN as a Class I Airshed indicates the importance of high visibility to the appreciation of the monument. The high air quality is supported by proximity to the coast (35–40 miles) and a surrounding buffer of rural landscapes. Although the air quality is good at present, some indicators have shown a declining trend. Recent and ongoing growth of urban areas within the Salinas Valley and the southward expansion of the Silicon Valley metropolitan area reduce the distance between pollution sources and the monument.

The region's climate is strongly influenced by the North Pacific High Pressure System which typically migrates north each spring and south each autumn, influencing the direction of winds and storm systems arriving from the ocean. Summers at Pinnacles, the season when the most particulates are in the air, are typically hot and dry during the day, with infrequent winds. However, coastal fog often moves inland during the evenings and night, providing some mixing to the air. Additionally, during periods of low air movement, pressure sometimes forms inland, leading to irruptions of easterly winds. These winds push pollutants out to sea, but may also carry dust and particulates from the San Joaquin Valley into the monument. Most winds in the region, however, result from a combination of the offshore high-pressure system and lower pressure inland, resulting in westerly to northwesterly winds throughout much of the year. Less frequently, northerly winds and a persistent inversion layer draw air pollutants from Silicon Valley and the Santa Clara Valley into the monument.

Hydrologic Resources

Because PINN is situated in an arid, chaparral-dominated mountain range, its limited water resources are of particular value to biodiversity and visitors.

Streams

The terrain in the Gabilan Range is rugged and deeply dissected. Therefore, no regular drainage pattern has developed. Rather, streams are controlled by fault traces and fractures at intersecting angles. Many of the smaller streambeds in the monument are arroyos, dry except after significant rain. Chalone Creek, Bear Gulch Creek, Sandy Creek, and an unnamed stream in McCabe Canyon have stretches of perennial surface water, though above-ground flow may be very low during summer months.

Originating approximately 4 miles northwest of the NPS boundary, Chalone Creek flows the length of PINN from the northwest to the southeast corner. Approximately 70% of the Chalone creek drainage above its confluence with Sandy Creek lies within PINN, while about 40% of the Sandy Creek subwatershed lies within PINN (Figure 2). Nearly all of PINN's 41.4 square miles drains into Chalone Creek, which empties to the southwest into the Salinas River, in turn flowing northwest into Monterey Bay.

PINN protects the full length of streams in Frog Canyon and McCabe Canyon. However, most streams have significant segments on private lands. Furthermore, major creeks have been altered along some portion of their length. Chalone Creek is unimpeded throughout its course in the monument, but its uppermost branches on private lands are impounded in ponds. Sandy Creek has multiple earthen dams within its watershed both inside and outside of the monument. Though most of its length lies within PINN, Bear Gulch Creek is impounded behind a dam within the monument built during the CCC era.

Periodically, heavy rains cause extensive flooding within the monument. There have been three large floods in the Chalone Creek watershed during the past three decades, including a recent 40-year flood event in 1998. These have caused millions of dollars in damage to park facilities. Some sections of stream experienced considerable erosion, whereas others experienced high sedimentation. These stream processes may be viewed as negative or destructive as far as human development on the landscape is concerned, but they are natural processes that have shaped the landscape for millennia, and they are critical for maintaining certain habitats in stream channels and flood plains. Frequently-flooded areas at PINN tend to support a high diversity and abundance of plants and animals, and many species would exist at PINN only rarely or not at all if it were not for these natural processes.

Some of the physical characteristics that make this watershed prone to erosion and flash flooding also make it susceptible to water quality degradation. Alluvial sands conduct water and also potentially pollutants quickly and with little buffering. Also compounding these issues, the narrow canyons have forced human facilities to be located very close to surface waters. On the other hand, the streams seem to be well buffered, reducing their sensitivity to acidification from reasonably foreseeable levels of S and/or N deposition. And the aquatic macroinvertebrate fauna indicates that the streams are healthy.

Water Chemistry

Groundwater chemistry is affected by the substrate through which the water flows. Three geohydrologic units are present at PINN: 1) granitic and metamorphic rocks, 2) volcanic rocks — the Pinnacles Formation, 3) and porous sedimentary rocks — the Temblor Formation. The volcanics are regionally unique. This, combined with the diversity of other rock types, has the potential to produce unusual groundwater chemistry. This can be expressed in the water that emerges from seeps and springs, as well as in sections of stream where groundwater upwelling occurs.

Subterranean Water

When surface streams have gone dry in the summer months, groundwater continues to flow through the valley alluvium. This alluvium, with a depth of at least 38 feet (12 m) in places, is permeable and of high hydrologic conductivity. Where the valley crosses a resistant rock unit, groundwater is often brought to the surface in perennial pools.

Where groundwater upwelling occurs within a flowing stream, unique conditions may exist within the interstitial spaces in the alluvial sand and gravel. An undescribed species of *Eremidrilus* worm found at PINN may be just such a species. It has nephridia (kidney-like organs) unlike any other member of its genus, suggesting adaptation to specific water quality conditions (Steven Fend, USGS, pers. comm.)

Seeps and Springs

Nine springs including Superintendent's Spring, Chalone Bridge Spring, and Oak Tree Spring, were known and marked within the monument prior to the 2000 and 2006 park boundary expansions. Recently acquired lands have not been fully inventoried for hydrologic resources, but a minimum of five spring-fed wetlands occur in McCabe Canyon, the bottomlands, and the Pinnacles Campground. Additional small seeps may appear seasonally in wetter years. Springs generally occur along fault lines (as with Willow Spring) and along rock fractures or lithologic contacts. Springs are no longer used as domestic water supplies for facilities due to their inadequate water production.

Within a chaparral dominated landscape, the wetlands associated with these springs act as oases during hot and dry summer and autumn months. In addition to supporting a high diversity of plants, these wetlands provide important forage, resting, or rearing habitat for amphibians, butterflies, Neotropical migrant birds, and other wildlife that move through the park.

In addition to their contribution to water availability, seeps and springs may provide water with unusual chemical characteristics. A new species of *Stygobromus* amphipod known only from a single spring at PINN may be adapted to the particular water chemistry conditions there. In 2006 the USGS completed a study of water quality in seven springs within the monument (Borchers and Lyttge 2007). The tritium analysis suggested that spring water at PINN may be extremely old, but this topic requires further investigation (James Borchers, pers. comm.) A detailed table of the 2006 USGS spring water quality sampling data is available at: http://pubs.usgs.gov/ds/2007/283/table2.html.

Artificial Reservoirs

Bear Gulch Creek is impounded behind a dam within the monument built by the Civilian Conservation Corps in the early 1930's. Due to low input during the dry season, the 2.7-acre Bear Gulch Reservoir is stagnant for much of the summer and is subject to eutrophication. The reservoir is not used for domestic purposes, although it is now important habitat for federally threatened California red-legged frogs. Because this frog has been eliminated from over 70% of its historic range and most natural habitat has been significantly altered, such artificial habitats are valuable for maintenance of the regional population and conservation of genetic diversity within the species.

Five earthen dam stock ponds are found on lands acquired in 2000, plus two more on private property within the legislative boundary. One of these dams has already failed and another is near failing. Federally threatened California tiger salamanders have been observed at two of the ponds, with breeding confirmed at one. Fairy shrimp also occur in these ponds, but they have yet to be collected and identified to determine whether they are sensitive species.

Water Use

Four wells supply all of the monument's drinking water. Bear Gulch, Chalone, and Peaks View facilities are serviced by a well on a hillside near Peaks View. This well is believed to tap into the fracture zone of the Chalone Fault (Mike Martin, WRD, pers. comm.) This fault may be the source of water for fault-associated springs in the campground and McCabe Canyon as well as upwelling in Chalone Creek. The West Side Chaparral district is serviced by a deep artesian well that is pumped by both solar power and a back up propane generator. The new West Side facilities near the west entrance are serviced by a new well in that area. A fourth well at the northwest corner of the Pinnacles campground supplies water to the campground and bottomlands facilities. This well taps into alluvial water in Sandy Creek and was drilled in 2010 to replace a nearby well that failed. Additional wells exist in the monument, but do not provide public drinking water. All wells supplying potable water for staff and the public are chlorinated and monitored and maintained on a routine basis.

Total water use from all wells in 2006 was 3,101,614 gallons. No comprehensive study has been made of total private and federal water consumption in the watershed and the potential effects of use on long-term aquifer sustainability.

Water Rights

No adjudications of water rights have been initiated by the State of California within the vicinity of the monument. If such action were to occur, park water uses would need to be quantified, including consumptive needs of visitors and park administration, and needs for water-dependent resources such as for federally threatened California red-legged frog habitat and the hydrologic character of talus caves, which are integral to the monument's original declaration under the Antiquities Act.

<u>Biological Resources</u>

PINN is located in the heart of the California Floristic Province, a region noted for a high degree of biodiversity and endemism. The region's flora and fauna originated from both northern temperate and southern xeric elements. Over evolutionary time, the combination of a long-term equable climate with recurrent climatic fluctuations, diverse soil and terrain conditions, and geologic activity such as mountain uplift and faulting, has created ideal conditions for the evolution of new species as well as the survival of relict species (Raven and Axelrod 1978). Many of these factors are evident at PINN.

Although much of the monument is underlain by volcanic soils, faulting has juxtaposed different soil types on the eastern and western edges. Some species are restricted to, or more abundant on, certain soil types.

The steep terrain with hills and canyons in various orientations produces a variety of microhabitats. Species with xeric and mesic affiliations can be found in close proximity to each other on opposite sides of canyons. Vegetation associations tend to be heavily interdigitated, creating a complex patchwork of habitats with a rich network of habitat edges. This provides a diverse array of available niches.

The mild Mediterranean climate provides beneficial conditions for plant growth and animal activity throughout much of the year. Many taxa such as bees and annual plants “timeshare,” taking turns by occupying a space for only a short time window.

Even as dry as PINN is, its aquatic systems host a surprising level of diversity. Several miles of perennial streams support species that require year-round flow. Intermittent streams support species that thrive in warmer water and get out before the stream dries up. Ponds, springs, and seeps add additional types of aquatic habitat. Even within a single habitat type, niche diversity appears to be high, as evidenced by the unusual co-occurrence of three congeneric caddisfly species in Chalone Creek.

Groundwater chemistry is heavily influenced by geology, so it stands to reason that PINN’s regionally unique geology would produce correspondingly distinctive groundwater. The aquatic faunal assemblage is composed of species common to surrounding areas as well as endemic species likely adapted to these unusual groundwater conditions.

Species endemic to the PINN region include the Gabilan slender salamander *(Batrachoseps gavilanensis)*, big-eared kangaroo rat *(Dipodomys elephantinus)*, Pinnacles shield-back katydid *(Idiostatus kathleenae)*, and Pinnacles riffle beetle *(Optioservus canus)*.

A new species of jewelflower *(Streptanthus)* is being described from PINN, and has been found nowhere else. Moth inventory work has turned up several species that have defied identification and may represent undescribed species. A sphinx moth *(Euproserpinus sp.)* currently under study may be new to science and is only known from the monument and a few locations within 100 miles to the south. A new species of *Eremidrilus* worm is known only from Chalone Creek, and a newly discovered *Stygobromus* amphipod is known only from a single spring at PINN.

The relatively intact state of the Pinnacles ecosystem has allowed the majority of its species to persist in the face of large-scale changes in much of California. Good air quality supports the continued existence of lichens and other species sensitive to air pollution. Natural processes such as flooding and fire persist on the landscape, maintaining spatial and temporal heterogeneity of habitats. Most of the landscape has either not been grazed, or grazed only intermittently and at low intensity. Only portions of valley bottoms have been significantly altered by modern agriculture. Although exotic annual grasses and other non-natives are abundant in some vegetation types such as grasslands and oak woodlands, much of the monument has little to no presence of exotic plant species. And although the California grizzly and perhaps some other large mammals have been extirpated, the historic complement of wildlife species seems to be fairly intact. Thus, many of the intricate interspecies connections are still functioning.

Vegetation

Although Pinnacles takes up about one-tenth of 1 percent of the land mass of California, nearly 10 percent of all plant taxa in the state are represented within the monument (Hickman 1993). Over 650 vascular plant taxa have been documented at PINN, and many species continue to be discovered. In addition to the vascular plant flora, 293 species of lichens are known to occur in the monument. Although little is known about the diversity of mosses, it has been projected that

Pinnacles may have approximately 125–175 of the 600 mosses currently documented for California (Norris and Shevock 2004).

Links to species lists of lichens and vascular plants are available at: http://www.nps.gov/pinn/naturescience/plants.htm.

Special Status Plants

Although there are no state or federally listed plants known to occur at PINN, 14 plants are listed as rare by the California Native Plant Society (Table 2; CNPS 2001). A new species of *Streptanthus* being described from PINN has been found nowhere else and will likely be added to this list. Nineteen species of lichens that occur in the monument are listed as rare by the California Lichen Society. A particularly rare species of lichen found at PINN, *Texosporium sancti-jacobi*, is known from only a few sites in the world, has been ranked as critically endangered, and is included on the Global Red List of Lichens by the International Committee for the Conservation of Lichens (Thor 1996).

Table 2. California Native Plant Society-listed vascular plants documented within PINN.

Common Name	Scientific Name	CNPS Rank
Douglas' spineflower	*Chorizanthe douglasii*	4.3
coast larkspur	*Delphinium californicum* ssp. *interius*	1B.2
virgate eriastrum	*Eriastrum virgatum*	4.3
protruding buckwheat	*Eriogonum nudum* var. *indictum*	4.2
San Benito poppy	*Eschscholzia hypecoides*	4.3
Indian Valley bush mallow	*Malacothamnus aboriginum*	1B.2
Paso Robles navarretia	*Navarretia jaredii*	4.3
slender nemacladus	*Nemacladus gracilis*	4.3
hooked popcorn flower	*Plagiobothrys uncinatus*	1B.2
slender pentachaeta	*Pentachaeta exilis* ssp. *aeolica*	1B.2
Brewer's clarkia	*Clarkia breweri*	4.2
Pinnacles buckwheat	*Eriogonum nortonii*	1B.3
spring lessingia	*Lessingia tenuis*	4.3
dark-mouthed triteleia	*Triteleia lugens*	4.3

Vegetation Zones and Types

Twelve generalized vegetation types can be grouped into five major vegetation zones in PINN (Figure 3, Table 3). An updated vegetation map and classification of the monument was completed in 2009.

Chaparral: Comprising more than 80% of the monument's vegetation, chaparral is characterized by a dense layer of shrub species with few or no trees and a sparse herbaceous understory. Chaparral is well adapted to tolerate the hot dry summers of a Mediterranean climate. Common chaparral shrubs are: chamise *(Adenostoma fasciculatum)*, buckbrush *(Ceanothus cuneatus)*, manzanita *(Arctostaphylos glauca* & *Ar. pungens)*, holly-leaved cherry *(Prunus ilicifolia* ssp. *ilicifolia)* and black sage *(Salvia mellifera)*. Chaparral plants have adapted strategies to survive and thrive in this harsh environment, including water storage structures, small waxy-coated leaves and deep taproots to reduce water loss, and summer dormancy to minimize transpiration during the arid summer months.

Fires in chaparral tend to be intense and tend to scorch all aboveground vegetation. Some plants such as chamise are able to rapidly re-sprout from their bases after fire, while other chaparral shrubs such as buck brush will vigorously germinate after fire. Some species such as Indian Valley bush mallow *(Malacothamnus aboriginum)* and golden ear-drops *(Dicentra chrysantha)* require fire to germinate.

Oak Woodlands/Savannas: This vegetation type is dominated by either blue oaks *(Quercus douglasii)* or valley oaks *(Q. lobata)* with a dense understory of herbaceous annuals. The herbaceous layer is generally dominated by non-native annual grasses (such as *Bromus* spp., *Vulpia* spp., *Avena* spp.) Native perennial grasses and forbs remain scattered throughout the oak woodlands. Oak woodlands are found in the monument in flat to steep sloping areas and alluvium where soils are deeper than where chaparral is located. Most valley oaks in the monument occur in the bottomlands along Sandy Creek.

Oak savannas provide food for many species of animals within PINN. Acorns, fruits, seeds and vegetative parts of these plants provide food throughout the year. Many species of small mammals that use the chaparral as a home will venture out into the oak savannas to forage.

Riparian Woodlands: The riparian vegetation type is restricted to the moist canyon bottoms, generally where surface water flows seasonally or intermittently. Dominant species in this type include sycamore *(Plantanus racemosa)*, coast live oak *(Q. agrifolia)*, willow *(Salix* spp.), and Fremont's cottonwood *(Populus fremontii)*.

Grasslands: Grasslands in PINN are dominated by a dense layer of herbaceous plants with shrubs and trees playing a limited role in the type. The grasslands are dominated by Mediterranean annual grasses with scattered non-native forbs and native annual and perennial grasses and forbs. Some of the grassland areas that occur on the steeper slopes may be present due to frequent burning of chaparral sites (NPS 2005). McCabe Canyon contains intact native grasslands and sedgebeds. Several species, including deergrass (*Muhlenbergia rigens*),white-root sedge (*Carex barbarae*) and chia (*Salvia columbariae*) are highly valued by Mutsun, Chalon and other California Indian peoples to maintain cultural practices such as for use in basket weaving and nutrient rich food sources. Such large stands of these ethnobotanically important species are now considered rare in California (NPS 2010).

Rock and Scree: Vegetation in this type is dominated by sparsely scattered herbaceous species. Soils are thinner and tend to have fewer non-native species than in the other herbaceous-dominated vegetation types in the monument. Although these areas appear rather sparse, they are relatively rich in species diversity.

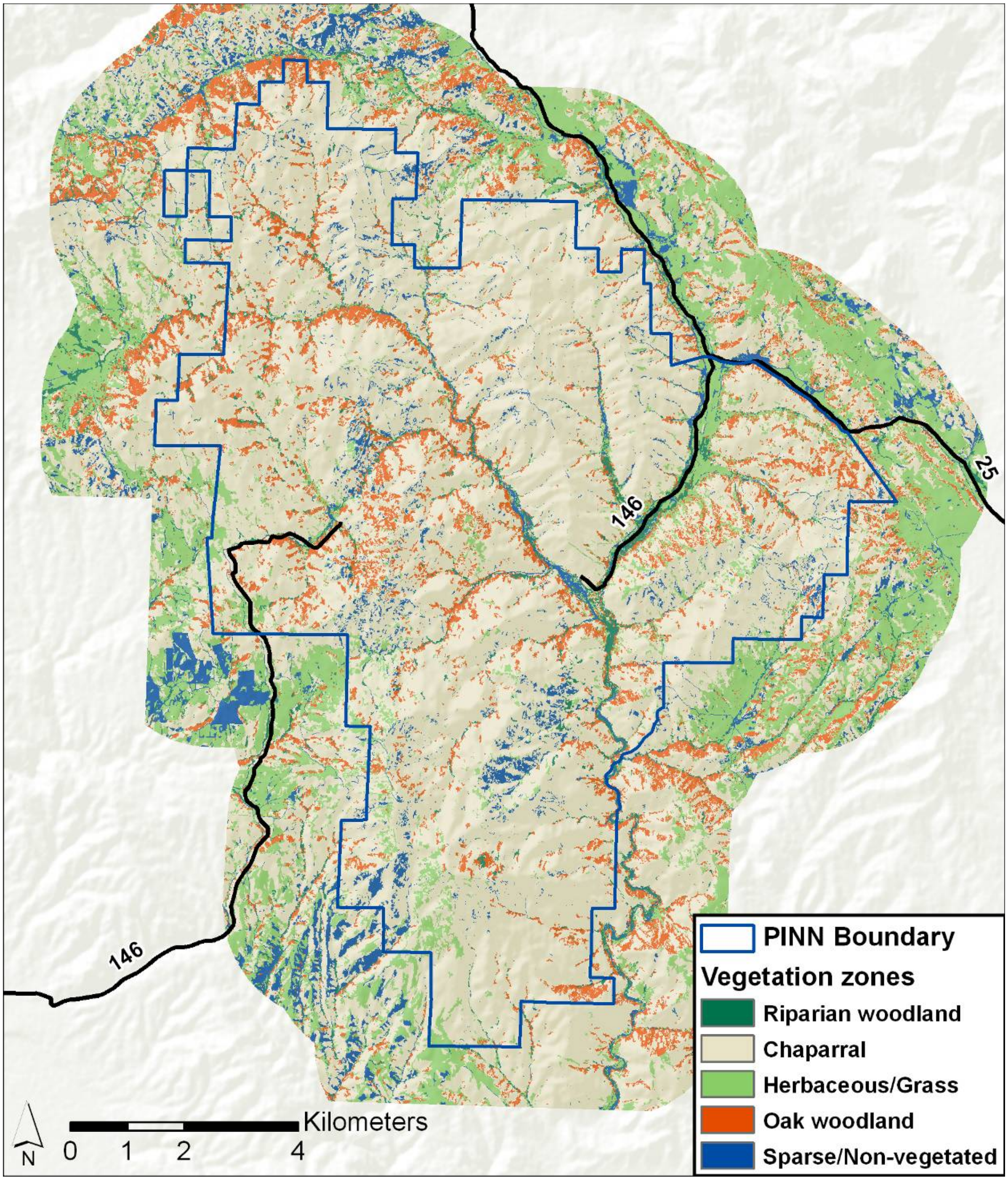

Figure 3. Map of vegetation zones in PINN generalized from the map of vegetation types.

Table 3. The five vegetation zones and 13 major vegetation types found within PINN.

Zone	Preliminary Alliances
chaparral	coastal sage scrub
	mixed chaparral
	chamise chaparral
	manzanita chaparral
	hollyleaf cherry chaparral
oak woodland/savanna	blue oak woodland
	valley oak woodland
riparian woodland	riparian woodland
	southern oak woodland
	California buckeye woodland
grassland	grassland
scree and rock	herbaceous

Human Influences

With over a century as a national park unit, vegetation at PINN has historically been and continues to be directly and indirectly influenced by human activities. These activities include: changes to the natural fire regime, invasion by non-native plants and animals, air pollution, disturbance/erosion from routine park operations, and climate change. These activities have played a critical role in shaping the current vegetation patterns in the monument.

Local indigenous peoples likely engaged in land use practices such as burning and cultivation to manage the landscape, significantly influencing native species assemblages. Over 100 plant species that occur within the monument have been documented as being traditionally used for medicine, subsistence, manufacturing and other purposes (Bocek 1984). Certain species, such as deergrass *(M. rigens)* and Santa Barbara sedge *(C. barbarae)*, were frequently cultivated by Indian peoples to produce basketry materials. Without knowledge or perpetuation of the practices of local indigenous peoples, the composition, spatial array and extent of vegetation communities in particular have likely changed.

Wildlife

PINN is a refuge for biodiversity of wildlife species as well as genetic variability within species. The highest diversity of lizards (8 species) west of the Sierra Nevada and north of the Tehachapi Range is found here (Morafka and Banta 1976). The monument provides habitat for 46 native mammals, including 14 of California's 24 bat species. There are 84 native species of birds confirmed or believed to nest at PINN, and an additional 35 migrant birds regularly occur here. Invertebrate species include 69 species of butterflies, more than 450 species of moths, and more than 250 species of aquatic invertebrates, including 40 dragonflies. A remarkable 400+ bee species have been documented within a 25 square mile area at PINN. Many more invertebrate species await discovery.

Links to wildlife species lists are available at:
http://www.nps.gov/pinn/naturescience/animals.htm.

Special Status Species

Many wildlife species at PINN are federally- or state-listed, or are otherwise considered to be of special status for protection. The only federal endangered species at PINN, California condor *(Gymnogyps californianus)*, is now breeding here for the first time in more than a century as a result of the Pinnacles California Condor Recovery Program, initiated in 2003. The park is one of five release sites of captive bred juveniles being released back into the wild and the only national park unit managing a flock. The condors regularly range outside the monument and mix with birds released by the Ventana Wildlife Society along the Big Sur coast. Management concerns include the presence of lead in the form of spent lead ammunition in carcasses and other contaminants in the environment on a geographic scale well beyond the monument boundary. The high level of public interest in the recovery of condors, coupled with the ease of viewing them in the wild at PINN, has brought an influx of visitors focused on enjoying nature. PINN staff members have taken advantage of this opportunity to increase public appreciation of our natural resources and the complex issues involved in protecting them.

Two federally listed threatened species occur within the monument. The California red-legged frog breeds in streams and ponds. Because a strong pond-breeding component is thought to be necessary for the long-term sustainability of a population, a re-establishment project was conducted at the Bear Gulch Reservoir from 2001 to 2003 and the population there has persisted. The California tiger salamander *(Ambystoma californiense)* breeds in stock ponds and summers underground in mammal burrows in grasslands and oak woodlands. It breeds in stock ponds on the monument.

A considerable number of wildlife species found at PINN are listed by the California Department of Fish and Game as California Species of Special Concern, others on their Special Animals List, and a few are considered by PINN management to be worthy of special protection (Table 4). Of all species that currently occur at PINN, the following percentages of major vertebrate groups have special status: 18% of nesting birds, 24% of mammals, 19% of reptiles, and 50% of amphibians.

Extirpations and Restoration

Historically grizzly bears and perhaps wolves and black bears all occurred at PINN. Jaguars may also have ranged here. These large mammals have not been seen in the area for a century or more. Given current land use patterns in the region, it may not be feasible to re-establish wolves, bears, or jaguars to the Gabilan Mountains and is not a consideration for the park.

Two other species extirpated from the monument during the 20th century are either being reintroduced or are a candidate for re-establishment to Pinnacles. California condors were observed regularly in the monument until the 1930s, with Condor Gulch bearing their name. The Pinnacles Condor Recovery Program, initiated in 2003, is currently re-establishing a breeding population at the monument.

Table 4. Special status wildlife species at PINN.

Taxon	CNDDB *	Status	Notes
Pinnacles shield-back katydid *(Idiostatus kathleenae)*	G1G2 S1S2		Locally endemic
Pinnacles riffle beetle *(Optioservus canus)*	G1 S1		Locally endemic; also found near PINN
primrose sphinx moth *(Euproserpinus* new sp.*)*			Undescribed species; northernmost locality
cave amphipod *(Stygobromus* new sp.*)*			Locally endemic; known from one spring
Gabilan slender salamander *(Batrachoseps gavilanensis)*			Locally endemic
California tiger salamander *(Ambystoma californiense)*	G2G3 S2S3	ST, FT, CSC	Confirmed breeding, 2008
Western spadefoot *(Spea hammondii)*	G3 S3	CSC, BLM:Sensitive	Attempted breeding, 2005
California red-legged frog *(Rana draytonii)*	G4T2T3 S2S3	FT, CSC	
foothill yellow-legged frog *(Rana boylii)*	G3S 2S3	CSC, BLM:Sensitive, USFS:Sensitive	Extirpated; re-establishment?
Southwestern pond turtle *(Emys marmorata pallida)*	G3G4 S3	CSC, BLM:Sensitive, USFS:Sensitive	
Coast horned lizard *(Phrynosoma blainvillii)*	G4G5 S3S4	CSC, BLM:Sensitive, USFS:Sensitive	
Silvery legless lizard *(Anniella pulchra pulchra)*	G3G4T3T4QS3	CSC, USFS:Sensitive	
San Joaquin coachwhip *(Masticophis flagellum ruddocki)*	G5T2T3 S2?	CSC	
two-striped garter snake *(Thamnophis hammondii)*	G3 S2	CSC, BLM:Sensitive, USFS:Sensitive	Not confirmed.
California condor (Gymnogyps californianus)	G1 S1	SE, FE, FP, USFS:Sensitive	Re-establishment in progress
Cooper's hawk *(Accipiter cooperi)*	G5 S3	CSC	
sharp-shinned hawk *(Accipiter striatus)*	G5 S3	CSC	
golden eagle *(Aquila chrysaetos)*	G5 S3	CSC	
white-tailed kite *(Elanus leucurus)*	G5 S3	FP, FWS:MNBMC	
American peregrine falcon *(Falco peregrinus anatum)*	G4T3 S2	FP, FWS:BCC	
prairie falcon *(Falco mexicanus)*	G5 S3	Audubon:Cal WL, FWS:BCC	
long-eared owl *(Asio otus)*	G5 S3	CSC	
burrowing owl *(Athene cunicularia)*	G4 S2	CSC, FWS:BCC	Two sightings, no nesting
Nuttall's woodpecker *(Picoides nuttallii)*	G5 SNR	Audubon:Cal WL, FWS:BCC	
olive-sided flycatcher *(Contopus borealis)*	G4 S4	CSC, Audubon:Cal WL, FWS:BCC	
loggerhead shrike *(Lanius ludovicianus)*	G4 S4	CSC, FWS:BCC	

Table 4. Special status wildlife species at PINN (continued).

Taxon	CNDDB *	Status	Notes
Yellow-billed magpie *(Pica nuttalli)*	G3G4 S3S4		
Oak titmouse (*Baeolophus inornatus)*	G5 S3?	Audubon:Cal WL, FWS:BCC	
yellow-breasted chat *(Icteria virens)*	G5 S3	CSC	Nesting unconfirmed.
grasshopper sparrow *(Ammodramus savannarum)*	G5 S2	CSC	Confirmed in Bottomlands, 2008
pallid bat *(Antrozous pallidus)*	G5 S3	CSC, WBWG:High, BLM: Sensitive	
Townsend's big-eared bat *(Corynorhinus townsendii)*	G4 S2S3	CSC, WBWG:High, BLM: Sensitive	
hoary bat *(Lasiurus cinereus)*	G5 S4?	WBWG: Medium	
Western red bat *(Lasiurus blossevillii)*	G5 S3?	WBWG:High	
Western small-footed myotis *(Myotis ciliolabrum)*	G5 S2S3	WBWG: Medium, BLM: Sensitive	
long-eared myotis *(Myotis evotis)*	G5 S4?	WBWG: Medium, BLM: Sensitive	
fringed myotis *(Myotis thysanodes)*	G4G5 S4	WBWG:High, BLM: Sensitive	
long-legged myotis *(Myotis volans)*	G5 S4?	WBWG:High	
Western mastiff bat *(Eumops perotis)*	G5T4 S3?	CSC, WBWG:High	
Big-eared kangaroo rat *(Dipodomys venustus elephantinus)*	G3G4T2 S2	CSC	
American badger *(Taxidea taxus)*	G5 S4	CSC	

* In the California Natural Diversity Database (CNDDB) ranking, the spatial scale is indicated by G=Global and S=State, and the severity of threat is indicated numerically from 1=Critically Imperiled to 5=Secure; T refers to taxonomic levels below species, and Q indicates questionable taxonomy. In the Status: ST=State Threatened, SE=State Endangered, FT=Federally Threatened, FE=Federally Endangered, CSC=California Species of Special Concern, FP=Fully Protected in California, BCC=Birds of Conservation Concern, WBWG=Western Bat Working Group, WL=Watch List. *Source:* California Department of Fish and Game 2011.

Foothill yellow-legged frogs (*R. boylii*) are also unlikely to return to the monument without active management efforts. These frogs were present in the park up until at least the 1940s, but the cause of their extirpation is unknown and the extent of suitable habitat at PINN needs to be evaluated. Re-establishment efforts would involve translocation of egg masses or tadpoles from the nearest genetic stock, which has been identified in areas to the east and southeast.

One species formerly extirpated from the monument, the peregrine falcon, has successfully returned due to both active hacking and dispersal enabled by regional recovery efforts. From 1989–1991, seven peregrine falcons were cross-fostered into prairie falcon nests at the monument. However, it was more than a decade before peregrines returned to breed at Pinnacles. A single pair of peregrines has nested in the monument every year since 2005.

Status of the Western spadefoot *(Spea hammondii)* and California tiger salamander is currently being assessed to determine whether habitat modification may have resulted in declines of this species within the monument, and whether translocations from another site or habitat restoration are necessary for maintenance of the Pinnacles population. The situation with the latter species is further complicated by the presence of non-native tiger salamanders in the PINN area. H. B. Shaffer (University of California, Davis) has been collaborating with PINN Resource Management to develop an experimental program to modify breeding habitat in an attempt to improve the situation.

Fire

Fire is a key natural process in the PINN ecosystem, with effects that include maintaining species diversity, sustaining fire-dependent plant and animal species, controlling insects and disease, and reducing invasive species populations. Altering the fire regime disrupts ecosystem-regulating processes, pushing the ecosystem into an unnatural state. We have limited knowledge of past fire history at PINN, including the frequency, size, and ecosystem effects of fires.

Native Americans in this region are known to have actively used fire as a management tool to improve yields of plant foods, enhance quality of basketry materials, facilitate harvests, increase visibility of predators and prey, reduce the threat of wildfires adjacent to settlements, and possibly to reduce frequency of insect pests. Fires of varying intensity and size were used depending on the objective. This set of strategies may have led to a diverse mosaic of vegetation communities in varying stages of succession. Because it is believed that most burning was conducted in valley bottoms, it remains unclear the degree to which these human induced fires influenced upper mountain slopes.

The ancient upland fire history may have been more influenced by lightning, probably causing infrequent autumn fires (Greenlee and Moldenke 1982). Available evidence suggests an average of one large fire (>2,500 acres) every nine years in the Gabilan Mountains and a reported fire return interval of 40 years. Today, the highly flammable chamise cover increases the potential for large lightning fires.

The primary general vegetation types at the monument are chaparral, oak woodland, grassland, riparian, and rock/scree. Of these, chaparral is by far the most prevalent, covering roughly 80% of the monument’s land area. In this habitat type, plant life demonstrates several adaptations to reoccurring fires. For example, many species of manzanita are able to resprout after fires, ceanothus produces seeds at an early age and has roots that are specially adapted to grow in recently burned areas, chamise also readily resprouts after fire and produces a portion of seeds that require intense heat stress to germinate, whereas lupines are able to fix nitrogen from the atmosphere (fires reduce available soil nitrogen). Generally, chaparral plants sprout and grow quickly and spread rapidly. Additionally, the structure, chemical composition, and low moisture content of mature chaparral encourage the rapid, complete combustion of chaparral shrubs in summer or fall fires, opening the landscape for growth of a new generation of plants. Other habitat types in the monument also demonstrate adaptations to periodic burning. Blue oaks re-sprout vigorously after fires and mature valley oaks survive low- to moderate-intensity fires. Oak post-fire regeneration is also benefited by animal dispersal of acorns. Monument vegetation communities are therefore adapted or resilient to fire influence. Currently, prescribed burning is used in grassland systems in the monument as a tool to control invasive species and restore native ecosystems.

Natural Darkness

The night sky over PINN has been identified as an asset, contributing to the monument's pristine landscape. Preserving this critical resource is important for the protection of the ecosystem, as well as for visitor enjoyment. The natural darkness at Pinnacles is among the best in the greater Bay Area, primarily due to the rural nature of the area (low population density, few organized communities) as well as being in a Class I Airshed (the air is clean and clear).

Natural Soundscapes

The soundscape is the total acoustic environment of an area. It often varies in its character from day to night and from season to season. PINN is generally a quiet landscape, with occasional short-term interruptions of the natural quiet.

The natural soundscape is an important resource and a critical component of the ecological communities the monument seeks to preserve. Understanding the role of sound in a healthy ecosystem is critical to effective management and protection. Studies suggest that the acoustic environment is important for intra-species communication, territory establishment, finding desirable habitat, courtship and mating, nurturing and protecting young, predation and predator avoidance, and effective use of habitat.

Resource Issues Overview

The current condition of the PINN ecosystem is the result of many factors, both past and present. These factors range in geographic scale from local, such as light and noise pollution in the campground, to global, such as climate change. And they vary in their mode of action from direct, such as non-native pigs eating native plant bulbs, to indirect, such as non-native yellow starthistle creating a dense thatch that increases predation on small mammals because they can no longer see predators at a distance.

Vegetation

Intensive uses such as tilling and grazing by domestic animals as well as fire suppression, particularly in the bottomlands, has likely altered the plant assemblages within grasslands. These areas are degraded with a dominance of invasive non-native plant species and require active management to restore greater native plant diversity and density.

Non-native plants invade an estimated 4,600 acres of federal land every day and already infest millions of acres in the national parks (NPS 1996). Over 15% of the approximately 650 plant species in Pinnacles are non-native. Several of these plants now completely dominate areas that once contained a much greater diversity of native species. Invasive species can rapidly spread from Pinnacles to adjacent lands outside of the park and inflict environmental and economic harm on other agencies and private landowners. Invasive plants will continue to change Pinnacles living resources if efforts to prevent their introduction and contain their spread are not maintained.

Non-native plants can be introduced into an area either accidentally or intentionally. Some species of common cultivated plants, such as periwinkle *(Vinca major)* and blackberry *(Rubus* *discolor)*, were intentionally planted at homesteads and have since begun to spread into natural areas. Other species such as yellow starthistle *(Centaurea solstitialis)* were accidentally introduced to California and have rapidly spread throughout the state. Stinkweed *(Dittrichia graveolens)* is a recent discovery and likely was accidentally introduced within contaminated fill material or heavy equipment associated with the rebuilding of the Chalone Creek bridge after it was destroyed during the 1998 flood event.

Invasive plant populations have been treated in the monument since the mid-1990s. These species include: yellow starthistle, field mustard *(Hirschfeldia incana)*, horehound *(Marrubium vulgare)*, Italian thistle *(Carduus pycnocephalus)* and other species. Although invasive plant control efforts have been effective at slowing the spread of invasives into uninfested areas, efforts must continue and expand in order to reduce their impacts. Recent land additions on the east side of the monument have increased the total acreage that is infested with invasive species. On the east side of the monument, the bottomlands area is a 250 acre grassland and valley oak savannah heavily infested with yellow starthistle and other highly invasive weeds. In 2009, the park initiated control of the invasive species in this site using multiple techniques including prescribed burning, herbicide, timed mowing and prescribed goat grazing. Additionally, the park began to test revegetation techniques in the site to determine what species and approaches may be most effective at larger scales. Non-native animals, such as wild turkeys *(Meleagris gallopavo)* and feral pigs, also play a role in altering the vegetation in Pinnacles. Little is known about how wild turkeys affect native vegetation in California, but multiple studies have examined the effects of feral pigs on vegetation in California and indicate that they do significantly alter native vegetation.

Habitat Fragmentation

Conversion of rangelands surrounding the monument into high intensity agriculture and suburbs or residential ranchettes is fragmenting regional habitat. Such fragmentation threatens sustainable population sizes of wildlife species with large home ranges. These species include the American badger *(Taxidea taxus)* and California condor. Viability of these and other species is threatened over the long-term if sustainable populations cannot be maintained in an area as small as PINN’s 27,000 acres.

Park Development

Within the monument itself, the concentration of development and visitor use in riparian areas has been and continues to be a threat to wildlife. Although riparian areas constitute only a small percentage of the landscape, many wildlife species depend on them for at least a portion of their life cycles. For some species, the mere presence of humans in riparian areas is enough to keep them from using an area. The location of roads, parking lots, and septic systems along streams impacts wildlife and water quality in many ways. The presence of buildings, roads, and trails in riparian woodlands requires occasional removal of trees deemed hazardous to humans. Such removals decrease available habitat for species that depend on tree resources.

The concentration of roads and development in riparian areas at PINN focuses these effects in these more sensitive areas. With the acquisition of the new bottomlands, the monument increased its amount of riparian habitat, but also increased the total amount of development in riparian areas. The Pinnacles Campground and Highway 146 along Sandy Creek are all examples on the new lands of threats to riparian habitats and the species that depend on them.

Light Pollution

Light pollution from developed areas and vehicle headlights may interfere with behavior of terrestrial and aquatic wildlife, potentially resulting in community level effects (Longcore and Rich 2004). Nocturnal species evolved with natural nighttime light sources such as the moon and stars. Any additional light sources may disrupt their activities. For example, elevated light levels make it easier for predators to see their prey, and the navigation of nocturnal animals such as moths is impeded by unnatural light sources.

Because light pollution levels fall off exponentially with distance from the source, small local sources can have locally greater effects than large distant ones. Currently, most buildings in the monument have outside lights that remain on all night. Although these lights are shielded to prevent light pollution from entering the sky, stray light often affects the surrounding area.

These localized examples of ecological light pollution can be contrasted with astronomical light pollution which lights up the sky and obscures the visibility of celestial objects. Recent population growth with its associated artificial lighting has degraded natural darkness. Light trespass from towns such as Hollister, Soledad, Greenfield, King City, and Salinas are visible to the naked eye. Research by the NPS Night Sky Team also shows light trespass from San Jose, Visalia, Fresno, Bakersfield, and even Los Angeles. However, the greatest external source of light pollution at PINN is from the Salinas Valley State Correctional Facility near the town of Soledad.

Currently no lighting ordinances have been enacted by neighboring communities. Though much of the area surrounding the park is rural, development is ongoing. Further growth without anticipatory planning will lead to an increase in light pollution at PINN. NPS hopes to stave off this obstruction by providing an example of night sky-friendly practices and educational efforts.

Noise Pollution

Noise pollution is influenced by atmospheric conditions, topographic features, and distance from the source. As with light pollution, noise pollution may originate from both internal and external sources. The primary external source of pollution at PINN is aircraft. A major jetway follows State Highway 25 (also known as “Airline Highway”) just east of the monument, causing regular disruptions of the soundscape throughout the day. Smaller planes and helicopters periodically fly at low elevation over the monument, despite aircraft flight restrictions instituted to protect the California condor. Military aircraft are also seen with some frequency.

Internal sources of noise pollution include park staff, visitors and their vehicles. Large groups of hikers can attain high noise volumes, especially within the caves. Aspects of monument operations, particularly heavy equipment and vehicle back-up safety beepers, can be heard up to a mile away from developed areas.

Air Pollution

The Clean Air Act provides the primary authority for protecting and enhancing the nation's air quality. In 1977, Congress amended the Act to prevent significant deterioration of air quality in clean air areas of the United States and to protect visibility in designated areas. The Pinnacles were included within a Class I area, a categorization that provides for the greatest restrictions to air pollutants. This designation requires federal land managers to protect the air quality-related values of the monument from air pollution impacts.

The NPS Air Quality Office and EPA established a monitoring station near the east entrance of PINN in 1987. Particulate and ozone monitoring has been continuous since that time. Additionally, as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network, visibility in the monument has been monitored using an automatic 35mm camera (1986–1995), a transmissometer (1988–1993), and an aerosol sampler (1998–present).

The monument also has a Remote Automated Weather Station located in Grassy Canyon and an official weather station located at the base of Condor Gulch. This station has provided long-term data, but the spatial variation in weather and climate has not been researched. Due to the limited instrumentation and lack of historical climate data, the monument lacks a detailed portrait of local microclimates.

The principal air pollutants of concern for PINN are ozone precursors and particulates. (SO2 emissions are not high.) The major point sources of emissions in the region are located near communities that are not adjacent to PINN, e.g., energy facilities in San Ardo and Moss Landing. Within Monterey and San Benito counties, non-point sources of pollution are the most significant.

The rate of urban and suburban growth in the Pinnacles region may lead to a significant increase in pollution during the coming years. The 2000 census of San Benito County showed a growth rate of 71% over the preceding 10 years. Monterey County's growth rate for the same period was 13%.

PINN currently uses petroleum fuel vehicles for most of its small fleet of transportation vehicles and heavy machinery, though several electric vehicles and a gasoline-electric hybrid vehicle are now in use. Petroleum fueled vehicles contribute an unidentified portion of the local air pollutants. Current practices are such that little pooling of government vehicle trips appears to occur among staff. The same is apparent with staff commuting in personal vehicles. Often there is one person per vehicle, however, a significant portion of staff also live in the park near headquarters. New facilities on the Westside are also increasing administrative vehicle use. More punctuated NPS pollution sources are prescribed fires. However, these roughly replicate an historical pollution source and are seasonally timed with permission from the California Air Resources Board. Campground fires and visitor automobiles often represent the most significant pollution sources within the monument. Finally, furnaces providing heat to monument residences, offices, and shops are regular, though minor sources of air pollutants.

Programs at the monument also work to minimize pollution sources. These include operation of a shuttle service that reduces the number of personal vehicles driving from the campground to the main trailheads in Bear Gulch. The monument has installed solar panels to power the campground/VC well, and the new West Side visitor contact station is entirely off the grid and LEED Platinum certified. While this effort may not measurably reduce pollution inside the monument, it will stand as an important symbol of our commitment to sustainability and serve as an example to visitors. Outreach encouraging conservation within the region's communities may also contribute to pollution reduction.

Exotic Animals

Other threats include introduction and/or expansion of invasive exotic species: e.g., feral pigs, bullfrogs, green sunfish, argentine ants, sudden oak death, yellow starthistle, summer mustard, diseases, parasites, etc. Visitors may bring in exotic species by carrying seeds or plants in on their shoes or tires, or even by deliberately introducing them (releasing pets, planting seeds, etc.) Park activities that may bring in invasive species include construction work using heavy machinery and fill material and importation of soil with restoration planting of nursery-grown plants.

Feral pigs have likely caused more destruction than any other non-native wildlife species at PINN. It is thought that escaped domestic hogs went feral as early as the late 1700s after Spanish missionaries brought livestock into Central California. These feral hogs later bred with descendants of the European wild boar which were brought into the Gabilan Mountains and adjacent Central Coast regions during the early 20th century. Hunters caught pigs and released them into new areas, hoping to create additional hunting opportunities. Many of the pigs survived and expanded their range as populations grew in size. By the 1970s, feral pigs were regularly documented in the monument. Significant impacts were recorded, such as destruction of wetland vegetation at wallows, tilling of soils, and limitation of oak reproduction. In response, PINN began constructing an exclosure around 14,500 acres of the monument's core in 1985. The fence was completed in 2003 and by mid-2006 all pigs were eradicated from within the exclosure by cooperator Institute for Wildlife Studies. In 2011 the monument constructed 9 miles of fence to enclose an additional 3000+ acres, including important springs and riparian areas in McCabe Canyon into the campground and bottomlands areas. This newly enclosed area is expected to be pig-free by the end of 2012.

Two additional non-native mammals, the house mouse *(Mus musculus)* and opossum *(Didelphis virginiana)* are uncommon and not considered threatening to the PINN native ecosystems.

Seven non-native species of birds occur at PINN. Most conspicuous are the flocks of non-native wild turkey. Introduced to the region multiple times in the past century as a game animal, the Rio Grande variety has flourished in recent decades. Although no population studies have been done on wild turkeys at PINN, anecdotal observations suggest that as many as a hundred may inhabit the monument. In addition to vast quantities of seeds (primarily acorns), turkeys are known to consume amphibians, reptiles, and invertebrates. Turkeys are thereby a direct threat to several rare or sensitive species. Two additional non-native birds commonly occur in the monument: European starling *(Sturnus vulgaris)* and rock pigeon *(Columba livia)*. Starlings are cavity nesters and thereby compete with native species for a limited resource. Rock pigeons are known to nest within the monument but are not believed to have an adverse affect on native birds. Brown-headed cowbirds *(Molothrus ater)* are uncommonly seen in the monument. They are nest parasites who limit the productivity of Neotropical migrants and other native songbirds. House sparrows *(Passer domesticus)* have been intermittently documented in the park in low numbers. Chukars *(Alectoris chukar)* are considered uncommon and may have been recently extirpated. Eurasian collared doves (*Streptopelia decaocto*) were first recorded here in 2009 and appear to be expanding their range within the monument. Research is needed to determine the level of impact these seven non-native birds have on native Pinnacles species and habitat.

Several non-native fish species have been documented at PINN in the past century but currently only mosquitofish (*Gambusia affinis*) remain, inhabiting the lower few miles of Chalone Creek. Although their presence probably has a minor impact on California red-legged frogs, eradicating them is currently impractical because there is nothing to prevent re-infiltration by populations downstream of the boundary. Non-native catfish (*Ameiurus sp.*) inhabited the Bear Gulch reservoir briefly during the late 20th century and were eradicated in the mid-1980s by draining the reservoir. Also, in the mid-1990s non-native green sunfish (*Lepomis cyanellus*) infiltrated Chalone Creek and lower Bear Gulch. They were considered a major threat to California red-legged frogs, and were removed by electroshocking in 1998–1999. Bluegill (*Lepomis macrochirus*) were found and eradicated in Sandy Creek in 2006, presumably washed in from upstream stock ponds during a recent flood. Rapid response to such invasions is considered crucial to control efforts. Two other fish historically in the monument that were apparently naturally extirpated are fathead minnow *(Pimephales promelas)* and Sacramento perch *(Archoplites interruptus)*. Further research is necessary to determine if Sacramento perch, a California native, may be native to this area.

Argentine ants *(Linepithema humile)* are not established at PINN, but a colony was inadvertently brought in and quickly eradicated in 2004. Despite their small size, these non-native ants are a major threat to California ecosystems. They aggressively displace many native ant species, causing cascading impacts to many species including horned lizards (which feed on large native ants), native plants (some of which rely on native ants for pollination and seed dispersal), and many invertebrate species (through predation, competition for resources, disruption of commensalisms, etc.) It is likely that without vigilant efforts to prevent future introductions, Argentine ants will eventually become established at PINN. However, it is likely that they would be restricted to areas in the vicinity of water or moist soil, leaving much of the monument without direct impacts (Ward 1987, Kennedy 1998).

<u>Cattle</u>
Cattle, while neither feral nor regularly found trespassing at PINN, have also impacted the landscape. Prior to designation of the monument, grazing in the 19th century resulted in expansion of alien plant populations. Grazing continued on some lands into the 2000s, prior to their annexation to the monument. Intensive grazing followed by complete exclusion of grazers can often lead to domination of non-native annual grasses and invasive plant species. This effect is apparent on some PINN lands. Grazing continues to this day on privately owned ranches adjoining the monument on all sides. The rugged terrain and lack of boundary fencing in many areas have made it difficult to keep cattle from periodically wandering into the monument, though efforts are underway in cooperation with adjacent landowners to fence cattle out of some remote areas between the pig fence and the boundary.

Other factors that may threaten the PINN ecosystem include pesticide drift, water pollution, animal poisoning, use of lead ammunition within adjacent open spaces, poaching, increased traffic, receding water table, and global climate change.

Resource Stewardship

The PINN Natural and Cultural Resources Management Plan (NPS 1999) does not include specific management directives or planning guidance. However, Foundation Statements with Fundamental Resources and Values have been developed for the draft PINN General

Management Plan. General Management Plan workshops have also identified some direction for future resource management efforts. The NPS I&M Program vital signs selection process has provided the most specific guidance on indicators and natural resources requiring close attention. In addition, PINN has embarked on a Resource Stewardship Strategy for natural and cultural resources in 2012, tiering off this document and the GMP.

Management Directives and Planning Guidance

Park purpose and significant statements have been drafted during the General Management Planning process (Table 5). Portions not pertaining to natural resources have been omitted. This is a general guidance document and does include desired conditions and some management target values.

Approximately 60% of PINN is federally designated Wilderness (Figure 4) and additional areas are managed as wilderness. An area south of the Pinnacles Campground is a special Resource Management Zone closed to the public, and a portion of McCabe Canyon has been proposed as a Resource Management Zone to facilitate cultural and ecological restoration there. Bear Gulch Cave is under an adaptive closure schedule that allows visitor access to the cave while also protecting a colony of Townsend's big-eared bats. Portions of the cave are opened to visitors seasonally as the bats move elsewhere. The Raptor Advisory Program identifies areas in which visitor entry is likely to cause disturbance to breeding cliff-nesting raptors. Visitors are requested to voluntarily stay out of these areas, and the advisories are lifted for each raptor territory as soon as the risk of disturbance has ended.

The following outlines the general emphasis of natural resource management efforts at PINN over the past decade and into the foreseeable future:

- Conducting baseline studies, inventories, research, and long-term monitoring.
- Managing visitor access in certain areas to protect sensitive resources.
- Re-establishing extirpated native species (California red-legged frog, California condor) and removing of exotic species (yellow starthistle, Italian thistle, feral pigs).
- Protecting and restoring riparian areas.
- Protecting geologic resources and processes.
- Managing fire to protect structures, lives, property, and to achieve desired resource conditions.
- Monitoring air quality: particulates, ozone, and visibility.
- Working cooperatively with surrounding neighbors, communities, local agencies, associated tribes, and organizations to protect regional resources.

Table 5. Park purpose and significance statements for PINN.

Park Purpose

The purpose of Pinnacles National Monument is to protect the Pinnacles Volcanic Formation, talus caves, associated lands and ecosystems for their scientific, educational and cultural values, by caring for their natural processes and wild character and providing opportunities for public enjoyment and understanding of these resources.

Park Significance

Pinnacles National Monument contains a remnant of an ancient volcanic field that was split and off set approximately 195 miles by the movement of two continental plates and provided key evidence for the theory of plate tectonics.

Fundamental Resources and Values:

- The Pinnacles Volcanics – remnants of ancient volcanic layers, containing eroded rock spires, cliff s, ledges and grottos.
- Physical evidence of plate tectonics and faulting – steep terrains, uplifted and tilted layers, spires eroded from fractured rock, varied landscapes, springs, narrow canyons, landslides and associated features.
- Knowledge about Pinnacles geology and plate tectonics – cumulative knowledge and opportunities for understanding the features and processes.

Pinnacles National Monument contains the most extensive assemblage of accessible rare talus caves within the National Park System and cares for the natural processes and ecosystems within.

Fundamental Resources and Values:

- Talus caves – structures and physical processes
- Ecosystems within the caves—including temperature, water, animals.
- Knowledge about the talus caves – cumulative knowledge and continued opportunities for understanding the geologic and ecologic features and processes.

Pinnacles Wilderness protects the natural character of central California's native ecosystems and provides opportunities to experience wildness in an area of expanding urban development.

Fundamental Resources and Values:

- Wilderness attributes—undeveloped land with high quality viewsheds, natural soundscapes, night skies, class 1 air quality, natural smells, and natural systems.
- Scenic viewsheds – dramatic views of the Pinnacle Rocks formation and the surrounding geologic landscapes.
- Inspiration and challenge provide varied opportunities for primitive recreation and solitude in wild settings.

Intact ecological processes and communities of Pinnacles National Monument, including oak savanna, riparian and chaparral ecosystems, provide a refuge for the exceptionally diverse native flora and fauna within the Gabilan ecoregion.

Fundamental Resources and Values:

- **Dynamic natural processes occurring at Pinnacles National Monument including, erosion, flooding, fire and tectonic activity.**
- **Diverse assemblage of native species.**
- **Integrity of native habitats, including living and nonliving components and the interactions among theme.**
- **Pinnacles National Monument's role as a component of larger interdependent ecosystems.**
- **Cumulative knowledge of natural systems and stressors.**

Table 6. Park purpose and significance statements for PINN (continued).

Other Significance / Important Fundamental Resources and Values	**The Native American archeological and ethnographically significant resources of Pinnacles National Monument are preserved within their ecological context and provide opportunities to study and continue traditional practices and resource management.** **Pinnacles National Monument still reflects the historically significant dry land subsistence agriculture practiced by homesteaders from the early period of American settlement in California.** **The development and character of Pinnacles National Monument were strongly influenced by the grassroots efforts that established the national monument, and by the work of federal unemployment relief programs including the Civilian Conservation Corps.** **Pinnacles National Monument plays a key role as a reintroduction site for the California condor, fostering public understanding and scientific research with the goal to one day remove this species from the federal Endangered Species List for the benefit of future generations.**

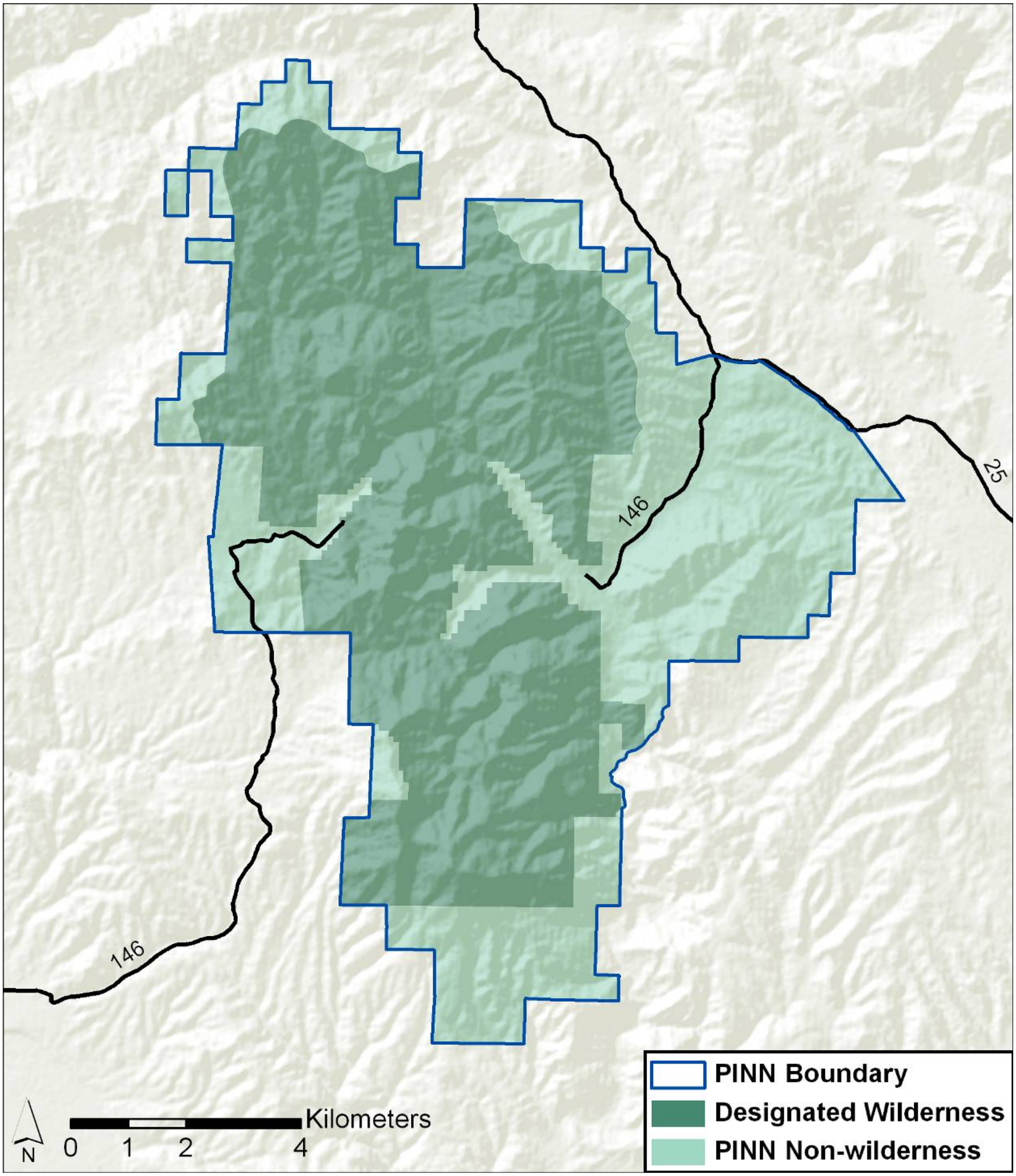

Figure 4. Map of PINN showing federally designated Wilderness.

Status of Supporting Science

Resource Stewardship Science

In 2003, the SFAN I&M Network implemented a conceptual model-based strategy to create a natural resources monitoring program. Subject matter experts and park natural resource managers convened to create a series of conceptual models that identified the natural drivers and anthropogenic stressors that are linked to key resources and natural processes of interest. More than 60 potential "vital signs" were identified based on these relationships. Vital signs are a subset of physical, chemical, and biological elements and processes of ecosystems, selected to represent the condition of natural resources, effects of stressors, or elements that have important management values. The subject matter experts and natural resource managers prioritized the list of vital signs using four ranking criteria—ecological significance, management significance, cost and feasibility, and legal mandate. The existence of active long-term monitoring datasets in the parks and region were also considered as a factor in the ranking. From the prioritized list of 63 vital signs, the network's monitoring plan prioritized 18 for which detailed protocol development would commence. This list was refined in subsequent years. The NPS currently monitors or is in the process of developing monitoring programs for vital signs indicators listed in table 6.

The current condition is updated annually and when enough data have been collected and analyzed, trends will be identified. Desired future conditions have not yet been established.

Table 7. Draft vital signs summary table for PINN.

Important Natural Resources	Vital Sign or other Indicator	Measures	Current Condition	Data Sources
Air Resources	Air Quality	Ozone trend	1.00 ppb/yr (0.00 p-value)	1
		Visibility Clean Days and Dirty Days	Visibility Clean Days: -0.09 dv/yr (0.27 p-value)	1
			Visibility Dirty Days: -0.05 dv/yr (0.55 p-value)	1
Species of Concern	Land Birds	Species Diversity	10.83	2
		Species Richness	12.34	2
		Index of Abundance	7.42	2
	Prairie Falcons	Number of occupied territories (in core area)	6	3
		Number of fledglings per nest (in core area)	4.3	4
	Raptors	Species Richness (of nesting raptors)	12	4
	California Red-legged Frogs	Relative Abundance	TBD	
	California Tiger Salamander	Number of breeding locations	TBD	
	Coast Horned Lizard	Number of occupied sites	TBD	
	Bats	Species diversity	14	5, 7
	Lichens	Species diversity	TBD	
Habitat of Concern	Bird Habitat	TBD	TBD	
	Fish Habitat	TBD	TBD	
	Wetland Communities	Wetland abundance in stream channel	TBD	
		Foliar cover		
		Channel width and substrate size		
Water Quality	pH Level	Standard unit: pH (percent samples exceed standards)	6.11–8.26 (53%)	6
	Dissolved Oxygen	Oxygen in mg/L (percent samples exceed standards)	2.3–13.86 (31%)	6
	Water Temperature	Water Temperature in Celsius	4.7–27.1	6
	Pathogens (Bacteria)	Total coliform MPN/100 mg/L (percent samples exceed standards)	160–41,000 (8 %)	6
	Nutrients	Total Kjeldahl Nitrogen mg/L	0.18–3.00	6
	Nutrients	Nitrate (NO_3) mg/L	0.1–1.22	6
	Conductivity	Micro-Seimens (µS) per cm	155–6,710	6
Stream Flow	Discharge	Base flow turbidity measured as Nephelometric Turbidity Unit (NTU)	TBD	
		Total annual discharge (cfs)	TBD	
		Mean Daily Discharge (cfs)	TBD	
		Peak flow event (cfs)	TBD	
		Low flow event (cfs)	TBD	

Table 6. Draft vital signs summary table for PINN (continued).

Important Natural Resources	Vital Sign or other Indicator	Measures	Current Condition	Data Sources
Vegetation Community	Invasive Species	Number of List 1 and 2 priority invasive species detections	TBD	
		Number of subwatersheds with invasive species	TBD	
		Percent of plots with Priority 1 or 2 invasive species.	TBD	
	Plant Community Change	Ratio of natives: exotic species	TBD	
		Species Richness	TBD	
		Percent of plots with disease present	TBD	
	Sudden Oak Death	Presence/absence	TBD	
Landscape	Landscape	TBD (may be percent cover of major land cover types and patch size metrices)	TBD	

Data sources: 1) NPS 2007, 2) Humple and Gardali 2005, 3) Jensen et al. 2008, 4) Emmons 2008, 5) Heady 2005, 6) Carson and Skancke 2009, 7) Sue Smith (pers. communication to Paul Johnson), confirmed *Myotis volans*.

Inventories

Natural resource inventory work at PINN is relatively extensive compared to many NPS units. Numerous inventories were conducted prior to the existence of the I&M Program and many gaps have been filled in since then (Table 7). In addition to these inventories, the I&M program has put considerable effort into data mining in order to collect all available information from park files and published scientific papers.

There is a long history of informal plant inventory work at PINN, with many participants throughout the years. The field work for the 2009 vegetation map, under the I&M program, added a significant number of new species to the plant list.

Over the years, outside researchers have contributed significantly to inventorying the natural resources at PINN. Some investigations cover broad taxonomic groups such as lichens, mosses, and bryophytes while in most cases the focus is at the genus or species level. Through their detailed knowledge of these taxa they have documented the presence of species that might otherwise have been missed.

Monitoring

The longest running PINN monitoring program is the breeding raptor monitoring program. Continuously performed since 1987, the program evolved from the 1984 raptor survey. Now under the direction of the I&M program, data are gathered to determine long-term trends of reproductive success and population levels of prairie falcons nesting from January through June. These data are also used to manage climbing activity in the park to ensure public access while protecting nesting raptors. Also under the I&M program, air quality, water quality, freshwater dynamics, and invasive plant species are monitored and a new protocol for monitoring riparian wetlands was implemented in 2012. Long-term monitoring protocols for coast horned lizards and pond-breeding amphibians are in development and expected to be implemented by 2013. The park is also monitoring California condors, Townsend’s big-eared bats, butterflies, oak woodlands, bees, fire effects, vegetation response to pig impacts and Sudden Oak Death.

Table 8. Summary of natural resource inventories at PINN.

Subject	Inventory Title	Time Period
Birds	Breeding Bird Survey	1984
Birds	Bird Surveys	1983–1985
Birds	Bird Surveys	1997–1999
Birds	Land Bird Inventory	2001–2002
Raptors	Raptor Survey	1984
Small Mammals	Small Mammal Survey	1984–1986
Small Mammals	New Lands Mammal Inventory	2003
Bats	Bat Inventory	2004–2005
Amphibians	Riparian Amphibian Survey	1991–1994
Reptiles/Amphibians/Fish	Riparian Aquatic Vertebrate Surveys	1998–2000
Reptiles/Amphibians	Cover Board Study	1998–2000
Reptiles/Amphibians	New Lands Reptile/Amphibian Inventory	2004
Vertebrates/Invertebrates	Riparian Aquatic Species Inventory	2001–2004
Bees/Wasps	Hymenoptera Inventory	1996–1998
Bees	New Lands Bee Inventory	2011–2012
Butterflies	Butterfly Inventory	1999–2001
Moths	Moth Inventory	2002–2004
Lichens	Lichen Inventory	2003
Mosses/Bryophytes	Bryophyte Inventory	2005–2005
Spring Water Quality	Level 1 Water Quality Inventory	2006
Soils	Soil Survey	2006

Chapter 3. Study Approach

Preliminary Scoping

As described in the Resource Stewardship Science section above, the regional network had previously developed an Inventory and Monitoring Plan that selected vital signs indicators and prioritized those for which protocols were to be developed (Adams et al. 2006). At the outset of this condition assessment, NPS staff provided a ranking of potential themes to be addressed (Table 8). They refined these general themes into the following set of preliminary management or research questions:

1. What is the significance of natural fires to the ecosystem in and around the park? What are the ecological effects of long-term fire suppression in PINN and in the region? How important is it to reintroduce this management tool and on what frequency?

2. What are the effects of non-native species invasions (plants and animals) along with disease?

3. What are the expected changes in visitation patterns based on census and economic data (e.g., will rock climbing become a bigger management issue for the park and breeding raptors)?

4. What have the changes in climatic factors been over the last 100 years (temperature, precipitation)?

5. What are the potential effects of changing climate in this region (e.g., rain, temperature, flooding, drought patterns), and how may this affect vegetation and wildlife communities (especially those important to the park)? What are the other implications for the park (e.g., to fire frequency)?

6. What are potential impacts of regional agriculture and pesticide use to sensitive park resources (e.g., amphibian populations)?

7. What are the effects of air quality (e.g., pollutants) on the park’s natural resources?

These general themes and questions were transformed into a set of stressors and resources to be assessed through ongoing discussion with the NPS coordinators. It was agreed that NPS staff would find more detailed analysis of some key issues and indicators more helpful than a superficial treatment of everything and that new analysis would be more efficient use of time than compilation of existing material.

Table 9. Priority rank potential focal themes for the natural resource condition assessment (updated version, 12/9/08).

Potential Themes and Analyses	Priority in PINN*
Global warming	3
Fire regimes (including historic fire regimes)	3
Fire suppression and fuels management	3
Urban encroachment/rural development	3
Recreation	3
Invasive species	3
Areas with evidence of invasive plant or animal species	3
Areas of focal species	3
Habitat for focal species	3
Caves or karst features	3
Moisture and climatic cycles	3
Phenological cycles	3
Clean water	3
Groundwater flow	3
Flooding regimes	3
Flood control	3
Bank erosion	3
Soil erosion	3
Roadless areas	2
Areas of pristine or old-growth vegetation (chaparral)	2
Wetlands & riparian areas	2
Lakes and streams	2
Solitude and silence	2
Soil compaction	2
Grazing (BLM lands; historic grazing)	2
Logging or habitat conversion	1
Road and trail development	1
Abandoned mine lands (mines with bat—PINN)	1
Water diversion	1
Airborne dust	1
Point sources of air pollution	1
Past logging and restoration of those lands	0
Karst processes	0
Mines (active)	0
Acid mine drainage	0
Mine restoration	0
Carbon sequestration	0

* Priority (Importance): 0 – None; 1 – Low; 2 – Moderate; 3 – High.

Study Resources and Indicators

Assessment Framework Used in the Study

The NPS Ecological Monitoring Framework is a systems-based, hierarchical, organizational tool for the NPS Inventory and Monitoring Program for promoting communication, collaboration, and coordination among parks, networks, programs, and agencies involved in ecological monitoring (NPS 2005). This framework uses a 6-category classification used to organize and report NPS I&M Program vital signs. The top reporting categories (Level 1) include: 1) Air and Climate, 2) Geology and Soils, 3) Water, 4) Biological Integrity, 5) Human Use, 6) Landscapes (ecosystem pattern and processes). Vital signs selected by parks and networks for monitoring are assigned to the Level 3 category that most closely pertains to that vital sign. The Ecological Monitoring Framework was selected as the hierarchical framework for this condition assessment because it is familiar to park resource staff, and it is a good fit for the indicators being assessed. The section of the report on Resource Conditions is organized around the categories of the framework.

Conceptual Models

Conceptual models describe the causal relationships among human activities—including park management decisions—environmental stressors, and endpoints of resources of concern in park management (Gentile et al. 2001). The exercise of developing these models provides several benefits in framing a resource condition assessment. The model graphically represents current belief of how the system functions and shows the relationships in a way that is understandable by non-scientists. Therefore the process adds transparency to the selection of condition indicators and potentially enhances communication. It can also help identify key uncertainties about the causal relationships and offer hypotheses to be tested (Gentile et al. 2001). The models also help identify the appropriate spatial and temporal scales for data collection and analysis. Conceptual modeling is used as the framework for this resource condition assessment.

There are four fundamental concepts contained in conceptual models: drivers, stressors, pathways, and endpoints (Gentile et al. 2001). *Drivers* are natural and anthropogenic processes that cause changes in environmental conditions. *Stressors* are the physical, chemical, and biological changes that result from natural and human-caused drivers and in turn affect ecosystem structure and function through *ecological pathways*. Drivers can be considered first-order influences and stressors second-order influences in chains of cause and effect. The ecosystem resources that are considered ecologically significant and important to the public (Harwell et al. 1999) are known as *endpoints*. Either endpoints or stressors or drivers can be used as condition indicators, depending upon feasibility of measurement. For instance, if it is impractical to census the entire population of a species of special interest (an endpoint), it may be necessary to assess the status and trends of key stressors that are more amenable to mapping or monitoring and then infer effects on the endpoint. Based on the hierarchical framework, it is sometimes ambiguous which indicators are stressors or endpoints. Fire regime is a condition, but if it changes in response to land use or climate change, it can also be a stressor on other conditions.

Describing a holistic conceptual model that contains every resource of concern in a park unit would quickly lose its capacity to communicate with non-scientists. Gentile et al. (2001) therefore recommend dividing the modeling into a higher level societal model that illustrates the role of social actions and choices (anthropogenic drivers) in increasing environmental stressors and a second level that relates stressors to resource endpoints through ecological pathways. The societal level conceptual model can be holistic with all the important drivers and stressors for the ecosystem being assessed, but it need not be comprehensive because some candidate stressors may only be of minor impact on park resources. The conceptual models presented in this report reflect primarily the anthropogenic drivers. The second level of models can be applied at any ecological level, e.g., landscapes, ecosystems, species, or other resources. What links the two levels of conceptual modeling are stressors. The relevant stressors, but not necessarily all, from the societal model become "inputs" into the resource level models. Examining which stressors apply in which resource conceptual models gives an indication of their relative importance and perhaps the priority to monitor them.

Based on the assessment questions and priorities of PINN staff, a societal conceptual model was developed (Figure 5). Six primary anthropogenic drivers, symbolized with rectangles, were identified. Clearly some drivers are related. For example, increased urbanization contributes to demands for recreation and fire protection as well as increased emissions of greenhouse gases. Nevertheless, this delineation provides a useful distinction of stressors (shown as ellipses). The model also identifies the spatial scale of the drivers and stressors. The gold color identifies processes that occur outside the park boundary, such as urbanization. Green symbolizes processes whose sources occur within the park unit. In some cases, the process and its impacts occur both internally and externally to the park unit, which is shown in yellow (e.g., light pollution occurs as skyglow from nearby urban areas but also from fixed and transient lighting within the park unit). Note that many of the stressors generated by the demand for outdoor recreation and by adjacent land management practices are similar to those from urban encroachment, but are not shown in the diagram for simplicity.

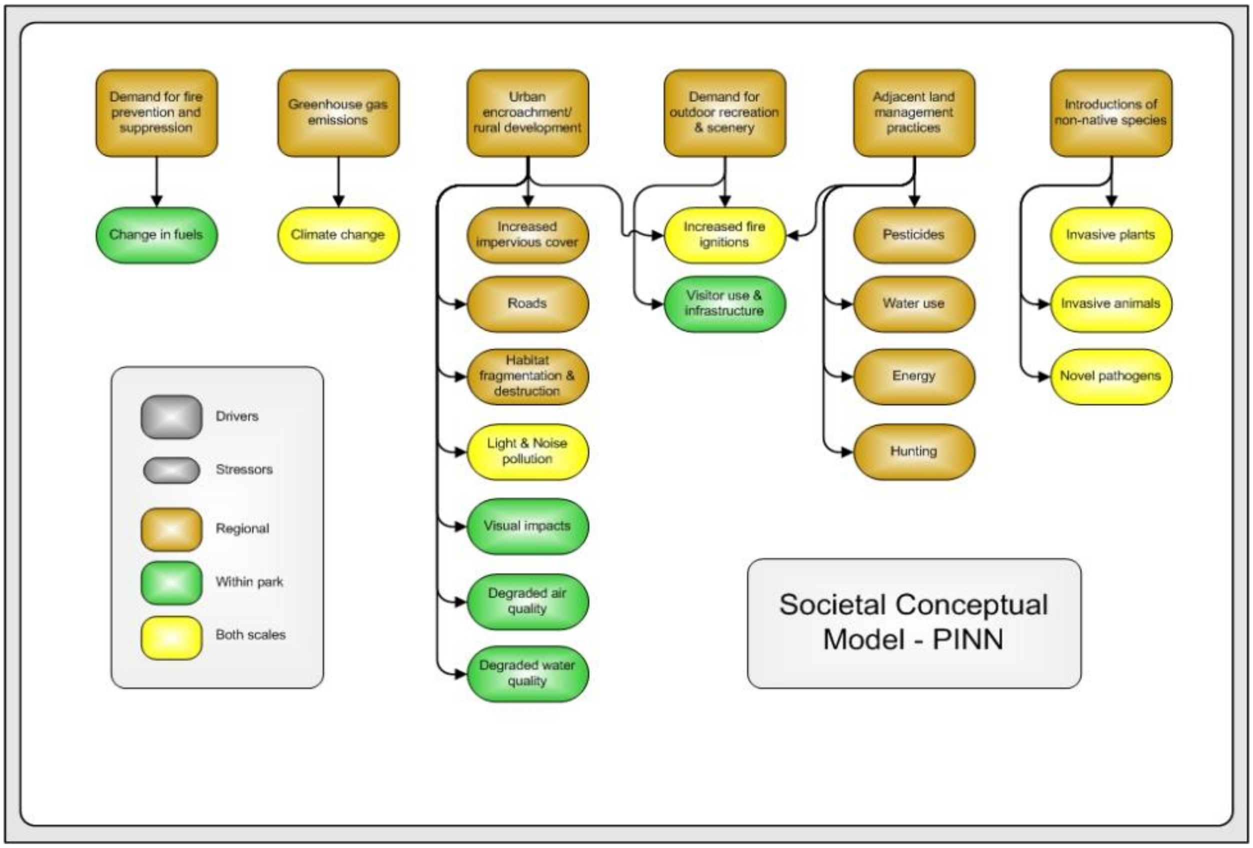

Figure 5. Societal conceptual model of drivers and stressors for Pinnacles National Monument.

Based on the set of management questions and resource indicators described above, second level resource conceptual models were developed (see Figure 6 for an example for prairie falcon nesting success). These models select the relevant environmental stressors from the societal conceptual model and link them through ecological pathways (diamond shapes) to one or more endpoint indicators (hexagons). The pathways qualitatively describe how the stressors may actually affect the indicators. For example, both rodenticides and rock climbers may affect nesting success of prairie falcons, but rodenticides may reduce the population of ground squirrels that prairie falcons prey upon, whereas rock climbers during nesting season potentially disturb falcons on their nests. Both pathways can reduce the number of eggs laid and chicks fledged.

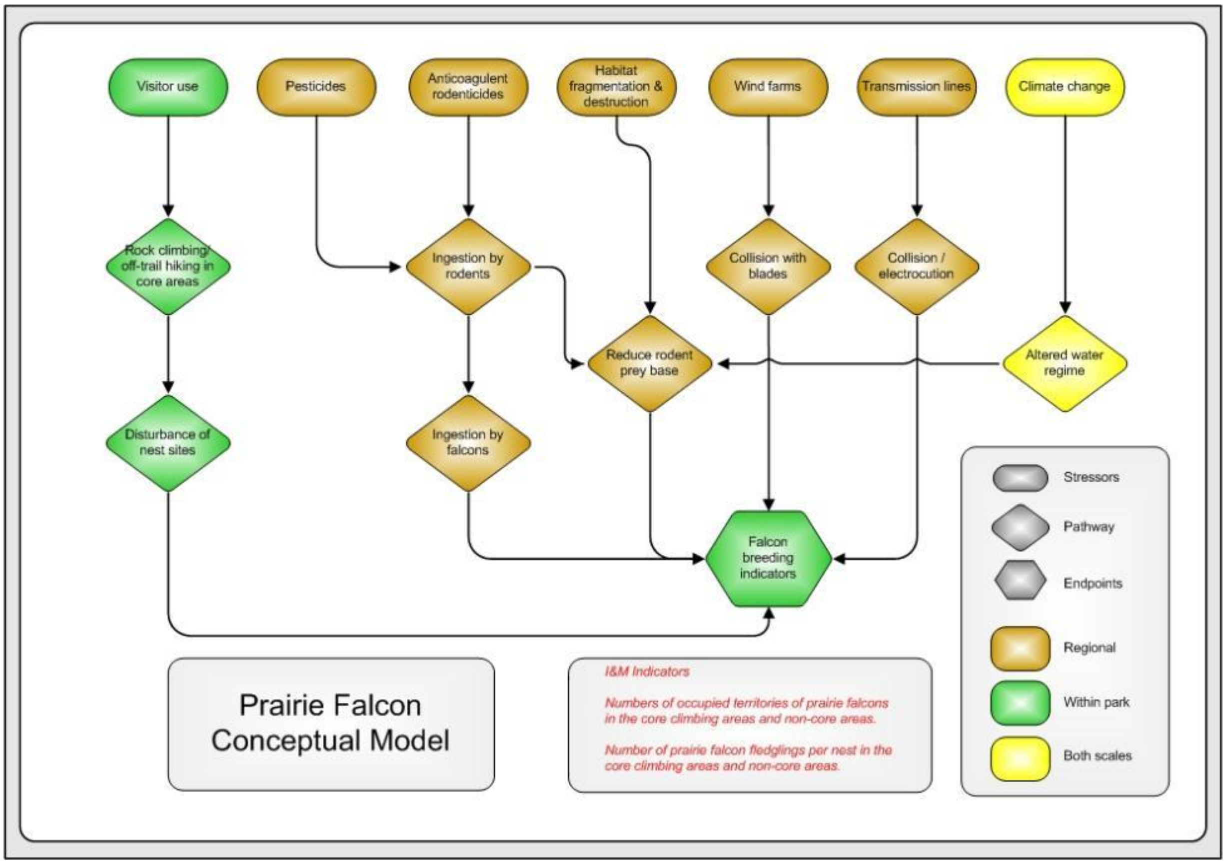

Figure 6. Prairie falcon conceptual model of stressors, pathways, and endpoint indicators.

Study Resources and Indicators

The societal conceptual models in the previous section identified key drivers and stressors associated with park resources. In some cases, a stressor is caused by multiple drivers, e.g., increased fire ignitions. The resource conceptual models defined the relationships between the resource endpoints and subsets of stressors. Stressors often appear in more than one conceptual model of the priority resource indicators selected for assessment in this report (Table 9).

Table 10. Relationships between environmental stressors and condition indicators in PINN.

Condition Indicators	STRESSORS Housing development	Road distance and accessibility	Pesticides affecting amphibians	Rodenticides	Human footprint
AIR AND CLIMATE					
Air quality	●	●			●
Climate	●				●
WATER					
Water quality	●	●	●		●
BIOLOGICAL INTEGRITY					
Invasive plants	●	●			●
Feral pigs	●	●			●
Prairie falcon	●	●	●	●	●
LANDSCAPES					
Fire regime	●	●			●
Response of fire to climate change and urban growth	●				●
Habitat connectivity	●	●			●
Habitat connectivity—badgers	●	●			●
Dark night sky	●	●			●

Study Methods

The approach used in this assessment generally follows a similar set of steps for most indicators.

1. Develop a conceptual model to gain insight and communicate the relationships between stressors and endpoints.

2. Select the relevant scale(s) of ecological patterns and processes for the assessment (see below for description of the standardized scales used).

3. GIS data compilation, manipulation, and modeling as needed. In a few cases where the data were aggregated to park-wide totals (e.g., prairie falcon nests), statistical analysis was used instead of GIS, although GIS may have been used to derive values of independent variables.

4. Summarization by reference scales and interpretation of status and/or trends.

Ecological assessment scales

As the color scheme in the conceptual models suggests, many drivers and stressors originate in a larger region beyond the park boundary. Air pollution from automobile exhaust within PINN is relatively insignificant compared to that produced by vehicles in nearby metropolitan areas of the Bay Area. Other stressors may predominantly operate within the park unit, such as outdoor recreation use. Stressors such as feral pigs can potentially move from adjacent lands into the park unit, but their influence is limited to lands in close proximity to the park. Resource endpoints, by definition, are features within the park unit, although they may be part of a larger population or ecosystem that encompasses the park. This inherent nesting of spatial scales of ecological processes is reflected in this condition assessment. Although every ecological process has its own characteristic reference region, we have chosen to simplify this diversity by employing just three scales or geographic domains in the assessment. First is the park unit itself. To assess stressors and endpoints at the landscape scale across adjacent lands, we delineated a buffer out to 10 kilometers surrounding the park boundary (Wittemyer et al. 2008), referred to in this report as park-and-buffer scale. Regional scale assessment required finding a regional boundary that contains lands that were ecologically similar to the park unit or that affect resources in the park (e.g., sources of air pollution). No single geographic division (e.g., ecoregions, counties, watersheds) was adequate to delineate such an assessment region. We had previously integrated GIS layers of river basins with EcoMap subsections from the U. S. Forest Service (Goudey and Smith 1994, Miles and Goudey 1997) as a useful compromise between optimal units for aquatic and terrestrial species and ecosystems (http://knb.ecoinformatics.org/knb/metacat?action=read&qformat=nceas&sessionid=&docid=bowdish.58). For the PINN condition assessment, a set of these "hydroecoregions" were aggregated to delineate an appropriate region. This region contains most of Monterey and San Benito counties and extends north into Santa Clara County almost to San Jose. The three assessment scales are depicted in Figure 7. The assessments of specific stressors and indicators were performed at the scale(s) deemed most appropriate. Note that because PINN is a relatively small park, summaries are not reported by subareas.

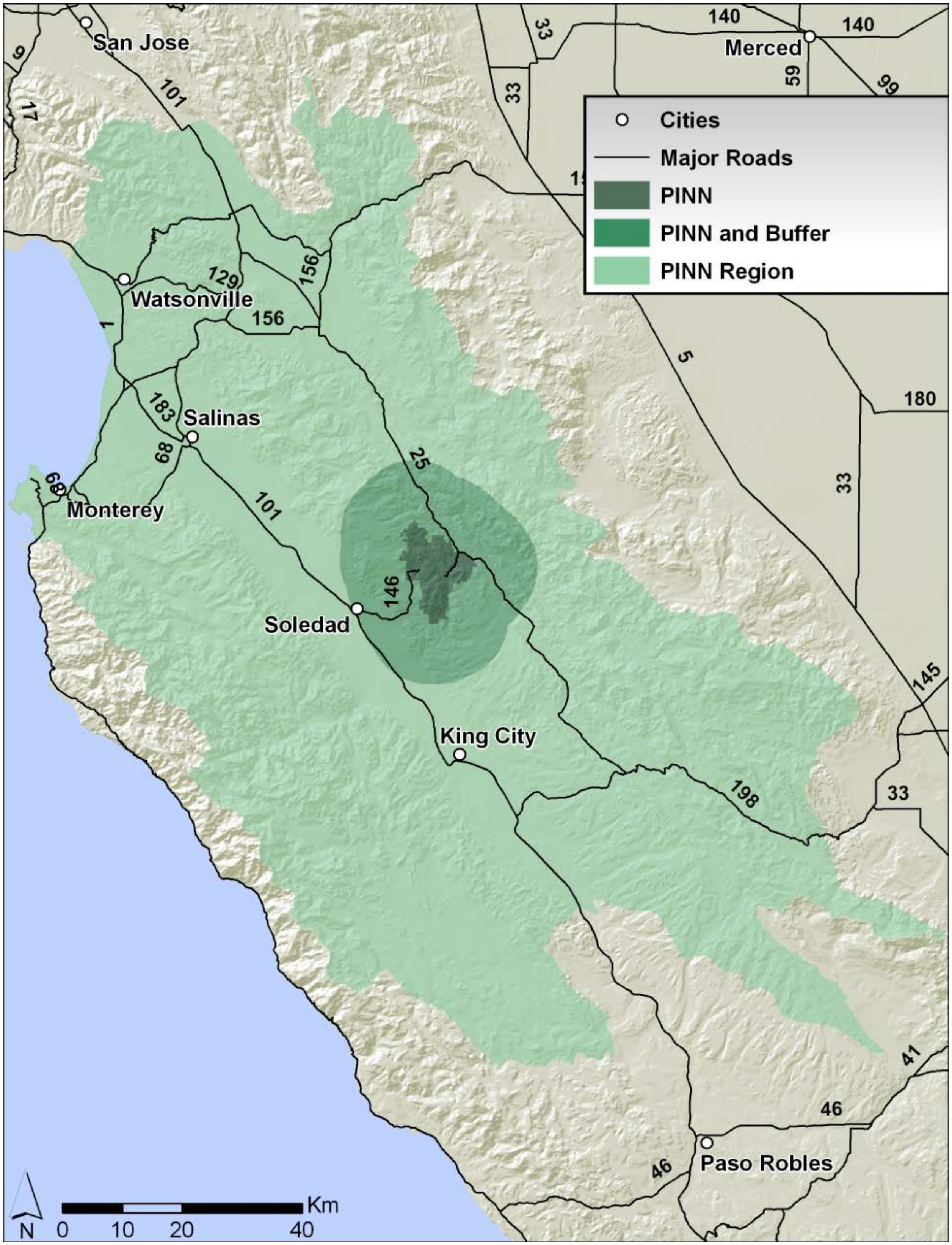

Figure 7. Geographic units for the three scales of condition assessment.

Climate change models

Several of the indicator assessments look not only retrospectively at current or recent conditions but also project responses into the future from changes in climate factors. This section provides background on the international efforts at projecting climate through the remainder of this century in response to continued emissions of greenhouse gases (GHG) into the atmosphere.

Climate is a complex system of interactions between the atmosphere, oceans, land, and the biota. All global climate models (GCMs) that model that complexity are based on principles of fluid dynamics and thermodynamics. Different research organizations, however, have developed GCMs to simulate the large-scale dynamics of the climate, but each uses a different set of parameterizations of variables to optimize for the climate feature of highest interest. Therefore the models generate similar but somewhat different results for a given set of assumptions about GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) states that:

> "There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. This confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes. Confidence in model estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). Over several decades of development, models have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases" (Solomon et al. 2007).

Three prominent GCMs that generated data for this assessment are the Centre National de Recherches Météorologiques CM3, Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 and National Center for Atmospheric Research PCM1.

The IPCC created a standardized set of scenarios about future GHG emissions over the coming century to integrate knowledge of demographic, economic, and technological systems to structure the policy discussion about climate change and its impacts (Nakićenović and Swart 2000). Of these scenarios, this condition assessment uses two that bracket the GHG emissions trajectories. The A2 scenario assumes business-as-usual, with a medium-high emissions trajectory leading to a CO_2 concentration in the atmosphere by end of century of more than triple the pre-industrial level. The B1 scenario assumes wider adoption of clean technologies and a transition to low GHG emissions, which remains double the pre-industrial level.

GCMs of necessity are coarse-scale models. California is generally covered by just a few grid cells. For regional analyses, these coarse-scaled projections are "downscaled" using local topography. For assessment of future distributions of tree species, the climate variables were downscaled to 90 meters. For interaction of climate and wildfire, the data were downscaled to 1/8 degree cells (see Cayan et al. 2009). The outputs are either daily or monthly values for temperature and precipitation. These were then aggregated into seasonal or annual values or into other ecologically-relevant variables for modeling ecological responses. Our assessments used the combination of downscaled outputs for GCMs and scenarios that were available for specific indicators. In other words we have not attempted an exhaustive assessment of the range of possible outcomes for resource indicators but rather have attempted to indicate the potential direction and magnitude of changes that may occur.

Chapter 4. Natural Resource Conditions

Regional/Landscape Context

Overview of Stressors

The remainder of this section contains assessments of the key stressor indicators. Each assessment follows a similar outline. Each begins with a brief summary of the findings about that stressor. The color of the title box indicates the level of concern about the stressor (green = low, yellow = moderate, and red = high). The arrow indicates the trend in the stressor and thus the level of concern with respect to the key resources in PINN. Then the methods are described followed by a description of the data used in the assessment. Results are presented next by status if only current conditions are known or trends if data were analyzed through time. The data and results sections discuss the relevant scales of assessment—regional, park-and-buffer, and park, as described above. Depending on the data, some stressors are reported by their spatial distribution in maps and some as trends in time-series plots. Each assessment then concludes with the identification of emerging issues and data gaps.

Stressor: Housing Development
Findings: Increasing

Housing growth near protected area boundaries decreases effective habitat area, decreases habitat connectivity, increases non-native species introductions, and disrupts ecological processes that maintain biodiversity (Shafer 1999, Hansen and DeFries 2007). This can decrease the probability of native species persistence within protected areas boundaries and constrain management options (Hansen and Rotella 2002, Wiersma et al. 2004, DeFries et al. 2007). Housing growth is influenced not only by population growth but also by demographic factors such as household size and socio-economic factors such as income, preference for residential setting, and seasonal home ownership (Liu et al. 2003). The direct impact of housing depends on the amount of land developed per unit which depends in turn on site level factors like the size of housing units and parcel configuration as well as larger scale factors like the road network, topography, and building regulations. Of the region beyond PINN's boundary, 20% (2350 km^2), is not developable for residential uses. The majority of these areas are federally owned and managed by the Bureau of Land Management, the Department of Defense, or the Forest Service. For the rest of the region that is vulnerable to development, we used multiple U.S. Census Bureau databases to assess year 2000 distribution of housing as well as trends in housing, population, and household size over time. We used a U.S. Geological Survey land cover change database to estimate land development associated with residential housing growth.

At the regional scale from 1940 to 2000, housing increased by 164,000 units, from 33,000 to 197,000. Overall housing density for the region increased from 3 units/km^2 to 15 units/km^2. Median housing density was zero for both 1940 and 2000, reflecting the large number of undeveloped census blocks. Median density of developed blocks increased from 29 units/km^2 in 1940 to 345 units/km^2 in 2000. Housing units increased by 12% from 1990 to 2000, population by 18%, and developed land by 4%. While housing growth has increased overall, each housing unit accommodated more people and required less developed land in 2000 than in 1990. At the park-and-buffer scale, average housing density was 3 units/ km^2 in 2000, but had grown 53% in the preceding decade. This has likely contributed to air quality issues at PINN because of atmospheric transport from developed valleys and larger urban areas to the north. The expansion of the road network and the increase in traffic volume has also fragmented habitat, likely leading to decreased large scale terrestrial connectivity with surrounding protected areas such as Los Padres National Forest on the Big Sur Coast.

Approach

For current status at the region and park-and-buffer scales, we used a year 2000 U.S. Census bureau census block database. Census blocks are the highest resolution of census division but are not available for censuses before 1990. To assess longer term change, we used a database provided by Hammer et al. (2004), which was derived from the U.S. Census Bureau decadal census at partial block group (PBG) scale. Partial block groups are subdivisions of census tracts and are the finest census division for which long-term housing data is available. We used PBG housing count data to tabulate the number of houses added to the region from 1940 to 2000. PBGs with >= 50% overlap with the regional extent were extracted from the PBG database and used to generate housing statistics and maps. For the 1990–2000 time period, we used census block relationship files to reconcile census block boundaries for the 1990 and 2000 decadal censuses. Reconciling decadal census blocks resulted in a spatial database of modified census blocks (MCB) with counts for population, housing, and occupied housing for 1990 and 2000. MCBs with >= 50% overlap with the regional extent were extracted from the database. Where MCBs intersected with the park-and-buffer analysis boundary, simple area weighting was used to allocate population, housing, and occupied housing units to the park-and-buffer extent. Household size was calculated by dividing population by occupied housing units. To assess change in developed land, we used the USGS 1992–2001 National Land Cover Database Retrofit Change Product, a 30m resolution database of land cover change at Anderson Level I thematic resolution. The area of urban land, which ranges in development intensity from industrial/commercial areas to golf courses and other green spaces, was tabulated in each MCB unit in each time period. The amount of urban land per housing unit for 1990 and 2000 was then calculated. Area of public lands and otherwise undevelopable area was calculated using a database of protected areas, PAD-US, maintained by the United States Geological Survey. See Appendix A for GIS layers generated for the assessment.

Data

Regional and park-and-buffer scales:

U.S. Census Bureau, Census 2000 Tiger/Line Files

U.S. Census Bureau partial block group database - Hammer, R. B. S. I. Stewart, R. Winkler, V. C. Radeloff, and P. R. Voss. 2004. Characterizing spatial and temporal residential density patterns across the U.S. Midwest, 1940–1990. Landscape and Urban Planning 69: 183–199. http://silvis.forest.wisc.edu/Library/HousingDataDownload.asp?state=United%20States&abrev=US

U.S. Census Bureau modified census block database – Jantz, P. Development of a National Database of Housing, Population, and Household Dynamics. *Working Paper*.

1992–2001 National Land Cover Database Retrofit Change Product - Fry, J.A., Coan, M.J., Homer, C.G., Meyer, D.K., and Wickham, J.D., 2009, Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit product: U.S. Geological Survey Open-File Report 2008–1379, 18 p.

Protected Areas Database of the United States - http://gapanalysis.nbii.gov/portal/community/GAP_Analysis_Program/Communities/GAP_Projects/Protected_Areas_Database_of_the_United_States

Status

Regional scale: In 2000, housing density was 15 units/ km^2, which can be considered exurban. However, housing is heterogeneously distributed in the region with the densest and most extensive settlements in the northwestern portion near the cities of San Jose, Watsonville, Salinas, and Monterey (Figure 10). The eastern half of the region is settled at very low densities. One percent of the region was urban, 4% was suburban, 6% was exurban, and 12% was rural. The rest of the area was settled at densities lower than 1 unit/ km^2.

Park-and-buffer scale: In 2000, housing density was 3 units/ km^2, with 9% of the area settled at rural densities. Urban, suburban, and exurban areas covered only 1% of the area, comprised mostly of small towns in the Salinas Valley southwest of Pinnacles.

Trends

Regional scale:

About 164,000 housing units were added to the area from 1940 to 2000 but were distributed unevenly throughout the region. Housing increases were relatively steady over time, averaging about 27,000 units/decade, except for 1970–1980 when 45,000 housing units were added, 67% more than the average for the study period (Figure 8). Areas classified as suburban covered 2% of the region in 1940 but received almost half of new housing units (Figure 9). Urban and exurban areas received similar proportions of new housing, 17% and 20% respectively. Almost 27,000 units, 17%, were added to rural and undeveloped lands. Most of the expansion in suburban and exurban areas occurred near established population centers in the western half of the region. The pulse of growth in the 1970s was part of a broader statewide increase in the rate of housing and population growth.

From 1990–2000 at the regional scale, housing increased by 12%, while population increased by 18% (Table 10). Household size increased 5% from 2.98 people/unit to 3.13 people/unit and the amount of developed land increased 4% from 924 km^2 to 960 km^2. Developed land per housing unit decreased 7% from 0.56 ha/unit to 0.52.

Park-and-buffer scale:

At the park-and-buffer scale, population and housing increased by 63% and 53%, respectively, a much greater rate than at the regional scale (Table 10). Household size increased 4% from 4.24 to 4.42 people/unit. The amount of developed land increased 3% from 33 km^2 to 34 km^2. Developed land per housing unit decreased from 1.89 ha/unit to 1.2. The relatively large amount of developed land per unit at this scale is likely due to high numbers of roads in less developed census blocks.

Table 11. Percent change in census and land use variables between 1990 and 2000 at region and park-and-buffer scales.

Scale	Population	Housing Units	Occupied Housing Units	Household Size	Developed Land	Developed Land Per Unit
Region	17.92	12.03	11.86	5.42	3.92	-7.24
Park-and-buffer	63.32	53.07	57.23	3.88	3.51	-32.38

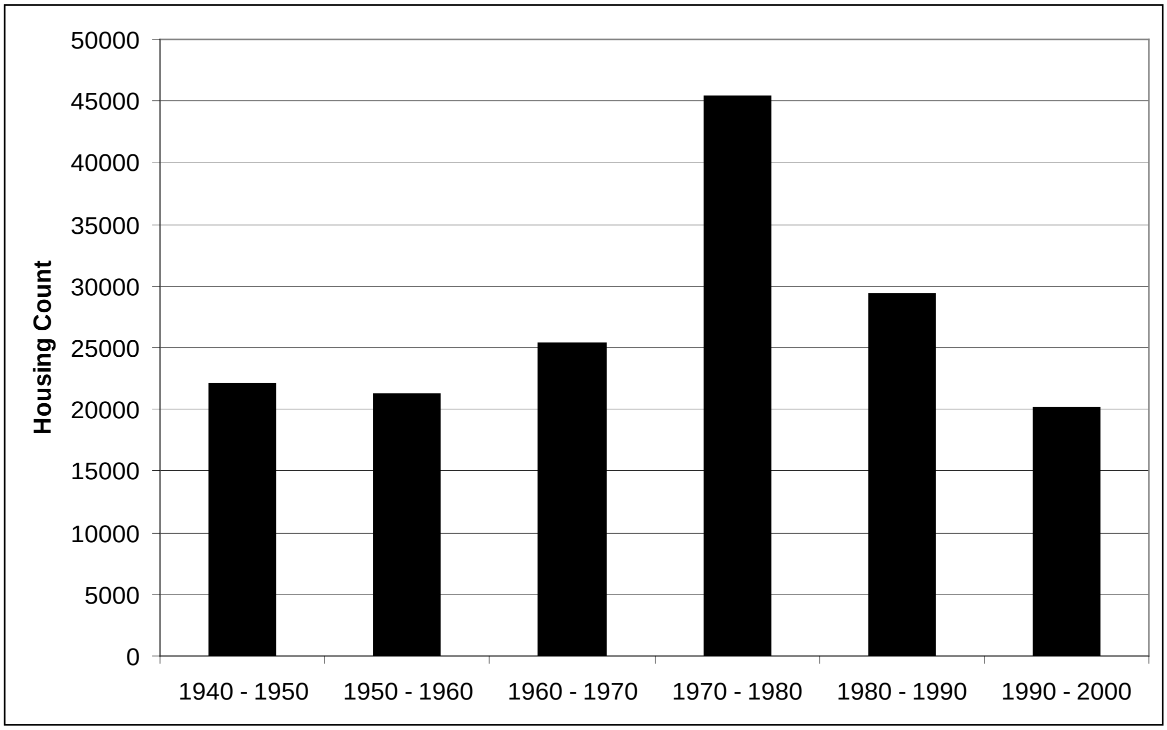

Figure 8. Housing units added per decade at the regional scale.

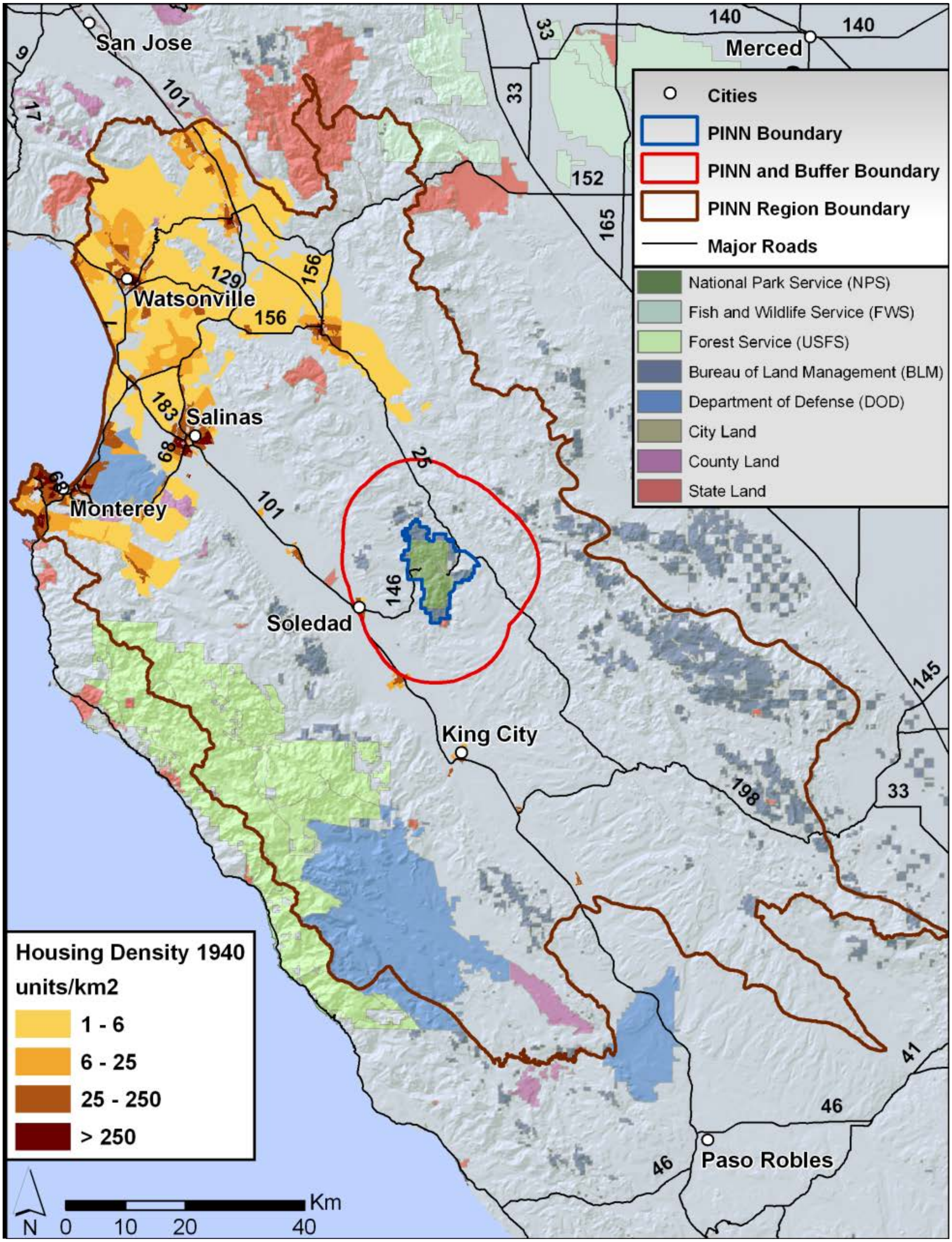

Figure 9. Housing density in 1940 derived from partial block group data. Protected areas are shown in semi-transparent colors.

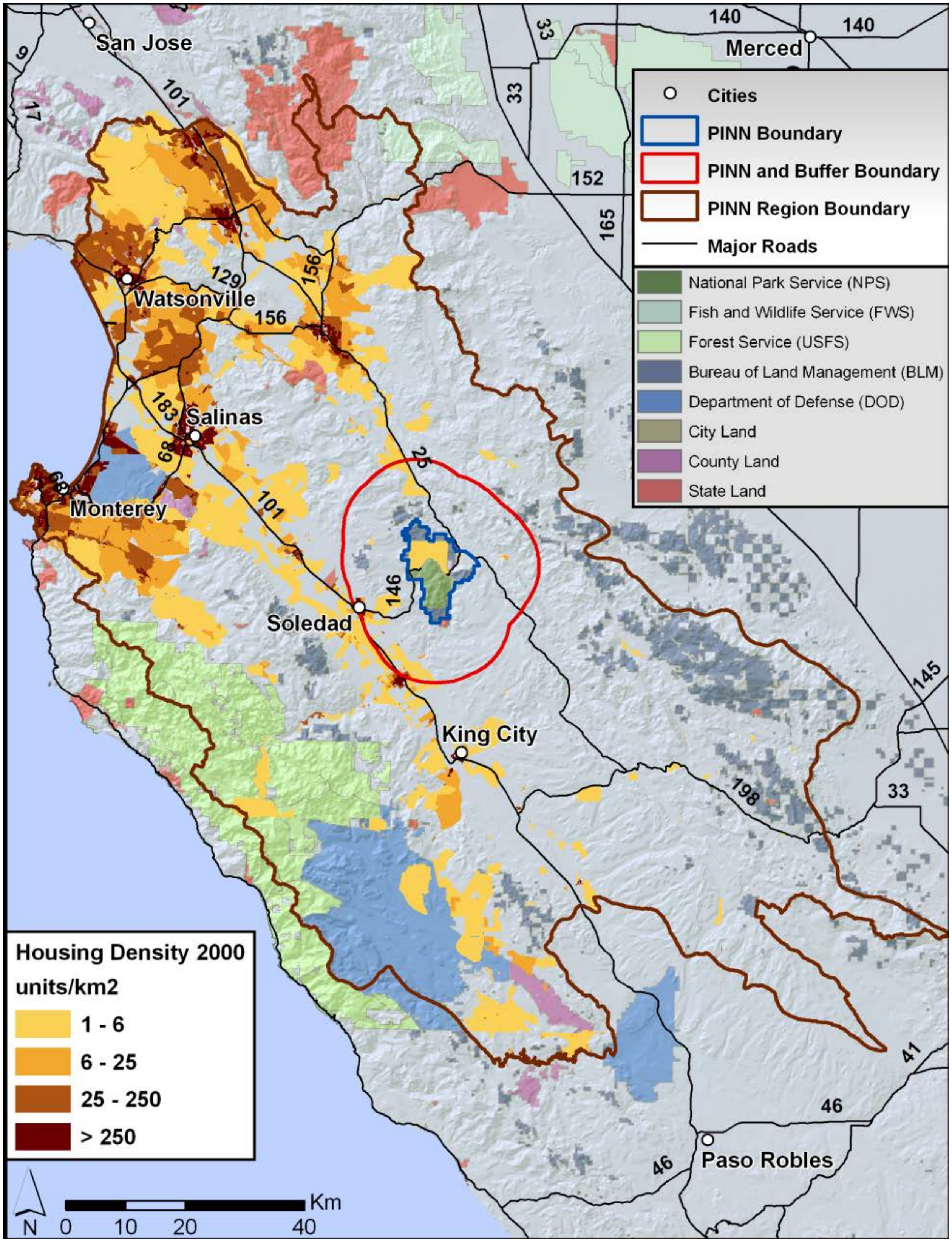

Figure 10. Housing density in 2000 derived from census block data. Protected areas are shown in semi-transparent colors. The gold polygon in PINN reflects park employee housing.

Emerging Issues

Secondary exposure of non-target wildlife populations to anticoagulant rodenticides in and around developed areas has been documented (Riley et al. 2007). Increases in residential development near Pinnacles will likely increase wildlife exposure to these and other toxicants. Development also subjects wildlife to predation from domestic animals (Lepczyk et al. 2003), fragments habitat for wide ranging carnivores (Riley et al. 2006), and exposes wild animal populations to infectious diseases, such as canine distemper, harbored by domestic animals (Daszak et al. 2000).

Data Gaps

We are limited in our knowledge of housing distribution below the scale of census units. This is especially a problem in less densely settled areas where partial block groups and modified census blocks can span 1000's of hectares. Finer resolution data would improve our estimates of the areas occupied by different housing density classes. County assessor records for Monterey and San Benito Counties or high resolution aerial photos could be used to locate lower density development where the resolution of census data is coarse. The NLCD retrofit change product, by design, does not depict areas of change smaller than a few pixels, limiting the contribution of low density residential development to developed area calculations.

Key References

DeFries R., Hansen A., Turner B. L., Reid R. and Liu J. G. 2007. Land use change around protected areas: Management to balance human needs and ecological function. *Ecological Applications* 17:1031–1038.

Hammer, R. B. S. I. Stewart, R. Winkler, V. C. Radeloff, and P. R. Voss. 2004. Characterizing spatial and temporal residential density patterns across the U.S. Midwest, 1940–1990. *Landscape and Urban Planning* 69: 183–199.

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Liu J. G., Daily G. C., Ehrlich P. R. and Luck G. W. 2003. Effects of household dynamics on resource consumption and biodiversity. *Nature* 421:530–533.

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Stressor: Road distance and accessibility
Findings: Baseline

Roads and, to a lesser degree, trails facilitate a variety of environmental impacts on the landscape in addition to their intended benefits (Forman et al. 2003). Their presence alters hydrologic processes and provides disturbed sites for invasions of non-native plant species. Their use can impact wildlife through habitat fragmentation, direct mortality, and behavioral modification. Increased access also increases the risk of wildfire ignitions and release of chemical contaminants and air pollutants. Two indicators related to overall influence of the existing road and trail infrastructure were assessed: mean distance from roads and accessibility or travel time. Mean distance to nearest road in PINN is 1.8 km; mean travel time from monument entrances is just less than one hour. Riparian areas and invasive plant sites tend to be much closer to roads and more accessible than the park as a whole. Because exotic plants are concentrated along hiking trails, park visitors serve as vectors for spreading them deeper into PINN. Assessing the ecological impacts of the road and trail infrastructure could be enhanced with data on annual and seasonal traffic volume.

Approach

Because PINN is not fragmented by roads nor is it likely that new roads will be constructed, we did not assess the usual fragmentation metrics associated with roads. Instead, two indicators related to overall influence of the existing road and trail infrastructure were assessed: mean distance from roads and accessibility or travel time. The exposure to risk of ecological impacts associated with roads is often a function of (or within a specific) distance to the nearest road (Riitters and Wickham 2003). This assessment extracted the main paved roads in and near PINN and applied standard GIS operations to calculate Euclidean or as-the-crow-flies distance to the nearest road (DTR) of 25 meter grid cells. Results were summarized as the mean distance for all of PINN and for subareas associated with management concerns such as land cover types and the invasive plant sections. The cumulative proportion within different distance zones was summarized for PINN and compared to results from a national assessment by Riitters and Wickham (2003).

The degree to which areas of PINN are accessible is related to their exposure to human impacts, such as disturbance of nesting prairie falcons or wildfire ignitions. Accessibility, defined as the one-way travel time for an average visitor to any location within a park, is increasingly used to represent intensity of human use and therefore exposure to stressors (Theobald et al. 2010). For this assessment, we applied the approach of Theobald et al. (2010) to model accessibility in terms of three phases—travel on roads from the park boundaries to trailheads, travel on trails accounting for along-trail slope, and cross-country travel from nearest trail, also accounting for slope and the permeability of land cover. Travel commences at the boundary of PINN on the east and west entrances on State Highway 146 using the speeds in the streets geodatabase. It was assumed that visitors could only access off-trail areas from the four parking lots at trailheads and not along Highway 146. Walking speed is typically 5 km/hr on flat ground. The effect of slope on walking speed was based on the equation of Tobler (1993). Walking speed can also be impeded by the density of vegetative cover. Therefore a permeability factor (Table 11) was applied. Low density vegetation such as grassland that would not seriously impede cross-country walking has high permeability. Dense chaparral is very difficult to walk through and therefore has low permeability. NPS staff adapted factors developed for Rocky Mountain National Park (Theobald et al. 2010) to fit the vegetation of PINN. As with DTR, accessibility results were summarized as the mean travel time for PINN, for land cover types, and invasive plant sections. The cumulative proportion within different travel times was summarized for PINN. Because the California Department of Transportation reports that both entrances receive annual average daily traffic of 170 vehicles (http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/2008all/r134161i.htm), it was not necessary to do a visitor-weighted average of travel times as was done for Rocky Mountain National Park (Theobald et al. 2010). See Appendix A for GIS layers generated for the assessment.

Table 12. Permeability of cover types for cross-country travel (adapted from Watts et al. 2003, Theobald et al. 2010).

Generalized cover type	Permeability value
Grassland	0.90
Coastal scrub	0.70
Chaparral	0.10
Woodland	0.80
Riparian	0.60
Sparse/Non-Vegetated	1.00

Data

Park scale:

Roads: streets_ac geodatabase, containing the 2003 Tele Atlas Dynamap Transportation version 5.2 product, extracted for PINN for the NPScape program. For the distance to roads assessment, the main paved roads to and near PINN were extracted. For the accessibility assessment, only State Highway 146 was extracted.

Trails: PINN supplied shapefiles of hiking trails and Climbing Access trails.

Slope: The 1/3 arc-second digital elevation model from the National Elevation Dataset was projected and resampled to 25 m cells and then converted to slope in degrees.

Land cover: coverrid11c raster from PINN, mapped by the Wildlife Spatial Analysis Lab at the University of Montana in 2005 using IKONOS imagery from 2000. Cover classes were aggregated to major types for this assessment.

Weed sections: PINN_invasive_Sections.shp shapefile from PINN.

Status

Park scale:

The average distance to a road within PINN is 1.8 km, with a maximum distance 6.8 km in the southern end of the park (Table 12). Generally the southern end is the most remote (Figure 11). Three percent of the park is within 100 m of a road, 32% is within 1 km, and over 60% is within 2 km (Figure 12). This is considerably below the national average, where 82% was within 1 km of a road (including unpaved roads; Riitters and Wickham 2003). Riparian cover lies much closer to roads than the average, followed by grassland and woodland. Chaparral, which is the dominant cover type in PINN, occurs at greater than average distance. Average distance to the nearest road from the invasive plant sections is less than half the park average, at only 789 m.

Table 13. Distance to nearest road and travel time (hours) to locations within PINN from two entrances.

	Averaging Unit	Mean distance to nearest road (m)	STD distance (m)	Mean travel time from entrance (hr)	STD travel time (hr)
PINN		1,843	1,330	0.93	0.84
Ecological systems	Grassland	1,357	1,244	0.83	0.89
	Coastal scrub	1,841	1,199	0.98	0.84
	Chaparral	1,954	1,360	0.96	0.84
	Woodland	1,586	1,364	0.77	0.68
	Riparian	1,295	1,320	0.56	0.64
	Sparse/Non-Vegetated	1,714	1,091	0.93	0.93
Invasive plant sections		789	991	0.39	0.39

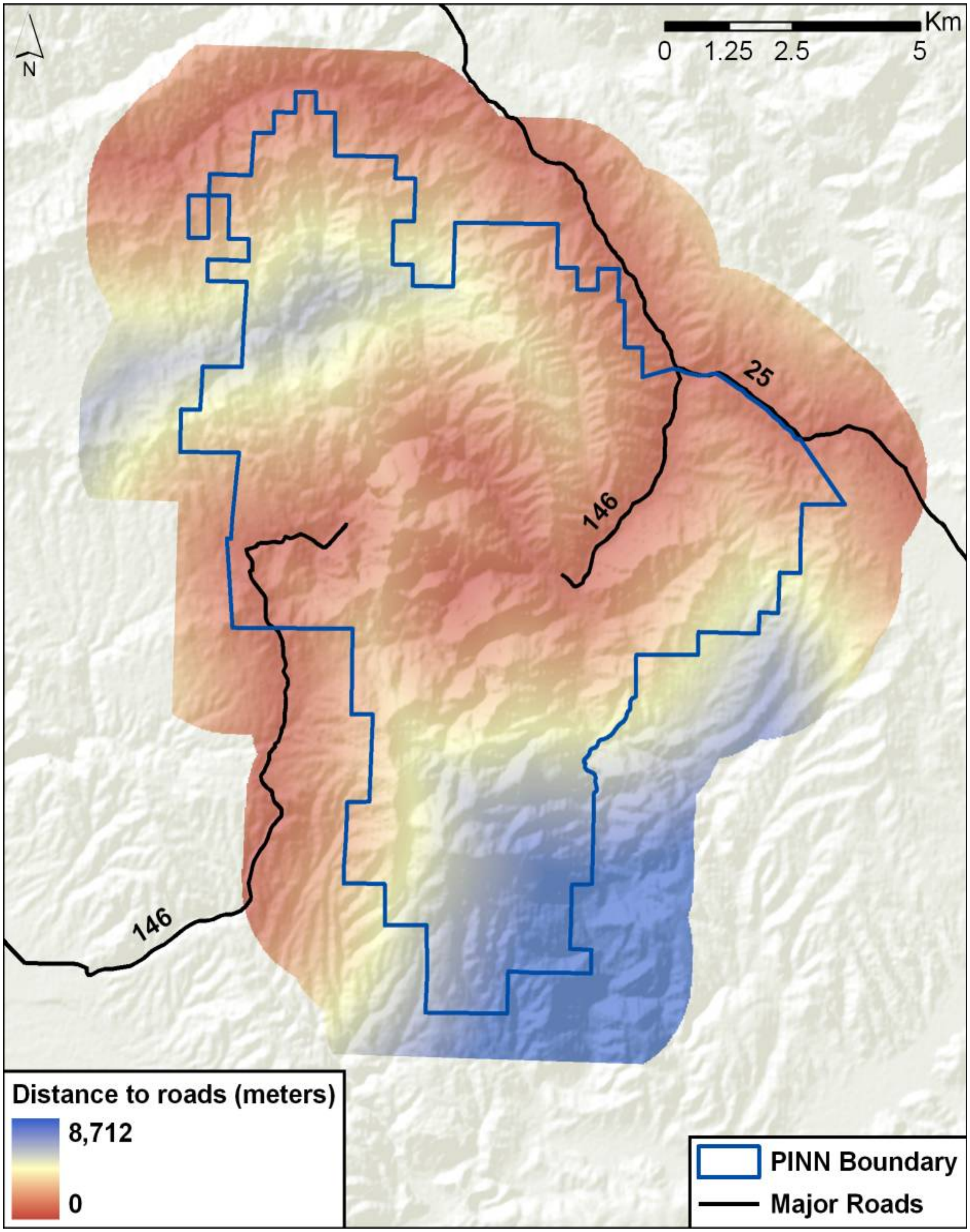

Figure 11. Map of distance to roads (DTR) for PINN.

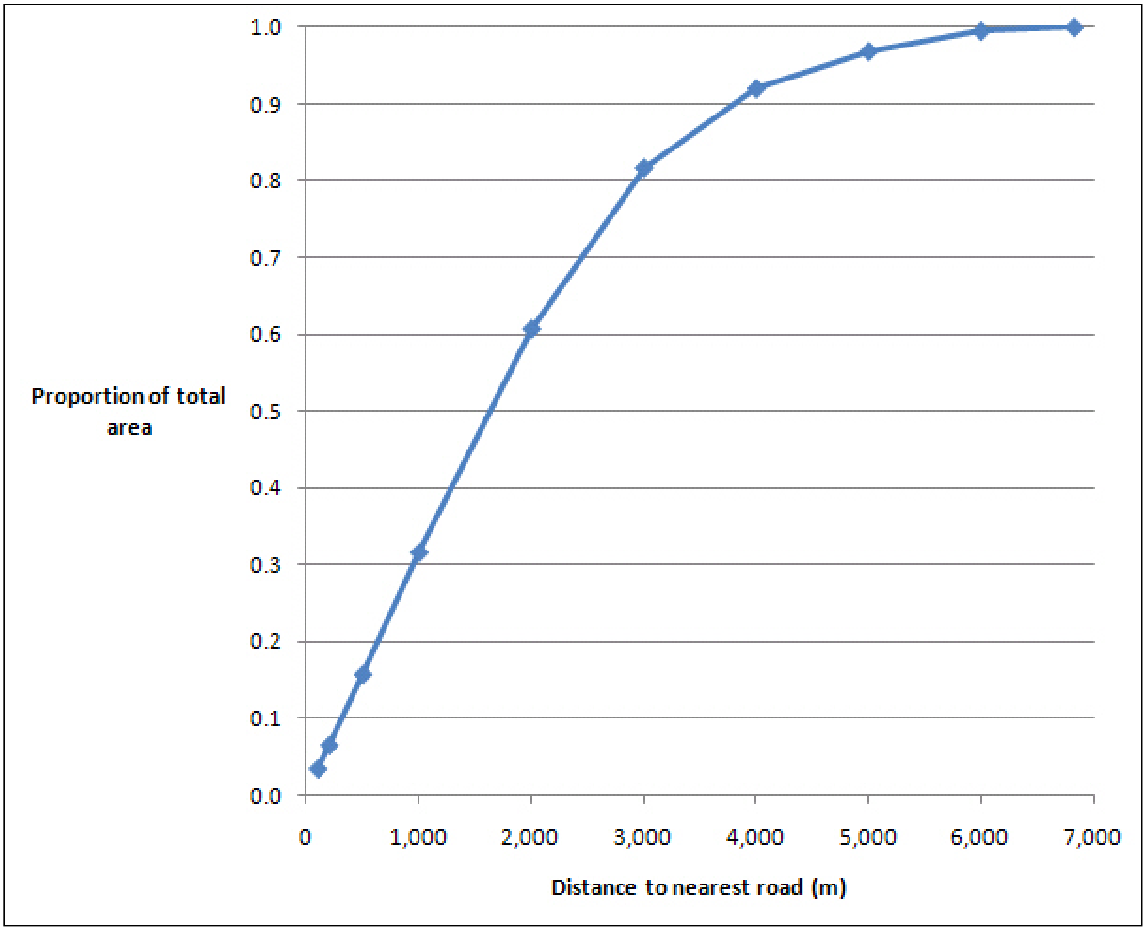

Figure 12. Cumulative proportion of the total area of PINN located within specified distances from the nearest road.

Accessibility, measured as travel time from one of the two park entrances, averaged a little under one hour (Table 12), although the far southern tip of PINN is estimated at roughly three hours (Figure 13). For context, accessibility in Rocky Mountain National Park averages 3.5 hours (Theobald et al. 2010). Only 15% of PINN is greater than 1.5 hours from the entrances (Figure 14). Riparian cover is the only type that is dramatically more accessible than average, with an average travel time of just 34 minutes (Table 12). This is noteworthy because two California Species of Special Concern, Cooper's hawk (*Accipiter cooperii*) and the sharp-shinned hawk (*A. striatus*), preferentially nest in riparian woodland. On higher use trails, they tend to hide their nests from view more carefully than on low use trails (Fletcher 2003). The federally Threatened California red-legged frog spends most of its life in riparian habitat. The invasive plant sections are only 0.4 hours from entrances.

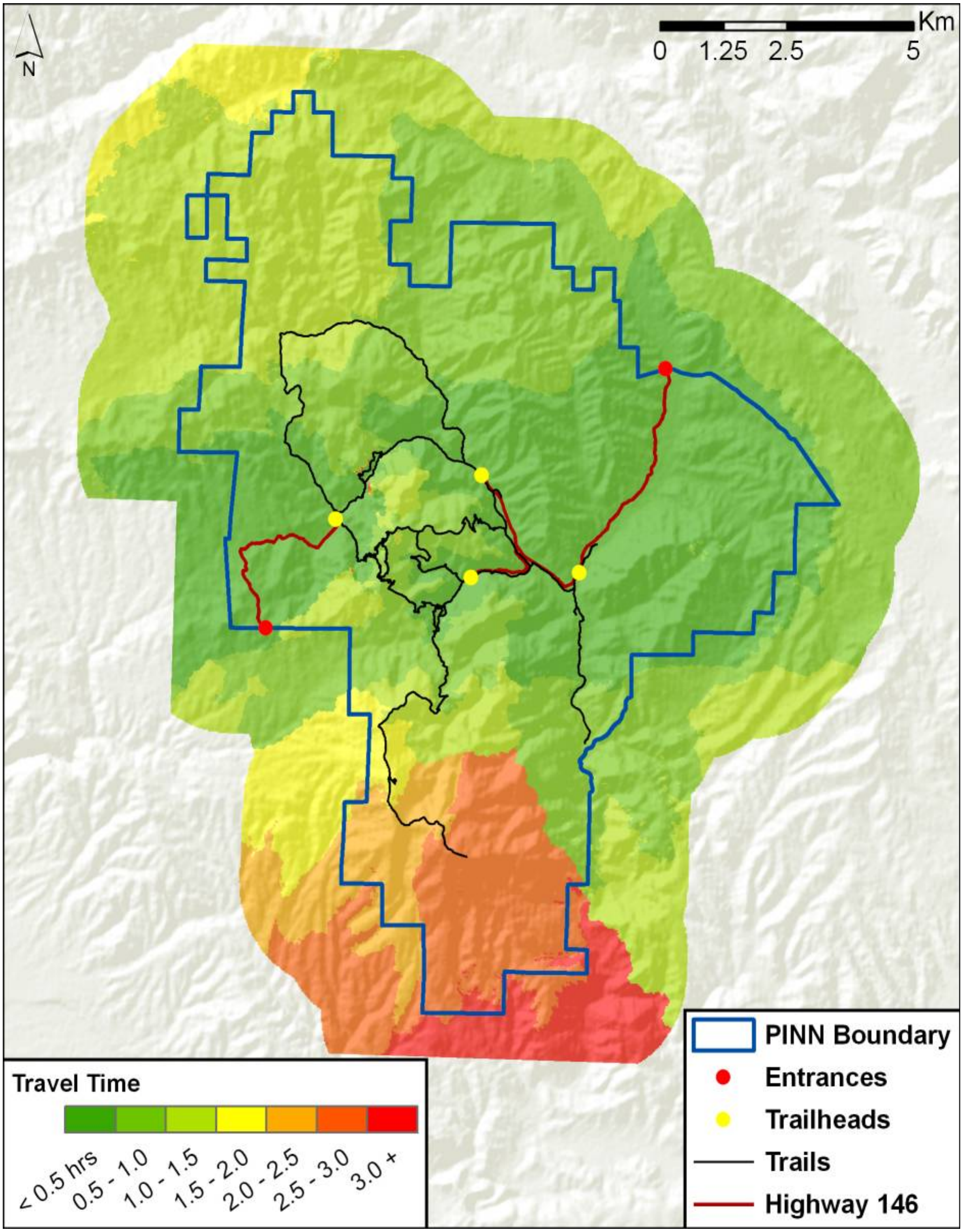

Figure 13. Map of travel times to locations in Pinnacles National Monument over roads, trails, and off-trail.

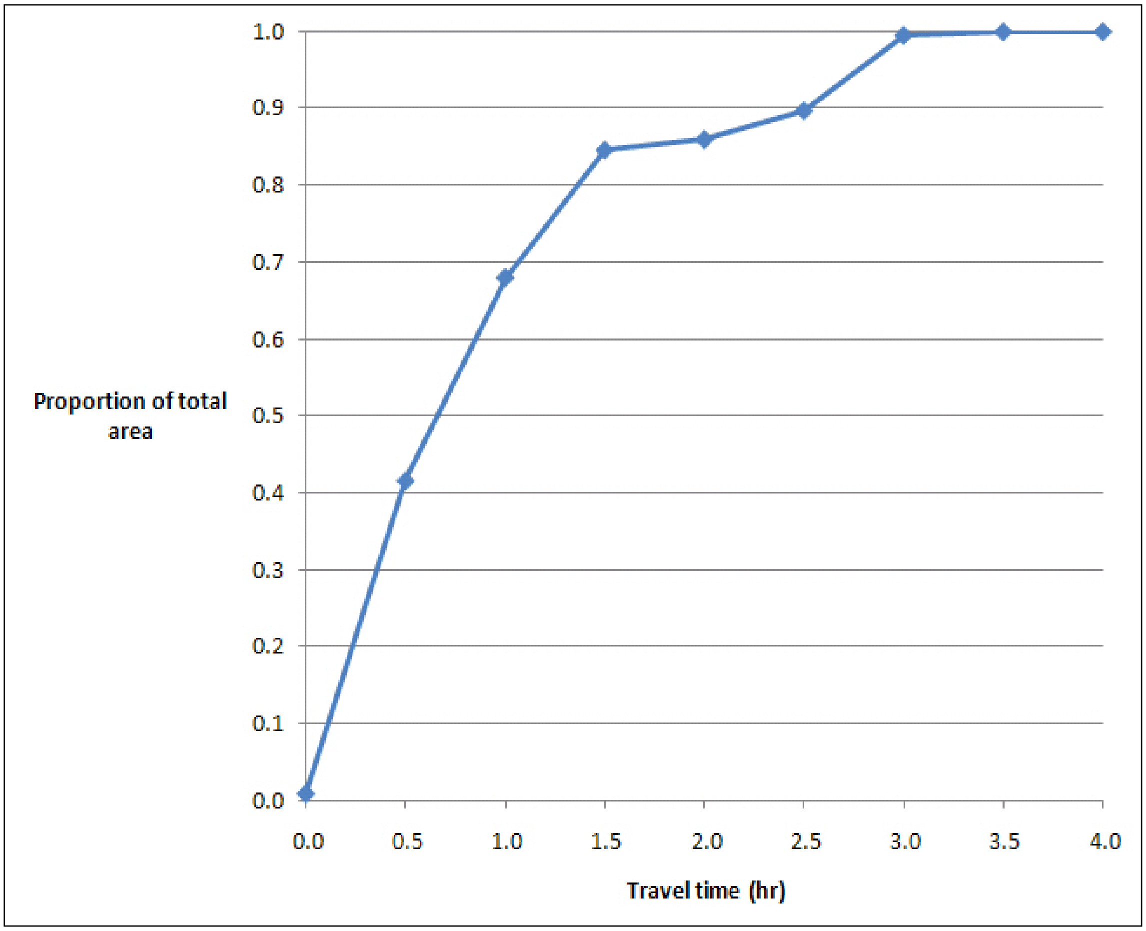

Figure 14. Cumulative proportion of the total area of PINN located within specified travel times.

Emerging Issues

The road and trail infrastructure provides visitor access while also stressing natural resources in PINN through a variety of pathways. Because of the topography of the park, roads and trails tend to be co-located with riparian areas. Similarly, invasion of non-native plants is primarily occurring along or near the transportation infrastructure. We expect impacts of the infrastructure to be a continuing management concern. Even though there are no plans to expand the existing road infrastructure in PINN, the new General Management Plan will consider alternatives with a significant expansion of the trail system and public facilities. It is likely that visitor use and impacts will increase even with the current trail system.

Data Gaps

GIS data on the location of roads and trails are good. Slope data were relatively coarse, which created some extreme values in areas with switchbacks that had to be adjusted. Higher resolution digital elevation data would improve the accuracy of the accessibility assessment but would probably not be a significant change. The permeability factor to adjust off-trail walking speed related to land cover were not available for PINN, so data from other western states were adapted with local knowledge of the vegetation. We ignored access over informal social trails, the fence around PINN to exclude wild pigs, and old roads and fire breaks because we assumed use is relatively minor. We assume the results would not change substantially if more accurate permeability data were developed specifically for PINN or if informal access routes were included. Perhaps the most important data gap is for the volume of traffic on roads and trails, and particularly by time of year when impacts could be most detrimental (e.g., disturbance to prairie falcon nesting in spring, road kill of migrating amphibians).

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Riitters, K. H. and J. D. Wickham. 2003. How far to the nearest road? *Frontiers in Ecology and the Environment* 1:125–129.

Theobald, D. M., J. B. Norman and P. Newman. 2010. Estimating visitor use of protected areas by modeling accessibility: A case study in Rocky Mountain National Park, Colorado. *Journal of Conservation Planning* 6:1–20.

Stressor: Pesticides affecting amphibians
Findings: Rapidly increasing trend

PINN lies to the east of the Salinas Valley, an important center of agriculture in California. Millions of kilograms of pesticides are applied annually to crops in the valley, placing downwind aquatic ecosystems of PINN at risk of pesticide exposure. Upwind pesticide use is a significant factor in declines of several amphibian species in California including the California red-legged frog, foothill yellow-legged frog, Cascades frog (*R. cascadae*), and the Sierra Nevada yellow-legged frog (*R. sierrae*) (Davidson 2004, Davidson and Knapp 2007). A fungal epizootic caused by *Batrachochytrium dendrobatidis*, also known as the amphibian chytrid fungus, is another major factor in declines of California anuran populations (Vredenburg et al. 2010), potentially exacerbated by immunosuppressant effects of pesticides (Davidson et al. 2007). Pesticides also cause declines in phytoplankton and zooplankton at low concentrations, disrupting aquatic ecosystems and increasing amphibian mortality (Relyea 2009). We georeferenced pesticide use reports to Public Land Survey System (PLSS) sections to calculate the weight of pesticide active ingredient applied from 1990 to 2007 for those known to affect amphibians at regional and park-and-buffer scales. We differentiated by three general pesticide application methods: aerial spray, ground, and other. At the regional scale, pesticide use increased by 75%, from 0.99 million kg of active ingredient in 1990 to 1.73 million kg in 2007. At the park-and-buffer scale, the amount applied increased by 84%, from 23,000 kg to 60,000 kg for the same time period. Trends at both scales show sharply increasing levels of pesticides loading from 1990 to 1994 and from ~2001 to ~2004, with slower increases in the intervening years. Ground applications made up the majority of pesticide applications for both scales and increases in ground applications were responsible for most of the observed trend. Because of the pervasiveness of pesticide use and its mode of transport on upslope air movements, aquatic communities across the Gabilan range are potentially at risk for pesticide loading. The ecological scales involved range from global to local where a disease with global extent, the amphibian chytrid fungus, may interact with environmental toxicants driven by agricultural practices and local atmospheric processes to impact PINN's amphibians and those in surrounding areas.

Approach

Current air and water quality monitoring efforts at PINN do not test for pesticides. The Western Airborne Contaminants Assessment Project monitored legacy and contemporary pesticides from 2002 to 2007 in several western U.S. park units but PINN was not included. In the absence of park level pesticide contamination data, it was necessary to use outside data sources to assess this stressor. The California Department of Pesticide Regulation requires users to record the type and quantity of pesticide applied in agricultural and some residential settings as well as the one mile square PLSS section where the application occurred. These data are published in annual Pesticide Use Reports. After associating each pesticide application record in the Pesticide Use Reports with a coverage of PLSS sections in a GIS, we calculated application rates for each PLSS section for 2007 (Figure 15) and the total amount of active ingredient applied at regional and park-and-buffer scales from 1990 to 2007 (Figure 16). Pesticide Use Reports are available from 1974 but the 17-year period reported here was judged sufficient to show the trend in this stressor. Although pesticides affect a broad range of taxa and ecosystems, we identified a subset of 48 pesticides determined by the U.S. Environmental Protection Agency (EPA) to have adverse effects on a federally threatened species, the California red-legged frog or its terrestrial and aquatic habitat. Many of these pesticides have also been shown to negatively affect other native amphibians and components of aquatic ecosystems. Because there is strong evidence of long-range transport (tens of kilometers) of currently used pesticides from agricultural valleys to adjacent mountain ranges in California, we assessed pesticide applications at both park-and-buffer and regional scales (LeNoir et al. 1999). See Appendix A for GIS layers generated for the assessment.

Data

Regional and park-and-buffer scales:

Compressed text files of statewide Pesticide Use Reports for individual years were downloaded from the California Department of Pesticide Regulation ftp site, ftp://pestreg.cdpr.ca.gov/pub/outgoing/pur_archives/.

Pesticides determined to have adverse effects on the California red-legged frog were identified from effects determinations published by the EPA. http://www.epa.gov/oppfead1/endanger/litstatus/effects/redleg-frog/

Public Land Survey System section GIS coverages for California are maintained by the Bureau of Land Management and can be downloaded from http://www.blm.gov/ca/gis/.

Status

Regional scale: Most pesticide applications were restricted to low elevation agricultural lands in the Salinas Valley to the west of PINN and the Santa Clara Valley to the north (Figure 15). In 2007, pesticide application rates were higher at the regional scale, with a mean of 817 kg/ km^2 (1802 lbs/mi^2) and a maximum 15,247 kg/km^2 (33,614 lbs/ mi^2), than the park-and-buffer scale with a mean of 479 kg/km^2 (1057 lbs/mi^2) and a maximum of 4316 kg/km^2 (9516 lbs/mi^2). The highest application rates were in the northern part of the Salinas Valley, roughly 40 km away from the monument boundary. Pesticide application rates in the Salinas Valley are similar in magnitude to those of California's Central Valley.

Park-and-buffer scale: This scale is dominated by grazing land, grasslands, and shrublands, accounting for the lower pesticide application rates when compared to the regional scale (Figure 15). Most pesticide use is concentrated in the part of the Salinas Valley that intersects the 10 km buffer. However, application rates of > 100 kg/km2 can be found in a small agricultural area directly adjacent to the PINN boundary where Highway 146 enters the monument. There are also isolated areas of pesticide use in relatively undeveloped grazing lands surrounding PINN.

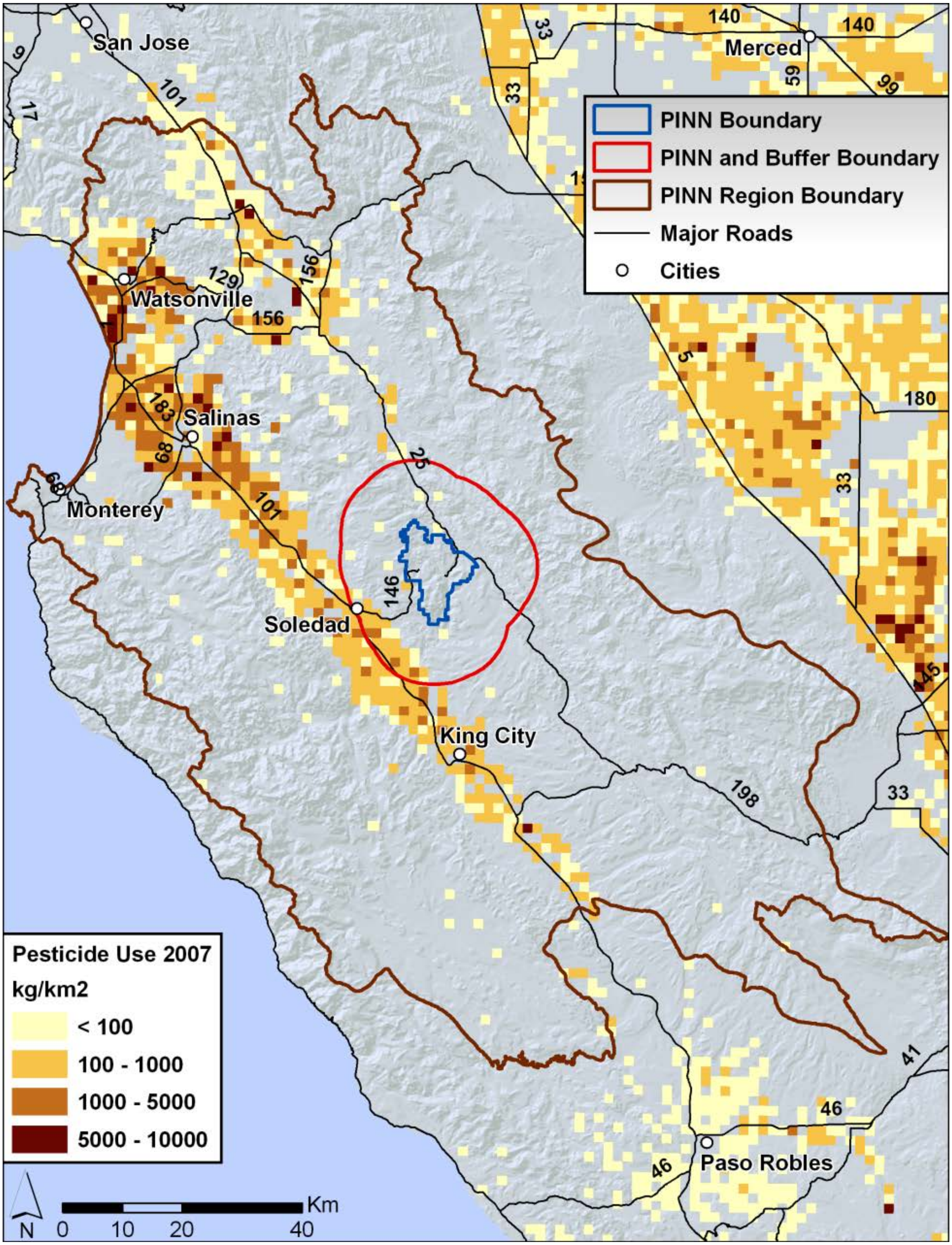

Figure 15. Pesticide use in 2007 by public land survey system sections.

Trends

Regional scale:

There has been a steep increase in pesticide use at the regional scale over the past 17 years (Figure 16). The temporal trend consists of two distinct periods of rapid increase separated by a period of slower increase and ending the period of observation with a decline. The large relative increase in overall pesticide use on top of an already large baseline at the regional scale likely reflects an expansion of agriculture, intensified management, a change in crop mix, a switch from other pesticides to the subset assessed here, or some combination of the above factors. However, most of the increase in pesticide use was in the form of ground applications, which are more of a threat for aquatic ecosystems directly adjacent to farmlands.

Park-and-buffer scale:

The overall and year to year trends in pesticide use at the park-and-buffer scale were similar to trends at the regional scale although the magnitude of change was less. Because the park-and-buffer scale includes a portion of the Salinas Valley, increasing pesticide use at this scale likely shares the same drivers as those at the regional scale. In addition, high value farmland, e.g., vineyards, has expanded near the entrance of PINN along Highway 146 since the early 1990's. While 48 pesticides were considered, only a few pesticides were responsible for most of the active ingredient weight in each year. Of the total weight of pesticides applied over the time period, ten pesticides contributed over 75% (Table 7).

Table 14. Contribution of the top ten pesticides by weight to the total weight applied across all years.

DPR Chemical Code	Chemical Name	Contribution (%)
369	Maneb	19.54
136	Chloropicrin	11.63
616	Metam-sodium	11.16
198	Diazinon	8.13
1855	Glyphosate, Isopropylamine Salt	5.59
1685	Acephate	4.17
382	Oxydemeton-methyl	4.16
383	Methomyl	4.12
216	Dimethoate	3.46
694	Propyzamide	3.16

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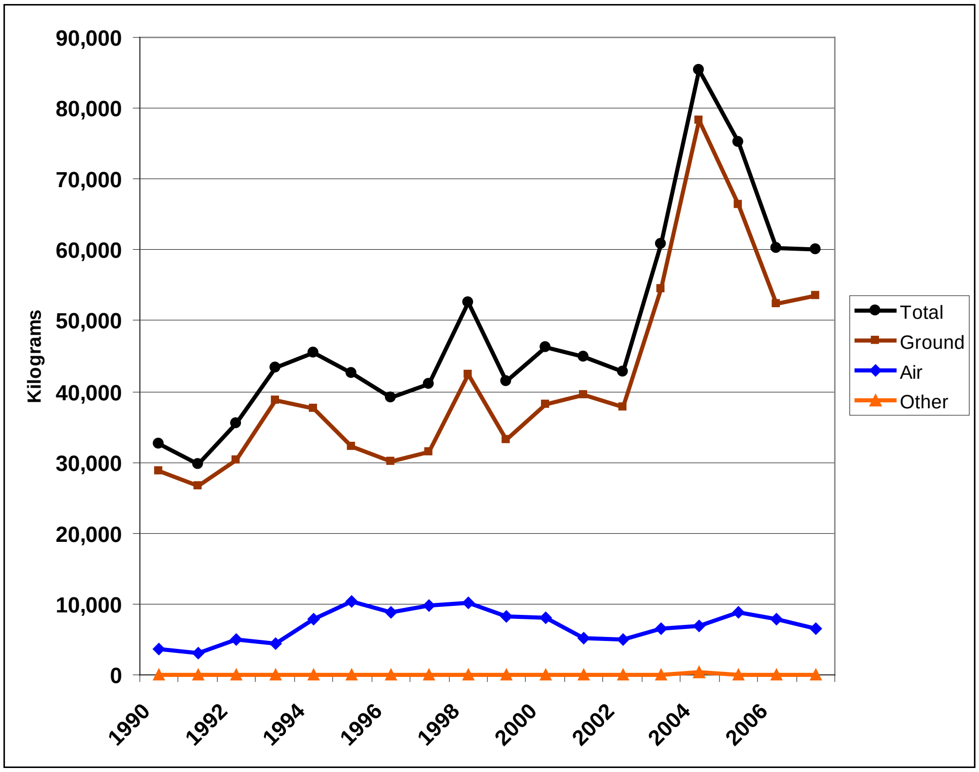

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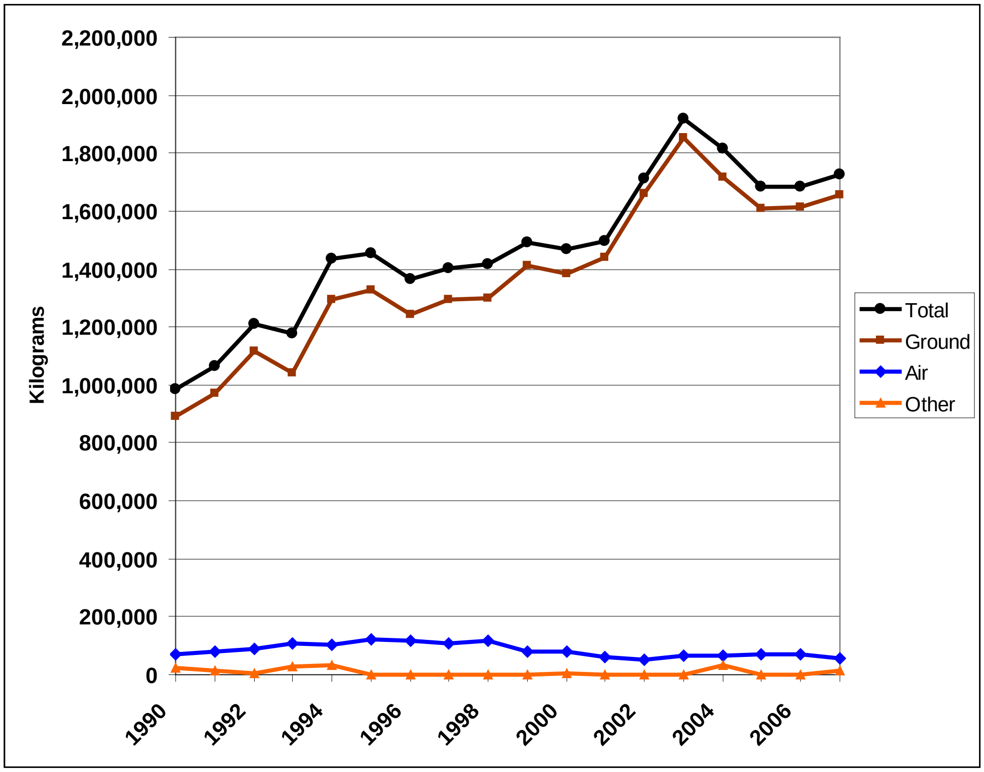

Figure 16. Trends in pesticide use at the a) park-and-buffer and b) regional scale.

Emerging Issues

While direct mortality from exposure to pesticide concentrations in the environment is possible, a more likely scenario is the interaction of sublethal exposure (e.g., immune system compromise) with existing stressors to increase mortality of aquatic organisms. For example, a decrease in surface water availability during amphibian breeding periods could increase the concentration of pesticides in remaining water bodies, increasing amphibian exposure during critical development phases. Pesticides can also decrease production of protective skin peptides in amphibians, rendering them more susceptible to infection by the amphibian chytrid fungus.

Data Gaps

The measurements reported here account for the loadings of active ingredients to the environment surrounding PINN. It is unknown what fraction of that loading is actually transported to PINN by aerial drift, and how much becomes biologically available to the amphibians in the monument. Direct measurements of pesticide levels in the environment are lacking but are key in determining the potential of this stressor to affect aquatic ecosystems and organisms.

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Stressor: Rodenticides
Findings: No significant trend

Anticoagulant rodenticides cause disease and mortality in raptors, meso-carnivores, and other non-target organisms (Stone et al. 1999, Brakes and Smith 2005, Riley et al. 2007). PINN's resident animals that forage or disperse in the agricultural or residential areas beyond PINN's boundaries and consume poisoned rodents are at risk of exposure to anticoagulant rodenticides. We georeferenced rodenticide use reports to Public Land Survey System (PLSS) sections to quantify rodenticide applications from 1990 to 2007 in the vicinity of PINN.

Rodenticides were applied primarily in the agricultural valleys around PINN and in the Watsonville Plain near Monterey Bay. There were no clear trends in rodenticide applications at any of the scales analyzed. Applications were steady at the regional scale until 2001, when applications increased considerably, peaking at 14.75 kg in 2005. This was followed by a steep decline from 2005 to 2007. At the park-and-buffer scale, there was no trend and applications were low overall (mean of 0.007 kg/year). Application rates (kg/km^2) in 2007 were 0.0172 kg/km^2 at the region scale and 0.0025 kg/km^2 at the park-and-buffer scale. Chlorophacinone made up the bulk of rodenticide used in most years. Thousands of individual rodenticide applications are possibly being applied near PINN every year. The more lethal second generation rodenticides, brodifacoum, bromadiolone, and difethialone, were applied infrequently at the regional and park-and-buffer scales. Rodenticides were applied within the foraging range of Prairie falcons (*Falco mexicanus*) and California condors (*Gymnogyps californianus*) that nest at PINN. The level of rodenticide application depends in part on pest population cycles, which, in the case of rodents such as the California ground squirrel (*Spermophilus beecheyi*), are tied to inter-annual variation in climate which affects forage and cover and therefore rodent abundance in lands outside PINN.

Approach

Presence of anticoagulants in animals can only be measured through analysis of liver tissue after death (Riley et al. 2007). Therefore an indirect approach based on loadings of anticoagulant rodenticides was used for this condition assessment. The California Department of Pesticide Regulation requires users to record the type and quantity of pesticide applied in agricultural and some residential settings as well as the one mile square PLSS section where the application occurred. All records of six anticoagulant rodenticides used in California were extracted from the database (Table 14). After associating each rodenticide application record from the Pesticide Use Reports with a coverage of PLSS sections in a GIS, we calculated application rates for each PLSS section with reported applications for 2007 and the total amount of active ingredient applied at regional and park-and-buffer scales from 1990 to 2007. Pesticide Use Reports are available from 1974 but the 18-year period reported here was judged sufficient to show any relevant trends in this stressor. See Appendix A for GIS layers generated for the assessment.

Table 15. Anticoagulant rodenticides used in California. Second generation rodenticides are marked in bold font.

DPR Chemical Code	Name
2049	Brodifacoum
2135	Bromadiolone
1625	Chlorophacinone
4014	Difethialone
225	Diphacinone
1636	Diphacinone, Sodium Salt
621	Warfarin

Data

Regional and park-and-buffer:

Compressed text files of statewide Pesticide Use Reports for individual years were downloaded from the California Department of Pesticide Regulation ftp site, ftp://pestreg.cdpr.ca.gov/pub/outgoing/pur_archives/.

Public Land Survey System section GIS coverages for California are maintained by the Bureau of Land Management and can be downloaded from http://www.blm.gov/ca/gis/.

Status

Regional scale: Rodenticides are applied primarily in the Salinas Valley (Figure 17). Application rates were highest in sections near Monterey Bay, but were less than 0.30 kg-km^{-2}. The average application rate was 0.0176 kg-km^{-2}, six times higher than the average rate of 0.0028 kg-km^{-2} for the state as a whole. Total application in the region was 2.19 kg in 2007. Chlorphacinone made up 97% of applications in 2007. Chlorphacinone and diphacinone are commonly used for California ground squirrel control and are usually delivered using bait stations (Clark 1994). Recommended practice is to load bait stations with up to 2.3 kg of 0.005% chlorophacinone bait. Assuming 2.3 kg of 0.005% bait, a bait station would receive about 0.000115 kg of active ingredient each day until control is achieved which can take several days to weeks (Whisson and Salmon 2009). One kilogram of active ingredient would be enough for thousands of bait station applications.

Although all the rodenticides used in California are lethal at low doses, second generation rodenticides are more potent than first generation. Recommended use for brodifacoum in bait stations is between 0.1 and 0.5 kg of bait per day at a concentration of 0.0025%. Less than 0.001 kg of second generation rodenticides were applied in 2007, enough for a few to several dozen applications. One kilogram of active ingredient of second generation rodenticide would be enough for tens of thousands of bait station applications.

Rodenticide applications over time were concentrated in the Watsonville Plain, Salinas Valley, and Santa Clara Valley (Figure 18), but were applied infrequently to most sections in the region.

Park-and-buffer scale: Only a few PLSS sections to the west and north of PINN had reported rodenticide applications in 2007. Application rates for these sections were less than 0.01 kg-km^{-2}. No second generation rodenticide applications were reported at the park-and-buffer scale in 2007.

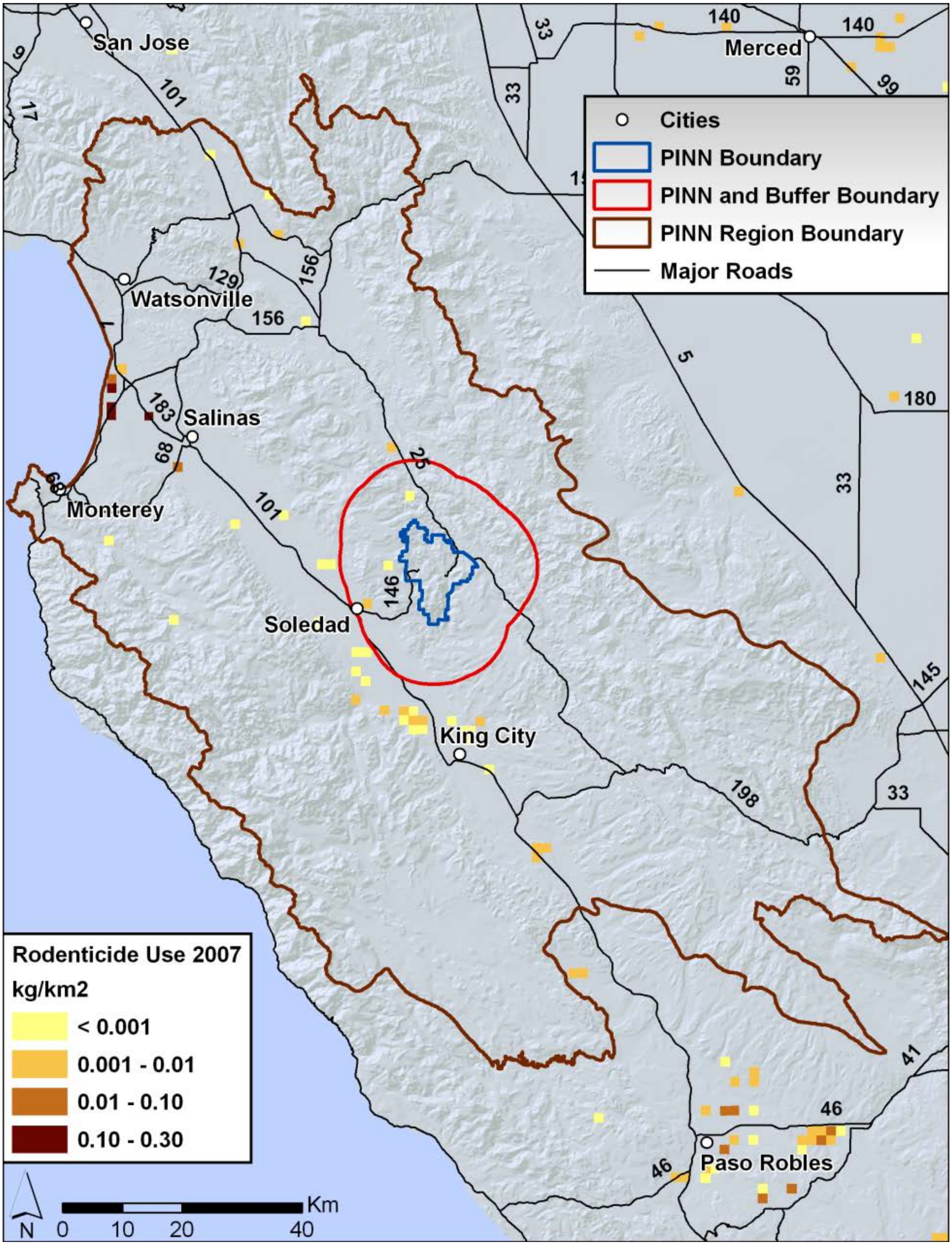

Figure 17. Rodenticide use in 2007 by public land survey system sections.

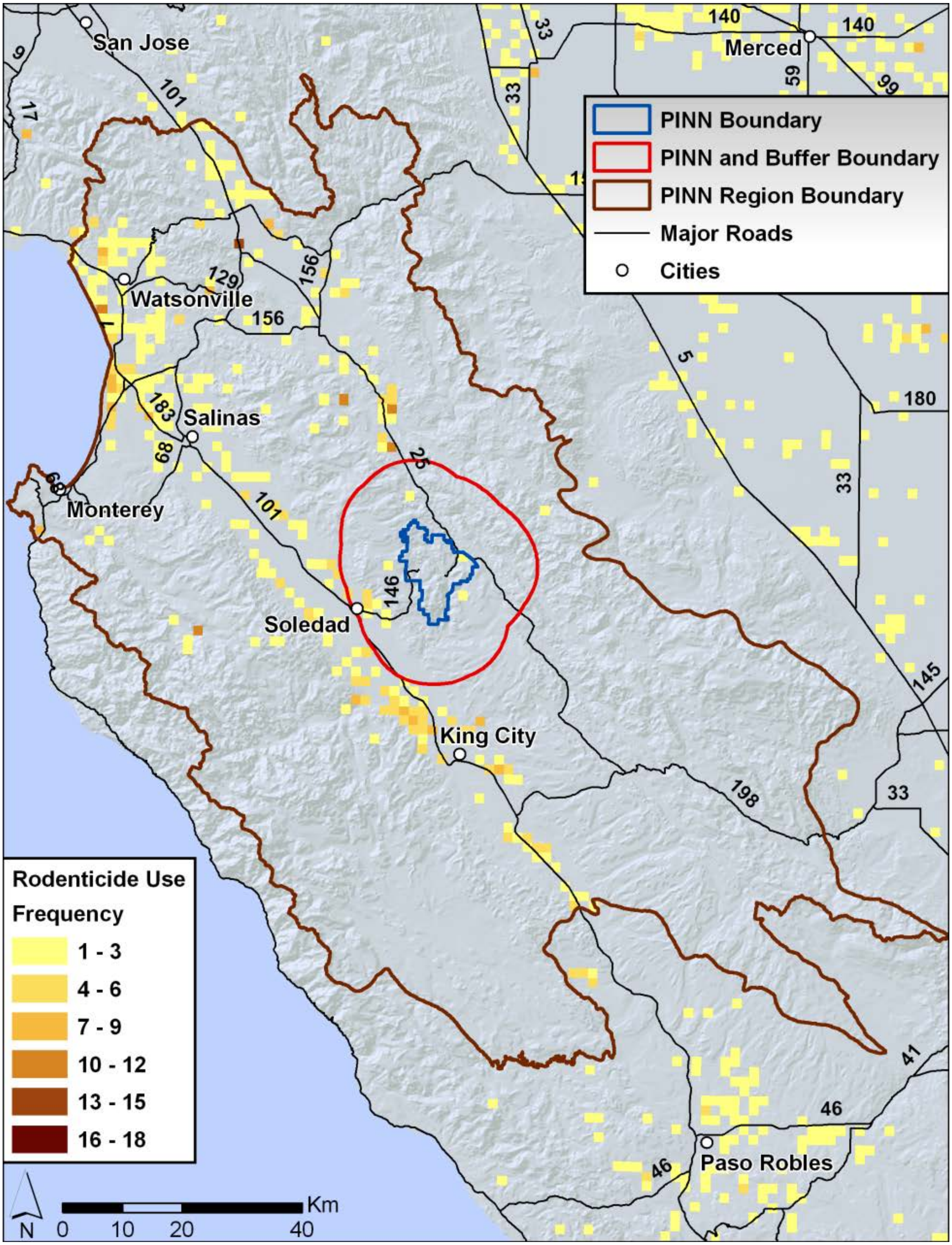

Figure 18. Number of years in which rodenticides were applied from 1990 to 2008 by public land survey system sections.

Trends

Regional scale: There was no discernible trend in rodenticide applications at the regional scale (Figure 19a). Applications were below 1.5 kg from 1992 to 2001. They increased rapidly to 14.75 kg in 2005 before dropping to 2.19 kg in 2007. The increase in rodenticide in 2005 use may be related to increases in ground squirrel populations following an El Nino in 2003 and subsequent years with wet springs. Chlorophacinone and diphacinone were the most commonly reported rodenticide at all scales although all six rodenticides were used at some point over the study period. The large increase in reported applications from 2001 to 2005 at the regional scale was due to chlorophacinone. Applications of second generation rodenticides were generally below 0.001 kg per year although difethialone use increased to 0.007 kg in 1998 which is enough for hundreds of bait station applications (Figure 19b).

Park-and-buffer scale: There was no discernible trend in rodenticide applications at the park-and-buffer scale (Figure 19c). Applications varied from year to year but within a narrow range, from 0–0.02 kg. No applications were reported in 2007 within the administrative boundary of PINN, with only rare applications since 1990.

Emerging Issues

Multiple stressors such as fragmentation, disease, and rodenticide exposure may interact to cause population declines in non-target species (Riley et al. 2007). More long-term studies of wildlife populations will be necessary to reveal stressor interactions. In 2008 the Environmental Protection Agency introduced regulations to restrict residential use of four rodenticides that carry the most risk for wildlife—brodifacoum, bromadiolone, difethialone, and difenacoum. Only the first three rodenticides have been reported in the CA-DPR database for the study period. The extent to which these restrictions will reduce wildlife exposure is unknown. The rodenticides that made up the bulk of use near PINN are not covered by these regulations.

Data Gaps

The CA-DPR pesticide database only tracks reported applications of rodenticides. Home and garden uses are generally exempt from reporting requirements, and thus their contribution to the exposure for wildlife is unknown. Rodenticide application methods are also unreported. The amount of active ingredient to which non-target species may actually be exposed is unknown but depends on availability of contaminated prey, which depends on a variety of factors including the timing and duration of rodenticide application, application method, bait formulation, and chemical concentration.

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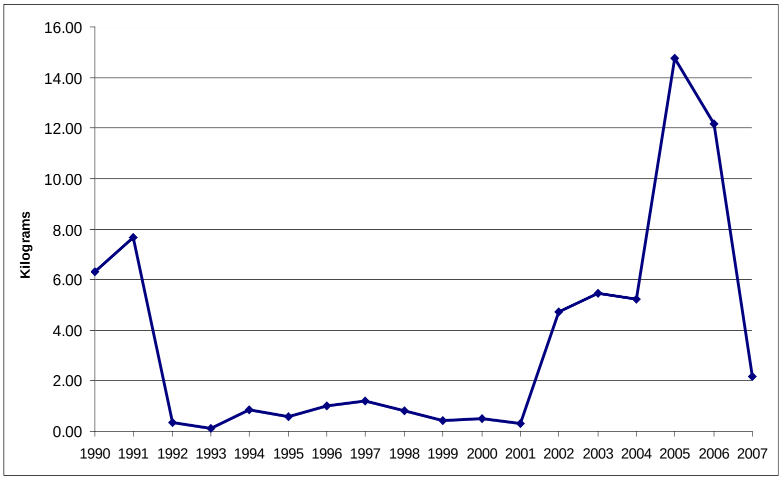

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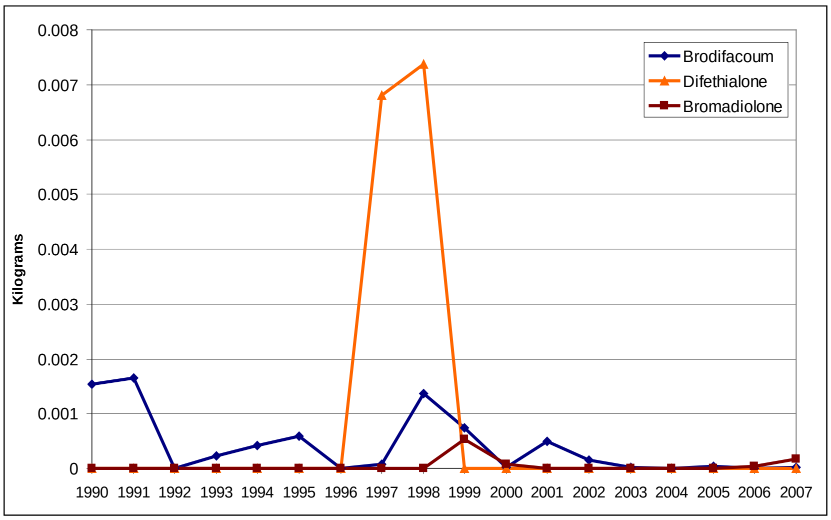

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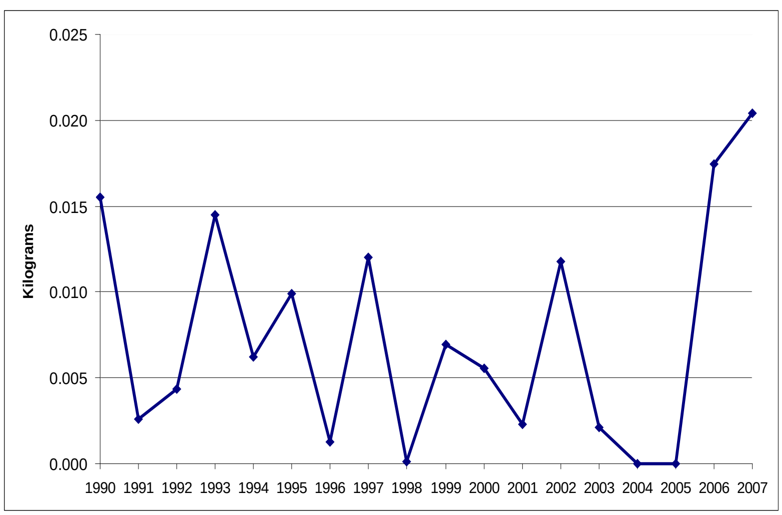

c)

Figure 19. Trends in rodenticide use at the regional scale (a). Trends in second generation rodenticide use at the regional scale (b). Trends in rodenticide use at the park-and-buffer scale (c).

Stressor: Human Footprint
Findings: Baseline only

The Human Footprint model synthesizes information about many stressors into a cumulative indicator of human-caused disturbance. The GIS database for the western states developed by Matthias Leu and colleagues at USGS categorizes levels of footprint intensity or disturbance. PINN is relatively isolated from urban development and other disturbance factors. Consequently PINN is only moderately impacted for a unit of the national park system. One-third of the area of PINN is mapped in the lowest intensity footprint classes, with the remainder in the medium intensity category. When including the surrounding landscape in the analysis, the vast majority is modeled as medium intensity. The human footprint has not been modeled for past times, so trend results are not available. However, we know that housing density and other factors associated with the footprint have increased and are most likely to continue increasing. We can presume then that the human footprint is increasing at all ecological scales, although relatively slower within PINN.

Approach

Stressors do not operate independently from each other to affect natural resources. Some attempts have been made to develop synthetic indicators of stressors. The human footprint (Sanderson et al. 2002, Leu et al. 2008) is such an indicator. It can be used to plan land management actions, prioritize areas for restoration, and identify areas of high conservation value. It can also compare overall ecological condition between sites or over time to assess measures of success for conservation or other management actions (Haines et al. 2008). For this condition assessment, we used the GIS layer of the Human Footprint in the West as a standardized product that could be applied to all western park units. Details of the methods for compiling this synthetic indicator are provided in Leu et al. (2008), but are summarized here.

The human footprint was derived from seven input models of human-caused disturbance (Figure 20). Each model accounted for both the physical area occupied by the feature (e.g., road surfaces) and the “ecological effect area” defined by the ecological neighborhood of that feature. Three models were considered “top-down” and modeled threat from populations of predators such as corvids (crows, ravens, and magpies), domestic cats, and domestic dogs that deplete native species. Threat was based on proximity to human land uses. Four “bottom-up” models accounted for threat to habitat, again on the basis of land use plus wildfires. National or regional spatial data sets were acquired and manipulated to produce the seven models at a spatial resolution of 180 meters. The standardized scores of the seven input models were summed, and then the continuous values were binned into ten footprint intensity classes from lowest (class 1) to high (class 10). The footprint model was tested with data from the Breeding Bird Survey (Leu et al. 2008). The tests found that the footprint was positively correlated the abundance of birds that are adapted to human-dominated environments and negatively for those that are sensitive to disturbance.

The GIS data provides a visual overview of the pattern of the intensity of the human footprint, but it helps to have some summary analysis. Because the intensity values are recorded as classes rather than numerical values, it is not possible to compute averages or similar summary statistics. Therefore for this condition assessment, the area of the intensity classes were tabulated and converted to percentages at all three ecological scales (park, park-and-buffer and region). Comparing across scales provides context about the degree of isolation of the park.

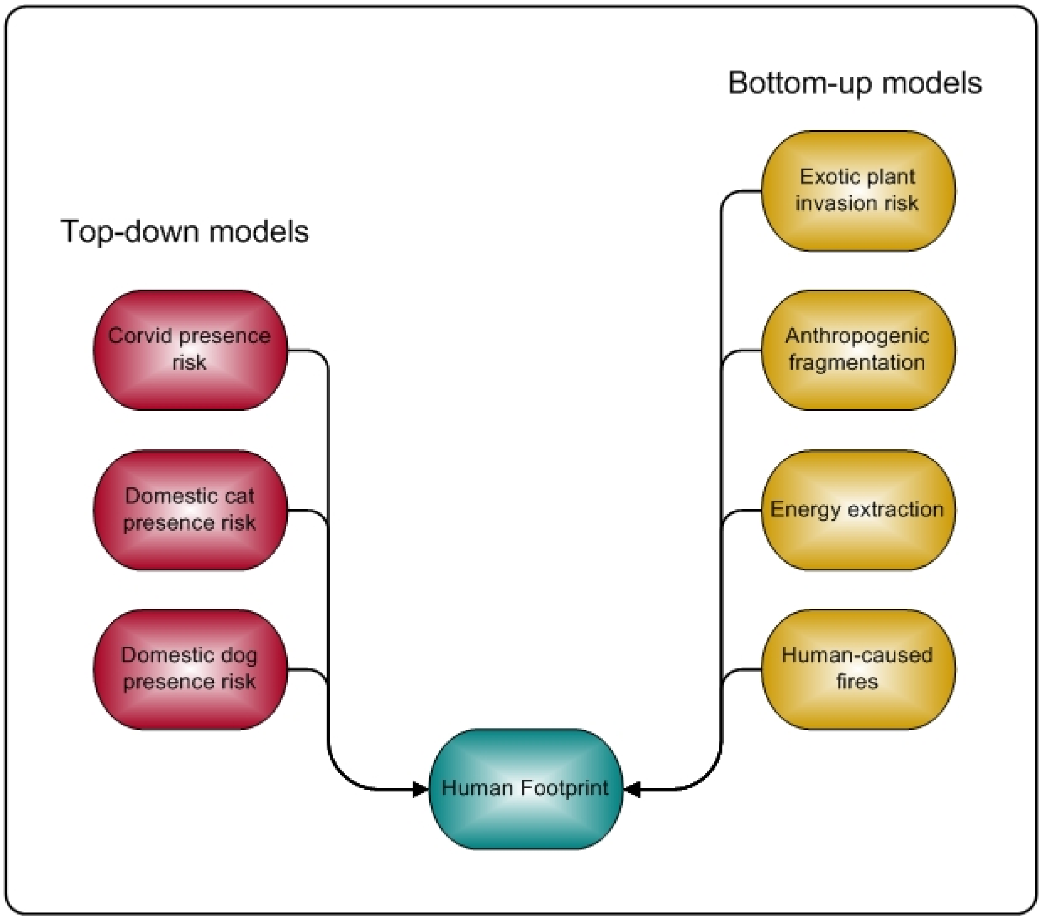

Figure 20. GIS conceptual model of the human footprint (redrawn from Leu et al. 2008). Each input model is based on multiple input factors.

Data

- Human Footprint in the West http://sagemap.wr.usgs.gov/HumanFootprint.aspx (Leu et al. 2008)

Status

The general pattern of urban development and agriculture can be clearly identified in the map of the human footprint with finer grain details produced primarily by the road infrastructure (Figure 21). The footprint is generally low to medium intensity within the PINN boundary due to the absence of development or agriculture in or near the park unit. At the park-and-buffer scale, the intensity tends to increase as the effects of agricultural land and small towns are incorporated into the footprint. The larger region is more complex, ranging from high intensity in the urban Monterey Bay area to the north to low intensity further east in the inner Coast Ranges and along the western boundary near the Big Sur coastline. PINN is far from pristine according to the human footprint analysis, but it is generally buffered by lands with a slightly higher footprint.

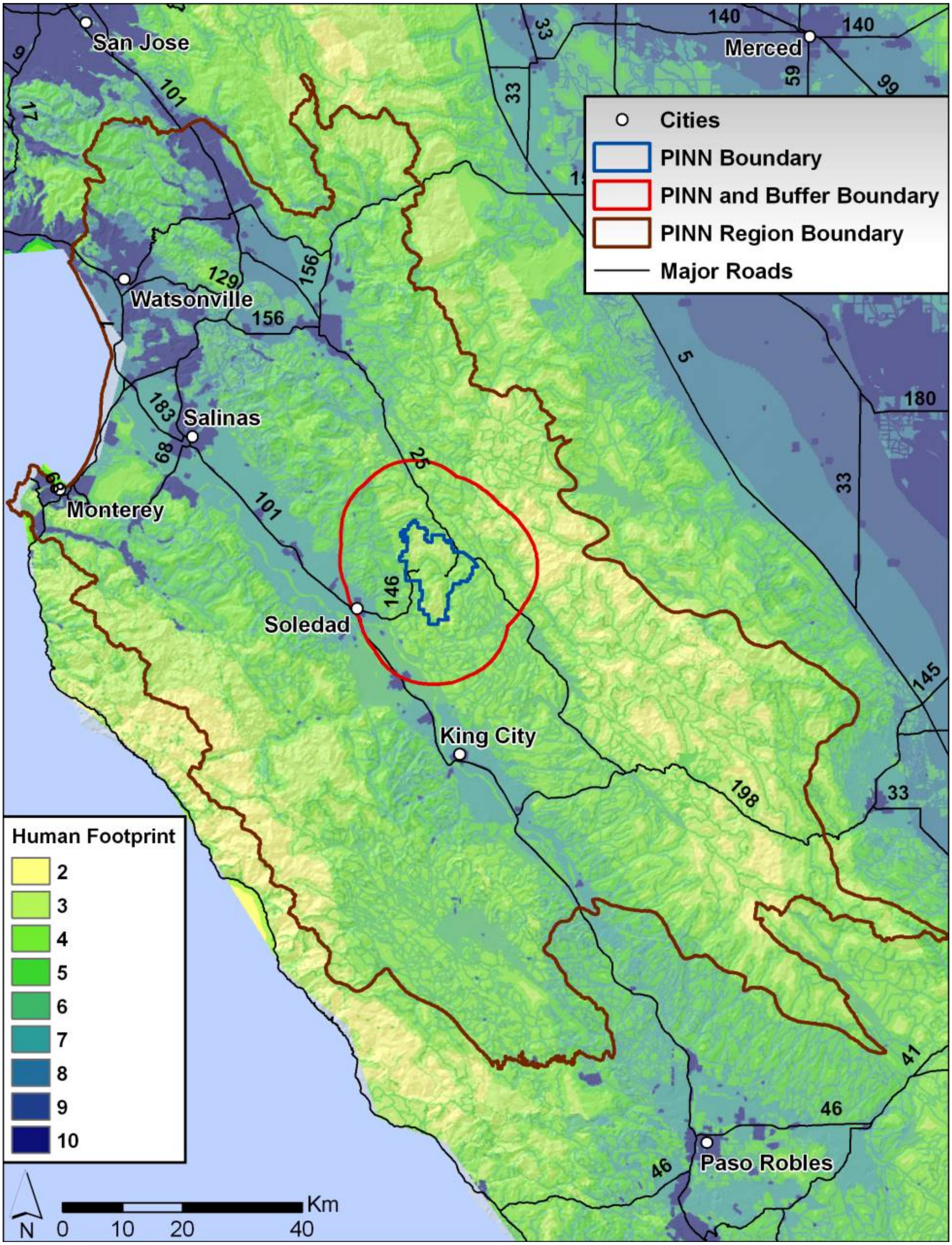

Figure 21. Map of the human footprint intensity (Leu et al. 2008) for PINN and surrounding regions.

Tabulating percentages of area in each class quantifies the visual impressions from looking at the map in Figure 21. At all three scales, the footprint intensity peaks at class 4 (lowest intensity class in the medium category, Figure 22). Within PINN, half of the park unit is class 4, with most of the remainder in class 3 (low intensity). No high intensity classes are found in PINN at this time. The park-and-buffer scale incorporates higher road density and some agricultural land in the neighboring valleys, which models a higher percentage of land in the medium intensity classes relative to the park unit itself. The regional scale includes a greater proportion of urbanized land and agricultural area and so has larger percentages in the high intensity footprint classes.

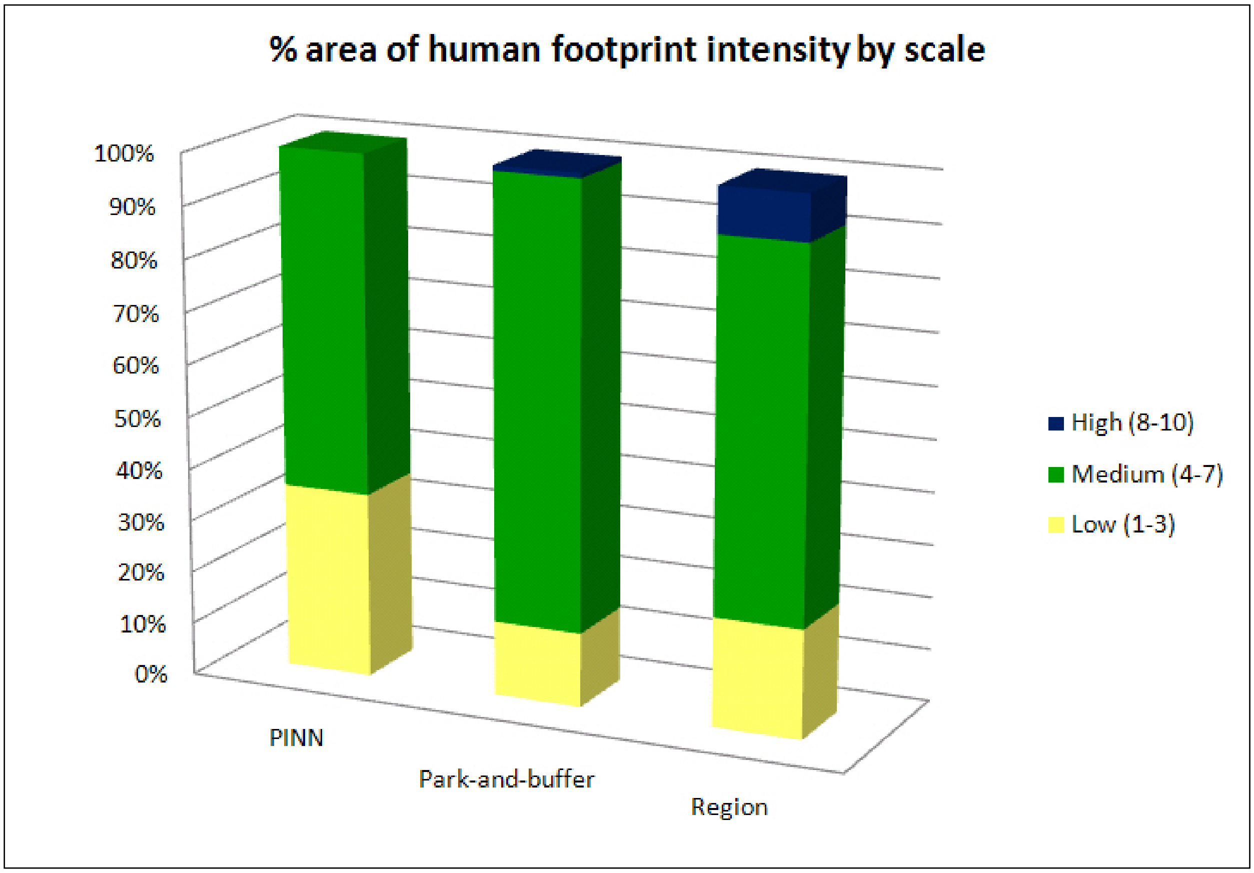

Figure 22. Bar graphs of the relative percentage of human footprint intensity for PINN, the park-and-buffer landscape, and the region as the percentage of intensity grouped into low, medium, and high categories.

Emerging Issues

The human footprint synthesizes several of the stressors addressed individually elsewhere in this assessment. Consequently the areas of most intense footprint are also evident in the results for fire, housing density, fragmentation, and invasive plants. The footprint method extends the physical area of disturbance to incorporate the ecologically affected area as well. Thus a human footprint analysis in the future may detect broader impacts than the other stressor indicators from increasing low density development near PINN.

Data Gaps

The human footprint data are a snapshot for a single point in time (circa 2000). Therefore trend data are not currently available to determine where (and how much) the human footprint has changed. Urban development has the greatest influence in the footprint model, so the change should closely follow the pattern found in the Housing Density stressor section. In addition, we would only expect the footprint to increase over time, because most of the inputs represent permanent change. The human footprint classes may be a conservative estimate of disturbance because of the equally-weighted summation method used to combine the seven input models. No matter how severe the impact of any one input model, it can only contribute 1/7th of the total score. An alternative approach would be to use the maximum score of any input model (Davis et al. 2006). Many of the input models use the same factors (e.g., agricultural lands, human populated areas). Hence there is a risk of cross-correlation of inputs and therefore of double-counting them. Finally, the footprint process standardized scores of input models by division of the highest value (Leu et al. 2008). If the highest values increase in the future, indicating an even more intense human footprint, the scale of scores would shift and make comparison with baseline scores harder to interpret.

Key References

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Haines, A. M., M. Leu, L. K. Svancara, J. M. Scott and K. P. Reese. 2008. A theoretical approach to using human footprint data to assess landscape level conservation efforts. *Conservation Letters* 1:165–172.

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Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo and G. Woolmer. 2002. The human footprint and the last of the wild. *BioScience* 52:891–904.

Summary of Stressors

Table 15 summarizes the assessment of status and trends of stressors. Trend indicator icons reflect the direction of stressor measures rather than the condition of resources affected by the stressors.

Table 16. Summary of status and trends of stressors in the PINN condition assessment report.

STRESSOR	MEASURES	RECENT DATA	STATUS	TREND
Housing development	Regional housing density Park-and-buffer housing density	15 units/km^2 3 units/km^2	In 2000, overall housing density in the region was 15 units/ km^2, which can be considered exurban. Average housing density at the park-and-buffer scale was 3 units/ km^2, but the number of units increased 53% from 1990 to 2000.	
Road distance and accessibility	Mean distance from roads Mean travel time	1.8 km (within park) 0.93 hr (within park)	32% of PINN is within 1 km of a paved road. Riparian cover and invasive plant sections tend to occur much closer to roads than the average. Accessibility or travel time from the park entrances averages just under an hour.	
Pesticides affecting amphibians	Regional pesticide application in 2007 Park-and-buffer pesticide application in 2007	1.73 million kg active ingredient 60,000 kg active ingredient	Application rates in the Salinas Valley of pesticides known to have adverse effects on amphibians are similar in magnitude to those of California's Central Valley where studies have attributed amphibian population declines in Yosemite and Sequoia/Kings Canyon National Parks to regional pesticide use.	
Rodenticides	Regional pesticide application rate in 2007 Park-and-buffer pesticide application rate in 2007	0.0176 kg-km^{-2} active ingredient <0.01 kg-km^{-2} active ingredient	The amount of rodenticide active ingredient applied near PINN was enough for dozens to thousands of individual rodenticide applications per year. The more lethal second generation rodenticides were applied infrequently. Rodenticides were applied within the foraging range of Prairie falcons (*Falco mexicanus*) and California condors (*Gymnogyps californianus*) that nest at PINN.	
Human footprint	Regional area of low intensity Park-and-buffer area of low intensity PINN area of low intensity	21% 14% 35%	The footprint is generally low to medium intensity within the PINN boundary due to the absence of development or agriculture in or near the park unit. At the park-and-buffer scale, the intensity tends to increase. The larger region is more complex, ranging from high intensity in the urban Monterey Bay area to the north to low intensity further east in the inner coast ranges and near the Big Sur coastline.	

 = baseline only  = no significant trend  = increasing trend

Resource Briefs

Overview of Indicators

The remainder of this section contains assessments of the key resource indicators under four level 1 categories: Air and Climate, Water, Biological Integrity, and Landscapes (Ecosystem Pattern and Processes). Each assessment follows a similar outline. Each begins with a brief summary of the findings about that resource. The banner of each section is colored according to a qualitative judgment of the current condition of that resource, along with an icon indicating the trend. Then the methods are described followed by a description of the data used in the assessment. Results are presented next by status if only current conditions are known and/or trends if data were analyzed through time. The data and results sections discuss the relevant scales of assessment—regional, park-and-buffer, and park, as described above. Depending on the data, some resources are reported by their spatial distribution in maps and some as trends in time-series plots. In some cases, the time-series data for the resource, e.g., prairie falcon nesting success, are regressed against temporal climate data. Each assessment then concludes with the identification of emerging issues and data gaps.

Air and Climate Level 1 Category

Air and Climate—Air Quality
Findings: No significant change

Clean, clear air is a high profile resource at PINN, leading to its designation under the Clean Air Act as a Class I national park unit. PINN is located in the North Central Coast air basin which includes populated areas around Monterey Bay and which receives intra-basin air transfers from the San Francisco Bay (CARB 1996). Although air quality is important for visitor experiences at PINN, pollutants such as ozone and nitrogen, primarily from fuel combustion from mobile and stationary sources, can affect PINN's natural resources by altering stream chemistry, damaging vegetation, or altering plant community composition (Fenn et al. 2003).

Although there was a minor decreasing trend, 0.43 ppb/year, concentrations of the annual 4th highest 8 hour ozone exceeded the 75 ppb "significant concern" threshold for most of the years between 1989 and 2007 (NPS 2009). In a risk assessment conducted for vital signs monitoring of network parks, three ozone sensitive plant species at PINN were identified as susceptible to foliar damage based on exceedance of multiple ozone injury thresholds (Kohut 2007). However, foliar damage has not been documented in the field (Sullivan et al. 2001).

Nitrogen and sulfur deposition rates correspond to "good condition" and no significant trends in deposition rates have been observed (NPS 2009). However, the most sensitive ecosystem components, lichens and streamwater nitrate levels for example, can be adversely affected at total N deposition levels of 3 kg/ha/year (Fenn et al. 2003). This level was approached or exceeded in five of the eleven years between 1996 and 2007. Stream waters in PINN are well buffered, do not appear to be acid sensitive, and are not expected to be affected by current N loadings (Sullivan et al. 2001). Lichen communities have only been recently surveyed at PINN so long-term community changes, such as increases in nitrophytic species associated with elevated N levels, have not been observed.

Visibility condition at PINN is rated "significant concern" as a result of high haze index values relative to estimated values in the absence of human caused degradation.

The ecological impacts of air quality are a result of interactions between emissions, largely anthropogenic in the region around PINN, transport, and deposition processes. Changing climate parameters, such as the amount and timing of precipitation, will likely influence pollutant transport and deposition pathways across the entire air basin in the future.

Approach

The Air Resources Division (ARD) of the NPS publishes annual reports on trends in ozone, sulfur, and nitrogen. The ARD report uses an Environmental Protection Agency (EPA) ozone metric, which is the annual fourth highest 8 hour ozone concentration, referred to hereafter as ozone concentration. Concentrations above 75 ppb are considered of "significant concern" for vegetation and a three year average of greater than 75 ppb exceeds the National Ambient Air Quality standard for ozone. For sulfur and nitrogen, wet deposition estimates were produced by multiplying analyte concentrations in precipitation by 30 year normalized precipitation estimates.

Data for ozone was available from 1987 to 2010, while data for nitrogen and sulfur was available from 1998 to 2007. Visibility data was available for 1999–2008. Data and condition assessments were compiled from the 2008 report. We acquired additional nitrogen and sulfur deposition data from the Environmental Protection Agency's Clean Air Status and Trends Network and additional ozone and visibility data from the NPS Gaseous Pollutant and Meteorological Data Access Page as well as NPS air quality estimates.

Data

Park:

NPS Gaseous Pollutant and Meteorological Data Access Page - http://12.45.109.6/

Clean Air Status and Trends Network - http://java.epa.gov/castnet/

National Park Service, Air Resources Division. 2009. Air quality in national parks: 2008 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2009/151. National Park Service, Denver, Colorado.

Status

Park scale: Recent ozone concentrations are near the EPA non-attainment standard of 75 ppb. PINN is one of only two park units (along with Cape Cod National Seashore) showing improvement in ozone (Figure 23). PINN ranked 16 of 47 parks in ozone concentration in 2007 (NPS 2009). Nitrogen deposition is relatively low at PINN although it is elevated above the natural background deposition rate of 0.25 kg/ha/year in the western U.S (Figure 24) (NPS 2009). Sulfur deposition is low at PINN and just above natural background deposition rate of 0.25 kg/ha/year (Figure 25). Visibility condition at PINN is just above the threshold for significant concern (Figure 26). Visibility conditions at PINN, relative to reference conditions, are similar to those of Sequoia/Kings Canyon NP and Santa Monica Mountains National Recreation Area.

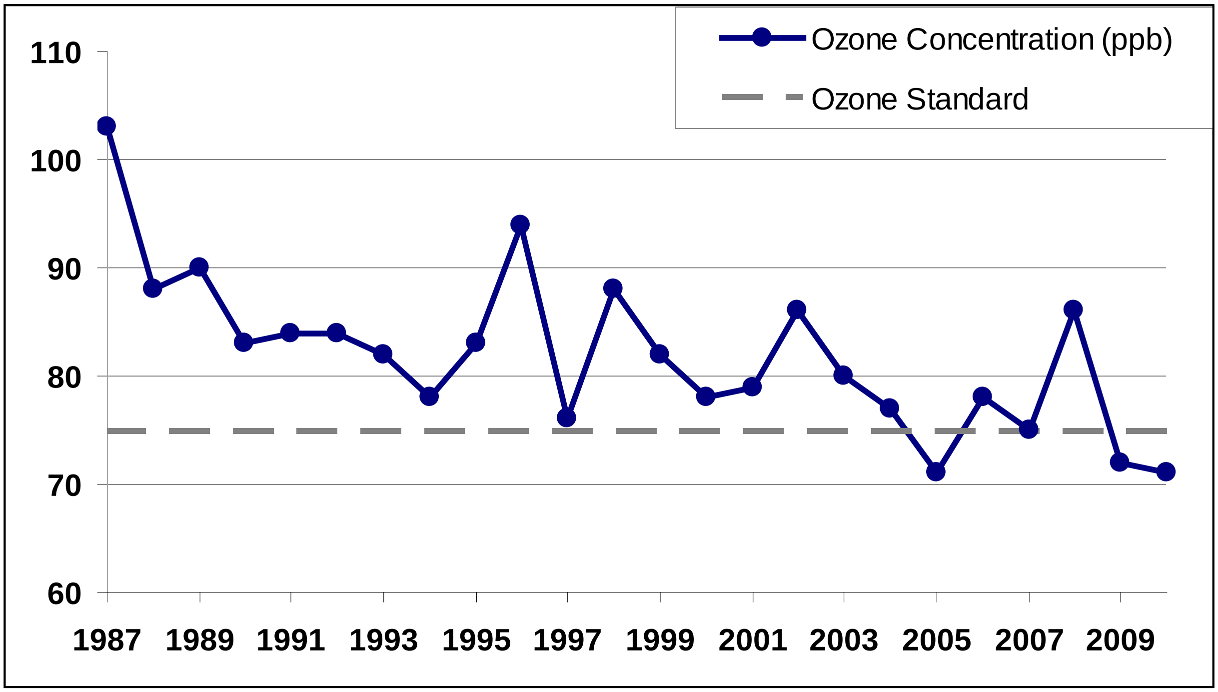

Figure 23. Trends in ozone concentrations in parts per billion (ppb) for PINN.

Trends

Park scale: Ozone concentrations have been decreasing at a rate of 0.43 ppb/year since 1989, usually varying between 70 and 95 ppb. Only within the last decade have concentrations gone below the EPAs 75 ppb standard. Total nitrogen deposition has declined since 1996. Analysis of wet deposition revealed no statistical trends, however (NPS 2009). Wet deposition of NH4, ammonium, and NO3, nitrate, made up a larger proportion of total deposition between 1996 and 2001. Dry deposition of HNO3, nitric acid, has stayed relatively steady over time and dominates total deposition in recent years. Sulfur deposition has generally stayed below 1 kg/ha since 1996. Visibility, after improving from 1999–2003 to 2001–2005, has been declining since. Visibility condition was moderate from 1999–2003 to 2003–2007 but passed the threshold to significant concern in 2004–2008. California's regional haze plan calls for an improvement of 57% over the worst visibility days at PINN, currently 18.5 deciviews, by the year 2064.

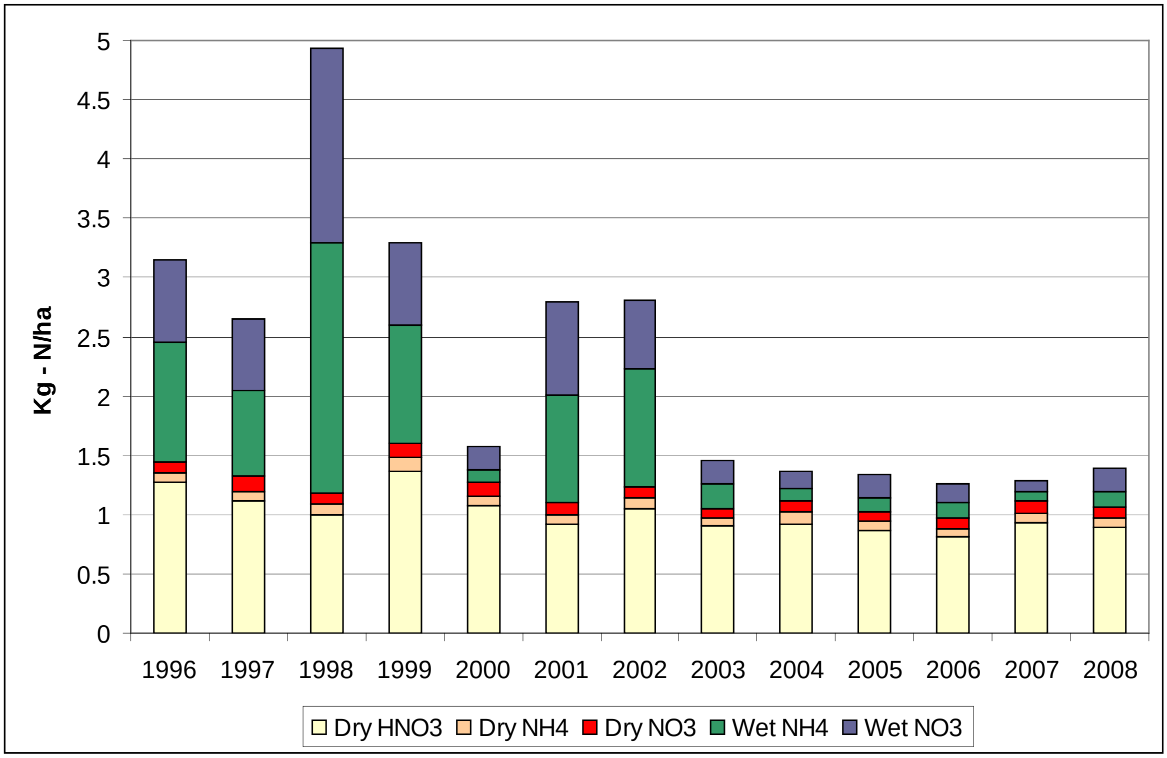

Figure 24. Nitrogen deposition by analyte and deposition pathway.

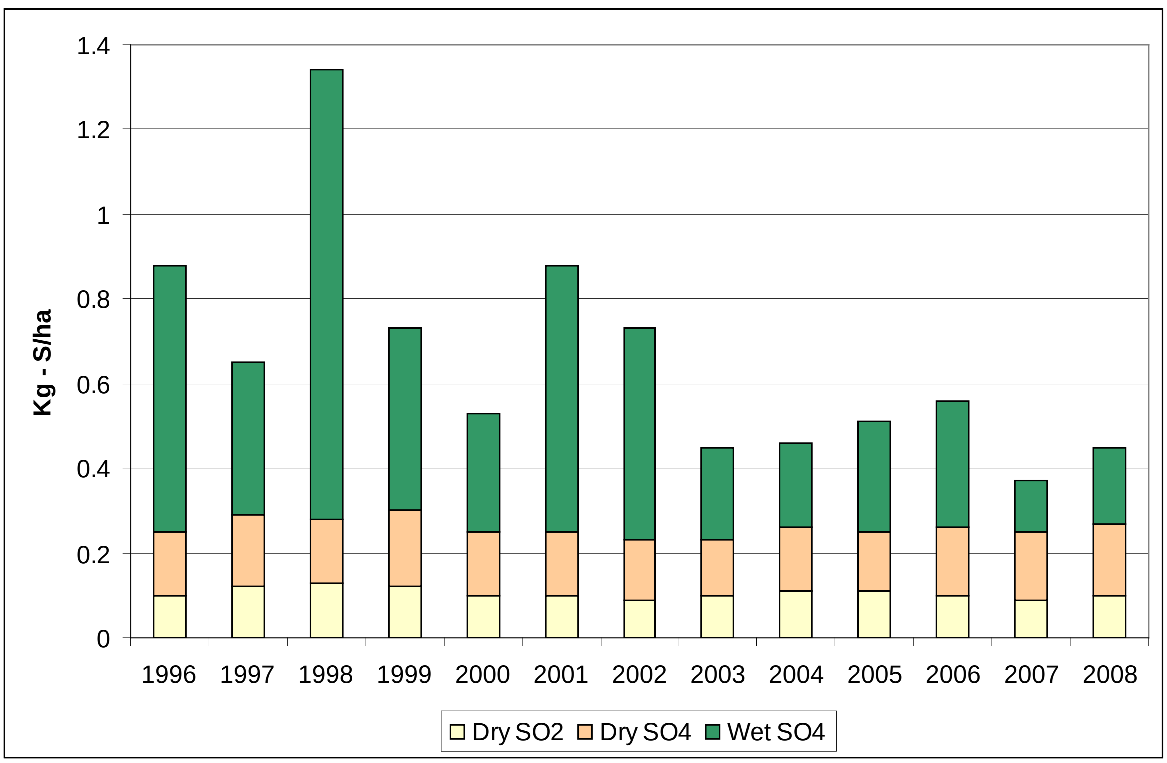

Figure 25. Sulfur deposition by analyte and deposition pathway.

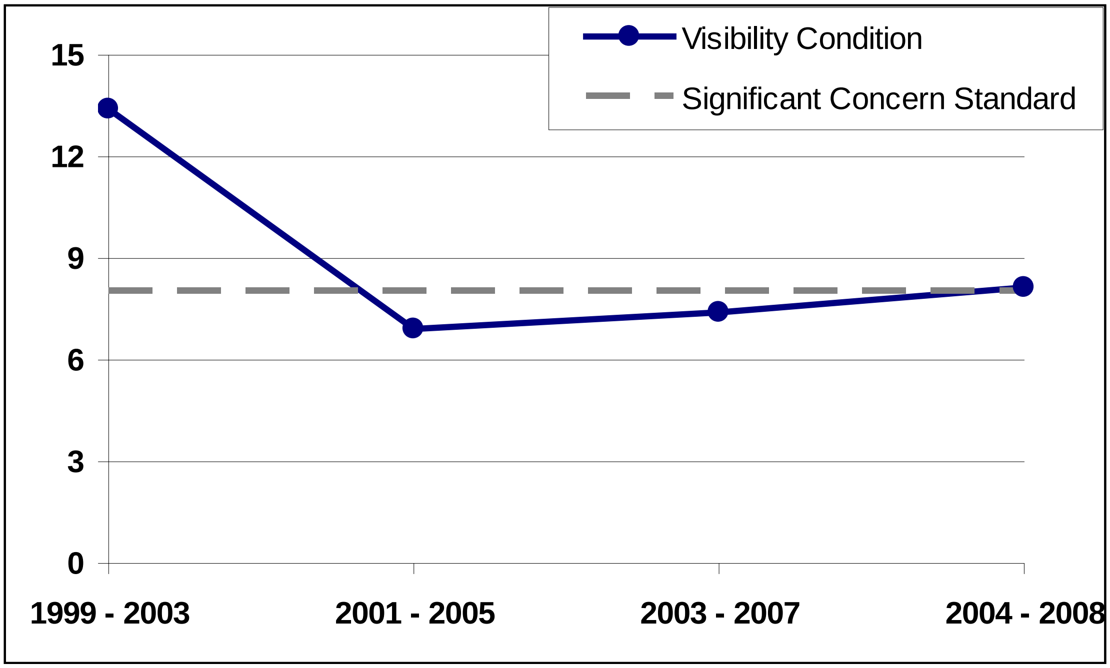

Figure 26. Visibility condition for PINN. Values for each 5-year period are interpolated average deciview values minus estimated deciview values in the absence of human caused degradation in visibility. Deciviews are a measure of light extinction. Values greater than 8 deciviews above reference conditions indicate significant concern.

Emerging Issues

The critical nitrogen load for lichen community change in chaparral and oak woodland systems in California has been estimated at 5.5 kg ha^{-1} yr^{-1} (Fenn et al. 2010). Although nitrogen deposition rates are relatively low at PINN, they are at levels that are associated with changes in lichen community composition in other parts of California, and chronic low level nitrogen loading at PINN may result in changes in lichen species over time (Jovan 2008).

Data Gaps

PINN's air monitoring program provides information on ozone, nitrogen, and sulfur trends but there are little data on the ecological effects of these trends.

Key References

Fenn M. E., Baron J. S., Allen E. B., Rueth H. M., Nydick K. R., Geiser L., Bowman W. D., Sickman J. O., Meixner T., Johnson D. W. and Neitlich P. 2003. Ecological effects of nitrogen deposition in the western United States. *BioScience* 53: 404–420.

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Kohut, R. J., 2007. Ozone risk assessment for vital signs monitoring networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail. NPS/NRPC/ARD/NRTR—2007/001. National Park Service, Fort Collins, Colorado.

National Park Service, Air Resources Division. 2009. Air quality in national parks: 2008 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2009/151. National Park Service, Denver, Colorado.

Sullivan, T. J., Peterson, D. L., Blanchard, C. L., and Tanebaum, S. J. 2001. Assessment of air quality and air pollutant impacts in class I national parks of California . National Park Service. Denver, CO. Available at http://www.nature.nps.gov/air/Pubs/pdf/reviews/ca/CAreport.pdf (accessed April 2011).

Air and Climate—Climate
Findings: No historical trend, increasing trend predicted

PINN's climate is subhumid and hot, with an average annual temperature of 15ºC (59ºF) and average annual precipitation of 43cm (17 in). Based on linear regressions of daily climate data, there were no directional trends in minimum temperature of the coldest period, annual growing degree days (GDD) above 5ºC , or annual precipitation at PINN from 1948 to 2001. Downscaled climate models consistently project a 32–38% increase in GDD by 2100 for the park scale, resulting in future conditions at PINN that are currently found in the southern San Joaquin Valley. Minimum winter temperatures are projected to increase by 2.0–2.7ºC while maximum summer temperatures are projected to increase by 3.7–4.0ºC. Seasonality, measured as the standard deviation of monthly mean temperatures, is projected to increase by 7–16%. Precipitation projections are variable, either increasing or decreasing depending on the global climate model (GCM). Climate can affect species distributions and ecological processes directly through changes in temperature and precipitation and indirectly through changes in species interactions. The combination of large projected increases in temperature and relatively modest changes in precipitation can be expected to reduce the growth and recruitment of many plant species at PINN. Modeled associations with climate and soil indicate that suitability is low across much of the landscape for two tree species found at PINN, California Buckeye, *Aesculus californica*, and Valley Oak, *Q. lobata*. This reflects the limited occurrence of these species in relatively cool and wet sites. Projected distributions based on climate models indicate that under future climates, probability of occurrence will rarely exceed 0.1 for either species in PINN, further restricting these trees to the coolest and wettest sites. Areas surrounding PINN are also expected to decrease in suitability, increasing the isolation of remaining trees. These changes could result in decreased cover and forage for the many bird and mammal species that use Valley Oak. Decreasing numbers of California Buckeye and changes in the timing of flowering and pollen availability could impact butterfly community composition.

Approach

We acquired historical climate data for the PINN California Cooperative weather station (ID# 046926) from the National Climatic Data Center. We constrained observation dates to 1948–2001 to match the availability of climate normals data which were substituted for missing values in the raw climate data where necessary. To test for temporal trends, we performed bivariate linear regressions where minimum temperature of the coldest period, annual GDD, and average precipitation were the dependent variables and year was the independent variable. GDD is a measure of cumulative heat during the growing season, which affects the timing of ecological processes such as flowering in plants or hatching of insects. It was calculated by taking the average of the daily maximum and minimum temperatures minus a 5ºC base temperature and summed over the days of the year. We also conducted tests for serial autocorrelation in the regression residuals.

We obtained spatial climate data at 90m resolution for historic (1971–2000) and future (2000–2100) periods that were downscaled by USGS from the Geophysical Fluid Dynamics Laboratory (GFDL) model and the Parallel Climate Model (PCM) global climate models (GCMs) for the A2 emissions scenario (medium-high emissions trajectory) (see Chapter 3 for details on GCMs and scenarios). We transformed the monthly temperature and precipitation data into five ecologically-relevant climate variables: GDD, minimum temperature of the coldest period, maximum temperature of the warmest period, mean annual precipitation, and temperature seasonality (the standard deviation of monthly mean temperatures). For the spatial data, GDD was derived from monthly average minimum and maximum temperatures and adjusted for the number of days in the month that would be above the 5ºC threshold. We summarized these variables as the spatial average at the three reference scales for the current time period and for future period forecasts generated by the two climate models. Comparing between models brackets the range of potential values and characterizes the degree of consensus about an uncertain future. Comparing across scales indicates how isolated PINN is climatically from its surrounding region.

To illustrate possible biotic responses to climate change, we compared the potential distributions of two tree species, Valley Oak and California Buckeye, with their potential future distributions under climate change.

Data

Park scale:

Comma delimited text files of daily surface measurements of minimum temperature, maximum temperature and precipitation from 1948 to 2001 were downloaded from http://www7.ncdc.noaa.gov/CDO/cdo. Space delimited web forms of daily dynamic climate normals were acquired for the same time period.

All scales:

Ninety meter resolution raster surfaces of climate variables were acquired from the USGS. Projections of each variable were generated for the A2 global emissions scenario by the GFDL and PCM models.

Ninety meter resolution raster surfaces depicting probability of occurrence of *Quercus lobata* and *Aesculus californica* under historic and projected climates. These data were developed by Maki Ikegami of the Biogeography Lab at the University of California Santa Barbara using the MaxEnt model with climate and soil variables.

Trends

Linear regressions indicate no significant trends in annual GDD, minimum annual temperature, and average annual precipitation from 1948 to 2001. Tests on regression residuals revealed no serial autocorrelation. Observed cyclical patterns are likely associated with the Pacific Decadal Oscillation and the El Niño/Southern Oscillation. GDD, minimum and maximum temperatures, and temperature variability are expected to increase from the current period (1971–2000) to 2100 (Figure 27). For example, future minimum temperatures at the park scale are expected to exceed the current minimum temperatures of the low lying areas surrounding the park. Future annual GDDs are projected to be similar to those currently found in the southern San Joaquin Valley near Bakersfield, CA (Figure 28). Future minimum temperatures are projected to be similar to those currently found near Soledad, CA. Annual precipitation increases in the PCM model but decreases in the GFDL model. Trends at the other park scales are projected to be similar to those at the park scale. In general, the GFDL model projects a warmer and drier future than the PCM.

PINN has lower minimum and higher maximum temperatures than its surrounding reference regions. GDD and precipitation are very similar across scales.

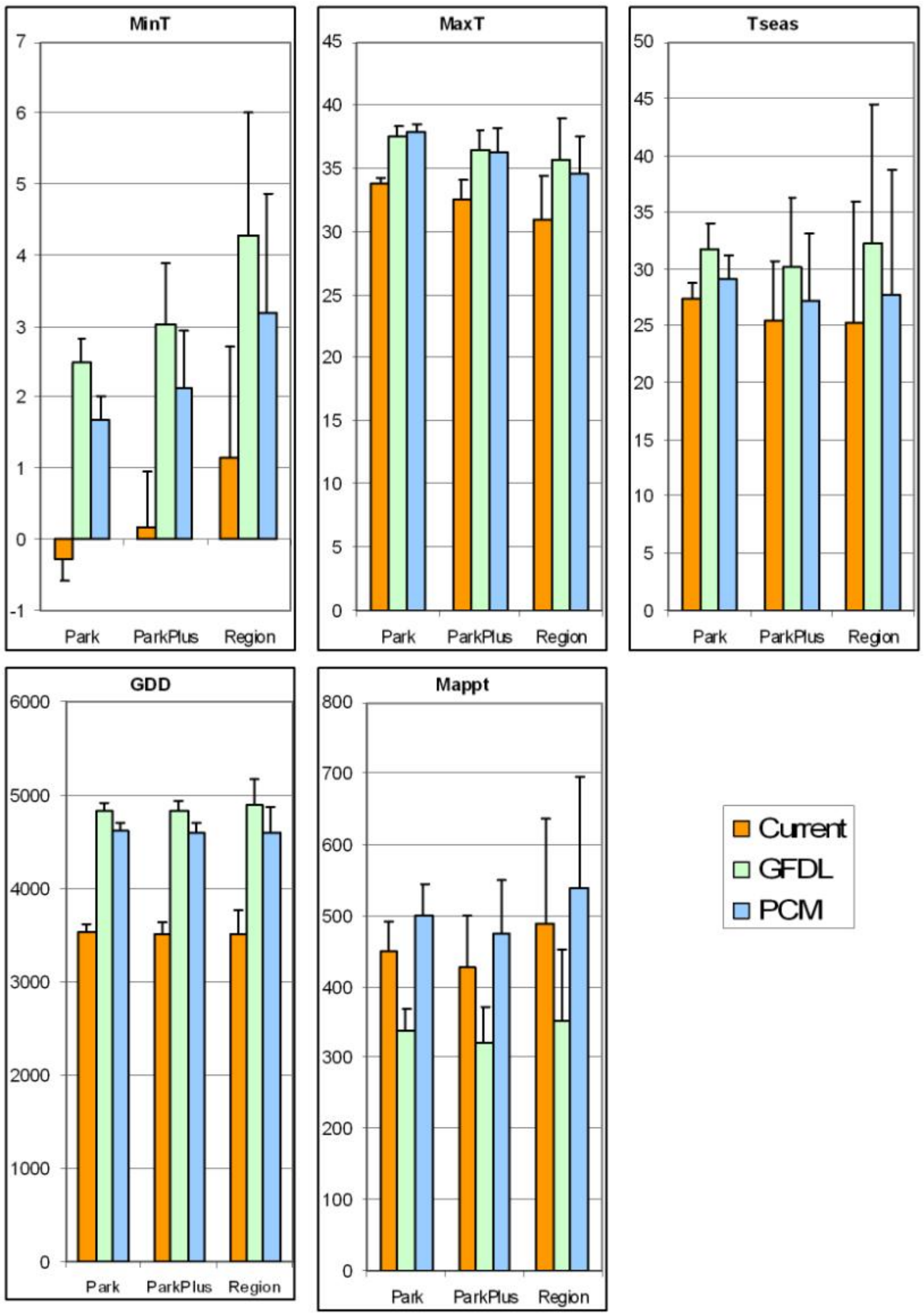

Figure 27. Current (1971–2000) and projected (2000–2100) values for climate variables summarized by three reference scales. Projected data from the Parallel Climate Model (PCM) and the Geophysical Fluid Dynamics model (GFDL). Error bars show the standard deviation of the spatial data at each scale. Climate variables are coded as follows: MinT = minimum temperature of the coldest period in oC, MaxT = maximum temperature of the warmest period in oC, GDD5 = growing degree days above 5oC, MAppt = average annual precipitation in mm.

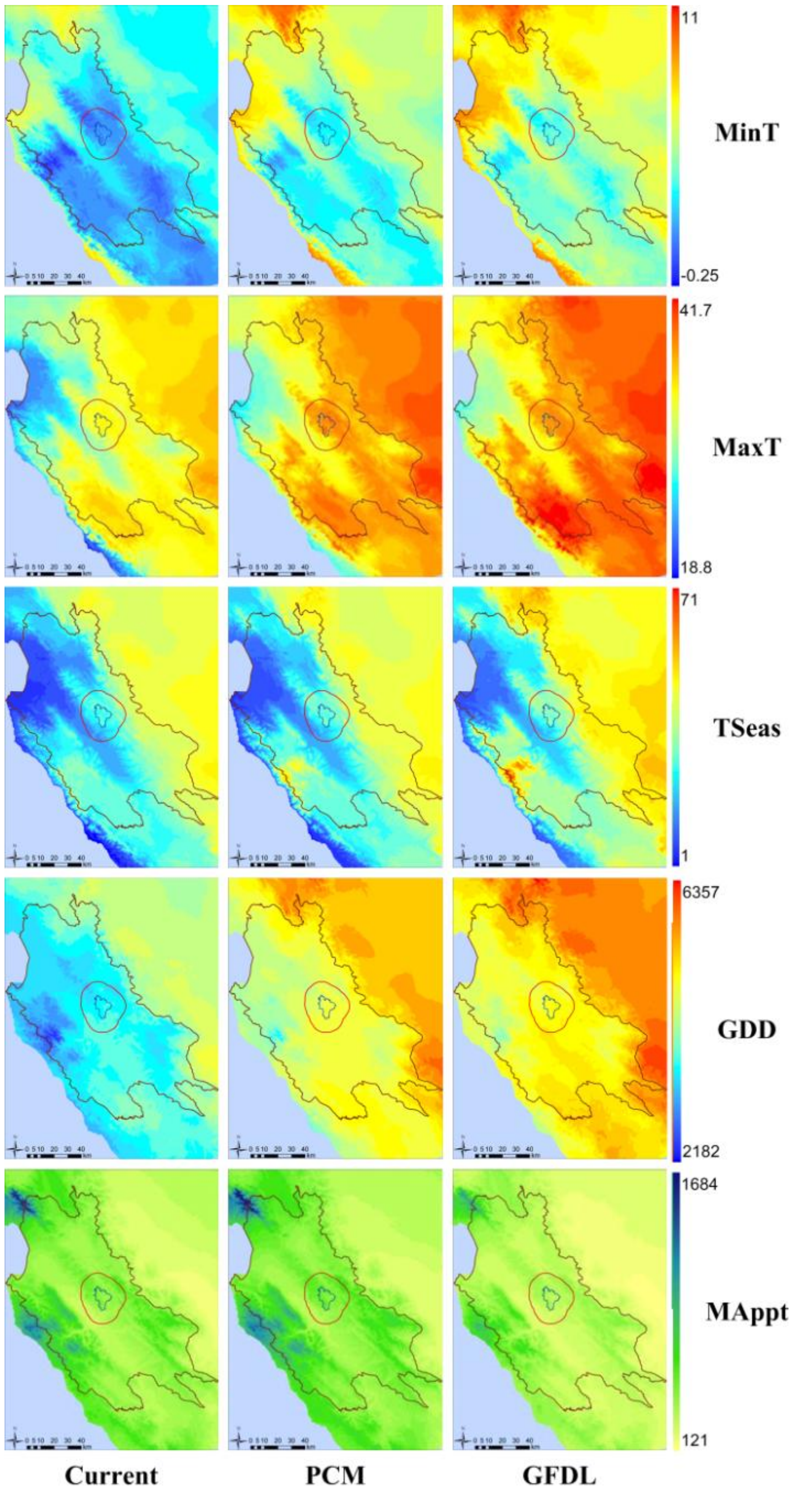

Figure 28. Maps show minimum temperature in °C of the coldest period (MinT), maximum temperature in °C of the warmest period (MaxT), temperature seasonality (Tseas), average annual growing degree days above 5°C (GDD), and average annual precipitation (MAppt) for the current time period (1971–2000), for 2000–2100 projected by the parallel climate model (PCM), and for 2000–2100 projected by the Geophysical Fluid Dynamics model (GFDL).

Occurrence probabilities for *Q. lobata* and *Aesculus californica* are expected to decrease to below 0.1 for most of PINN under both climate models although the PCM model results in slightly smaller decreases (Figure 29).*A. californica* is a vital seasonal source of nectar for many butterflies in the region so their loss could lead to a decline of butterfly diversity (Thorne et al. 2006). However, *A. californica* appears to be less important as a nectar source at PINN than in the surrounding region (NPS, P. Johnson, Wildlife Biologist, personal communication, 2011).

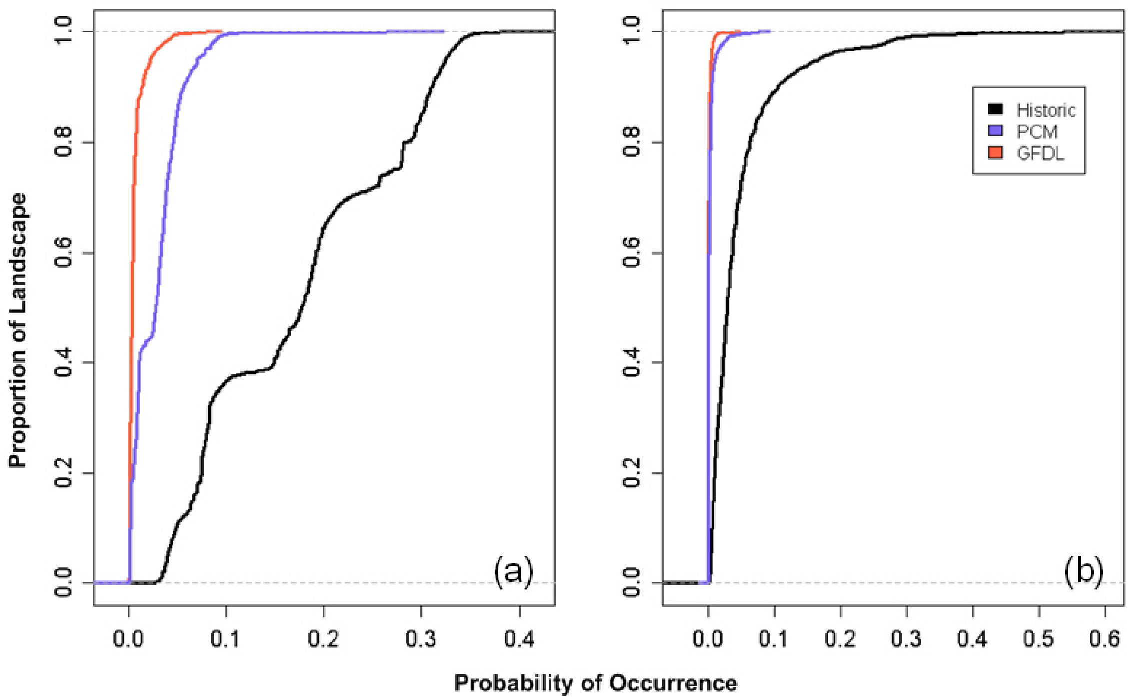

Figure 29. Empirical distribution functions of probability of occurrence for (a) *Quercus lobata* and (b) *Aesculus californica* under historic and projected climate conditions at the park scale.

Emerging Issues

Biotic responses to climate change, such as changes in range boundaries and community composition, have been well documented globally (Parmesan and Yohe 2003). However, species specific modeling approaches will likely be necessary to predict potential responses for PINN and surrounding areas (Hannah 2008). Phenological changes are likely as climate warms, altering plant-pollinator interactions which could affect the viability of PINNs numerous bee species. Change in precipitation, projections of which carry high uncertainty, will be an important determinant of the distribution and timing of breeding habitat for PINNs amphibian species. The interaction of climate change and wildfire are discussed in “Fire frequency and area burned in response to climate change and urban growth” section below. Emissions for 2000–2007 exceeded the most fossil fuel-intensive scenario from IPCC (Science Daily 2008), so these projected climate changes may be underestimated unless emissions are drastically curbed soon.

Data Gaps

The climate projections used here were generated globally and downscaled using topographic and other data. This approach potentially misses fine scale dynamics such as “reverse reactions” in which coastally influenced areas are cooled as warm inland air results in increased onshore flow (Lebassi et al. 2009). Further refinement of global models and addition of local modeling results will improve the reliability of forecasts. Although another modeling study finds similar decreases in suitability for Valley Oak in the south Coast Ranges (Kueppers et al. 2005), a longer record of climate reconstructed from tree rings or sediments could help refine our understanding of potential biotic responses to climate change at PINN. Monitoring data on biological responses to climate change, such as phenological changes, would be a useful complement to the climate data already collected at PINN. Hydrologic measurements could prove useful in assessing the relationship between altered precipitation patterns and water availability in streams at PINN.

Key References

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Lebassi B., Gonzalez J., Fabris D., Maurer E., Miller N., Milesi C., Switzer P. and Bornstein R. 2009. Observed 1970–2005 Cooling of Summer Daytime Temperatures in Coastal California. Journal of Climate 22: 3558–3573.

Water Level 1 Category

Water—Water Quality
Findings: Baseline

PINN falls under the jurisdiction of the Central Coast Regional Water Quality Control Board, which sets standards for ammonia, pH, dissolved oxygen, and pathogenic indicator bacteria. However, they do not set standards for other important indicators of water quality (e.g., nitrates, phosphates, temperature, specific conductance, turbidity or total suspended solids). The San Francisco Bay Area Network (SFAN) of NPS has ranked freshwater quality among the most important vital signs, indicators of ecosystem health that represent a broad suite of ecological phenomena. The SFAN protocol guides the monitoring of a large number of water quality indicators, which were sampled at eight sites in PINN in water years 2007 and 2008. In general, water quality indicators met the regional standards, but there were occasional exceedances at some sites such as for *E. coli* bacteria. Site MC1 in McCabe Canyon above the confluence with Sandy Creek is often the site of exceedances. Emerging issues include aerial drift of agricultural pesticides known to harm amphibians, nitrogen deposition from expanding human activities, and the effects of climate change on stream conditions and their effects on aquatic ecosystems.

Approach

The information about water quality condition indicators was excerpted from annual monitoring reports from NPS (Skancke and Carson 2009, Skancke and Booth 2010). Freshwater quality monitoring is conducted under the SFAN Freshwater Quality Protocol, version 2.11, approved in October 2006, which identifies stream monitoring stations and the parameters to be monitored at those stations, in five of the Network's national park units including PINN (Cooprider and Carson 2006). Eight sampling sites were selected within the Chalone Creek watershed, including five primary sites, and three secondary sites (Table 16 and Figure 30). Most of the eight sites have intermittent flow, and were monitored for core parameters, bacteria, and nutrient parameters (Table 17). Although some sites were designated as primary and some as secondary, an attempt was made during each monthly visit to sample at each location that had adequate flow. Most often, one or more of the sites did not have enough water to sample. Data were collected and reported by water year (WY), running from October 1 through September 30, for WY2007 (Skancke and Carson 2009) and WY2008 (Skancke and Booth 2010). Details about data analysis and quality control are provided in these annual reports. For this resource condition assessment, key findings are summarized from the reports and interpreted with respect to other indicators. The water quality parameters are affected by several stressors at varying spatial and temporal scales. Many are associated with watershed transport processes that move nutrients and particulates into stream channels. These watershed processes also interact with local disturbance processes such as invasive pigs or recreational impacts that can increase nutrients and pathogens. Regional climatic processes influence the flow and timing of precipitation and therefore of runoff and concentration of parameters in the water column.

Table 17. Chalone Creek watershed monitoring station locations–also see Figure 30.

Station	Type	Flow Regime	Site Description
CHA 3	Secondary	Intermittent	Approx. 1.5 mile upstream of the Bear Gulch confluence
CHA 2	Primary	Intermittent	Above the Chalone Creek bridge and upstream of the Bear Gulch confluence
CHA 1	Primary	Intermittent	Chalone Creek, 0.4 miles downstream of the Sandy Creek confluence at the Monument boundary
BG 2	Primary	Intermittent	On Bear Gulch, downstream of the visitor center
SC 3	Secondary	Perennial	Sandy Creek near the campground dumpstation
SC 2	Secondary	Intermittent	Unnamed tributary to Sandy Creek
SC 1	Primary	Intermittent	The furthest downstream site on Sandy Creek, 0.5 miles below the confluence with McCabe Canyon
MC 1	Primary	Intermittent	On McCabe Canyon, just upstream of the confluence with Sandy Creek

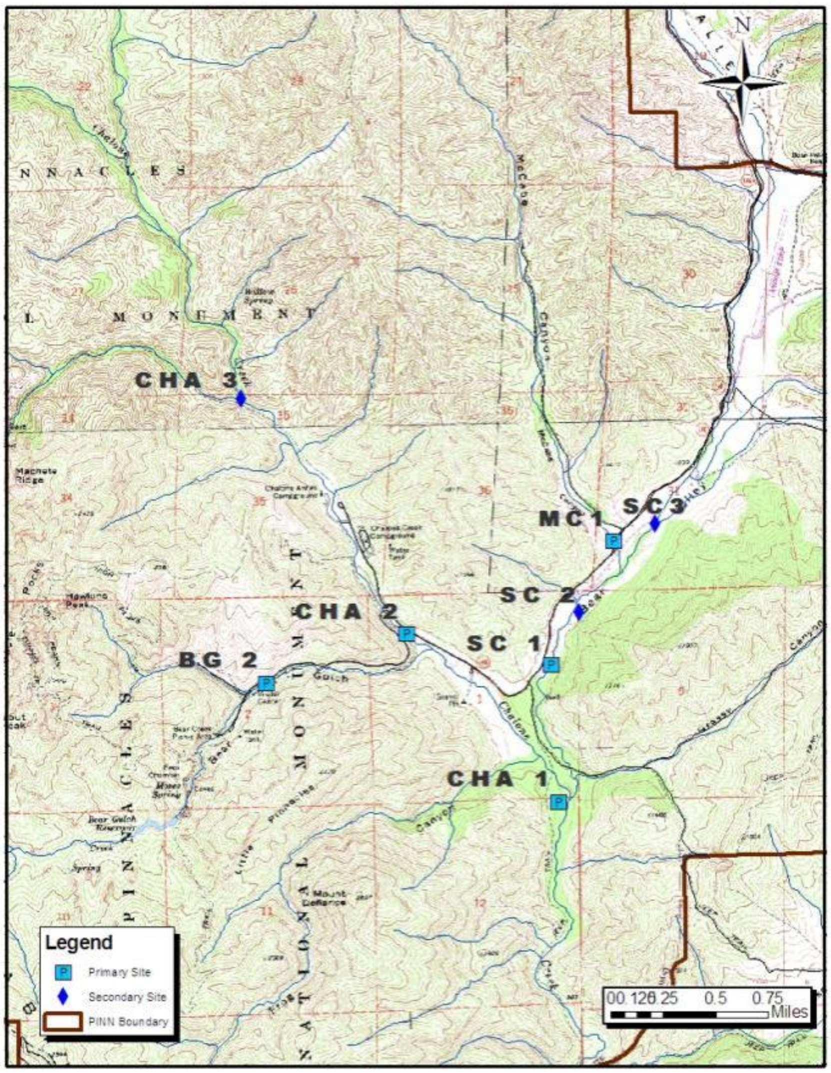

Figure 30. Chalone Creek watershed water quality monitoring stations. Source: Skancke and Booth 2010.

Data

Park scale: Data were summarized here from the annual freshwater monitoring reports.

Status

Park scale:

The results from the annual reports for WY2007 and WY2008 (Skancke and Carson 2009, Skancke and Booth 2010) are summarized in (Table 17). Water temperatures varied substantially within PINN, both between sampling sites (as much as 10°C) and throughout the year (over 20°C). Sandy Creek sites tended to have greater seasonal extremes than Chalone Creek. Temperatures in WY2008 tended to be milder than in WY2007. High conductance values greater than 500 µS/cm (as observed at SC2 and SC3 in WY2008) usually suggest high pollutant inputs, although the high results in PINN may be due in part to the geology of the area contributing high levels of dissolved solids. In WY 2007 the stations in Sandy Creek always demonstrated levels of conductance above 500 µS/cm, and showed high nutrient levels along with indications of bacteria loading. The low pH of surface water may also be influenced by the geology of the area. Dissolved oxygen sometimes fell below the objective, and declined throughout the water year as water temperature rose.

Exceedances for bacteria for contact recreational uses were more frequent in WY2007 than in WY2008. Site MC1 tended to have the highest values for both total coliform and *E. coli*.

The Chalone Creek watershed was the only SFAN watershed to have detectable levels of ammonia during WY2007, with one detection at MC 1 in March, and one at SC 2 in June. On both occasions a feral pig or evidence of pig activity was observed (at the time, this site was outside of a pig-free exclosure). However, the levels were well below the regional standard. Total coliform and TKN (3.0 at MC1) results from those visits were also higher than seen during other visits during the same water-year. There were no detections in WY2008. Nitrogen was most often detected as TKN while nitrate and ammonia detections were low, indicating that organic nitrogen is the dominant form of nitrogen seen in the watershed. Nitrate was rarely detected in WY2007 and only at very low levels. In WY2008, it was highest at CHA1, the furthest downstream site. The mean nitrate for all sites was 0.37 mg/L, but values above 2.0 were collected during a January storm monitoring event. PINN had the lowest mean nutrient levels of the park units in the SFAN. The nutrient response to occasional feral pig activity in WY2007 shows the importance of the removal of pigs and construction of the pig-proof fence for maintaining water quality, along with other monument resources.

Table 18. Results of water quality indicators for WY2007 and WY2008 relative to objectives.

Parameter Groups	Parameter	Objective or reference value	WY2007 [c]	WY2008 [d]
Core				
	Water Temperature		Min 4.6–16.4 °C; max 16.5–27.1	Min 8.9–13.2 °C; max 17.3–20.5
	Specific Conductance		74.6 µS/cm (CHA3) - 900 (SC2)	96.6 µS/cm (BG2) - 886 (SC2)
	Dissolved Oxygen	> 5.0 mg/L [a]	exceedance at CHA1 all the time, sometimes at BG2 and SC2	exceedance once at CHA1, twice at BG2
	pH	7.0 < pH < 8.5 [a]	5 of 8 sites < 7.0 most of the time	equipment errors; results not reported
Bacteria				
	Total coliform	median < 240 MPN/100mL; no sample > 10,000 (Contact recreation) [a]	2 exceedances at MC1 and one at SC1 with samples > 10,000	no exceedances but MC1 had a maximum of 4400 MPN/100 mL
	E. coli	Single Day Sample < 235 MPN/100mL; 30 Day Average < 126 (Contact recreation) [a]	exceedance at MC1 in 5 of 6 samples and at least one exceedance at 4 other sites	2 exceedances out of 8 samples at SC3
Nutrients				
	Total Kjeldahl Nitrogen (TKN)	< 0.36 mg/L [b]	highest at MC1 and SC1	highest values at MC1 with mean of 0.76
	Nitrate	< 0.16 mg/L (NO_3 + NO_2) [b]	rarely detected	highest at CHA1
	Ammonia	Annual median 0.025 mg/L as N [a]	2 detections at MC1 and SC2 associated with feral pig activity	None detected

[a] California Regional Water Quality Control Board Central Coast Region 1994
[b] U.S. EPA 2000 (reference values)
[c] Skancke and Carson 2009
[d] Skancke and Booth 2010

Emerging Issues

Some pesticides are applied in the Salinas Valley by aerial spraying and potentially drift into PINN where they may accumulate in surface water and wetlands. The pesticide stressor section above described the amount of pesticides known to be harmful to amphibians. The concentrations of these pesticides in surface waters are not currently being monitored.

Nitrogen is often a primary limiting nutrient on overall productivity of ecosystems. Atmospheric nitrogen deposition alters terrestrial and aquatic ecosystem function, structure, and composition. Nitrogenous air pollutants have many sources, including transportation, agriculture, industry, electricity generation, wildfire, and are a growing threat to the biodiversity of California (Weiss

2006). PINN is relatively remote from many of these sources, such that current levels of nitrogen nutrients in streams are low. If these sources increase, or new facilities are constructed closer to PINN, nitrogen deposition may increase and affect amphibians such as the California red-legged frog.

The section above on climate condition indicators showed dramatic changes forecast in temperature, precipitation, and other ecologically-meaningful factors. In some emissions scenario/GCM combinations, future trends would lead to less precipitation (and more erratic) and greater evaporation and evapotranspiration by vegetation, leaving less water to accumulate for in-stream flows. Assuming inputs of nutrients and pathogens remains the same, their concentrations will increase. Water temperatures are also likely to increase, and sampling sites would more frequently be dry. Dissolved oxygen is negatively related to water temperature so the occasional exceedance may become more routine in summer. These changes could have serious consequences for PINN's aquatic resources.

Data Gaps

Concentrations of pesticides in surface waters are currently not being monitored. Inferences in this condition assessment report about the potential impacts on California red-legged frog and other amphibians are based on spatial data on rates of application of pesticides known to be harmful to them.

The annual water quality monitoring reports (Skancke and Carson 2009, Skancke and Booth 2010) noted some high readings of specific conductance often associated with urban pollutant inputs. The pH readings were also frequently below the regional standard. The monitoring reports speculated that these anomalies were related to the unusual geology of PINN contributing high background levels of dissolved solids. Additional evidence would help confirm this assumption or reveal a previously unknown management issue.

Streamflow data collection began in 2010.

Key References

Skancke, J. S. and K. Booth. 2010. Freshwater quality monitoring in the San Francisco Bay Area Network: 2008 annual report. Draft—Natural Resource Technical Report NPS/PWR/SFAN/NRTR—2010/XXX. National Park Service, Fort Collins, Colorado.

Skancke, J. S., and R. G. Carson. 2009. Freshwater quality monitoring in the San Francisco Bay Area Network: 2007 annual report. Natural Resource Technical Report NPS/PWR/SFAN/NRTR—2009/177. National Park Service, Fort Collins, Colorado.

Biological Integrity Level 1 Category

Biological integrity—Invasive Species—Non-Native Invasive Plants
Findings: Baseline only

Invasive species are second only to habitat loss as threats to global biodiversity (e.g., Scott and Wilcove 1998). At PINN, about 140 of approximately 675 plant species are nonnative. Several of these species are invasive, with the potential for creating serious ecological damage and detracting from the uniqueness of the monument's native plant community. Pinnacles National Monument Weed Control Program is focused primarily on yellow starthistle (*Centaurea solstitialis*), Italian thistle (*Carduus pycnocephalus*), and mustard (*Hirschfeldia incana*), and because of their potential for native habitat alteration. A new GIS-based assessment was performed to estimate the relative vulnerability of PINN to invasion from high threat populations in weed control areas. This assessment used data from the Weed Control Program to measure relative exposure to invasion and combined that with environmental data on the invasibility of plant communities and disturbance factors to measure sensitivity to invasion. The product of exposure and sensitivity identified relative vulnerability. Areas of highest exposure to invasions in the weed control zones coincide substantially with the land cover types that are also disturbed, primarily as along roads and trails, and thus most sensitive to invasion. Most of the remote areas of PINN are dominated by chaparral and are considered to be of relatively low vulnerability. Fire and climate change can alter the land cover and make these sites more sensitive to invasion, however. The Early Detection Monitoring Program provides critical surveillance of additional potential invaders and locations of potential new sources of exposure. The data from the Weed Control and Early Detection programs are too recent to identify trends in the exposure component.

Approach

Vulnerability to invasion by non-native plants was modeled as the product of exposure to invasive plants and of sensitivity of the landscape to invasion (Figure 31). The exposure component is based on the potential sources of non-native invasive plants. NPS staff had previously mapped the primary sources in 13 "weed zones" in 146 sections along roads, trails, the "pig fence" (see section on feral pigs) and riparian areas. Field crews recorded the presence/absence of the non-native invasive plants (Table 18) in each section where they are being treated. The potential of a section to be a source was based on the number of invasive plants being treated within it (ranging from 0 to 12). However, sections not currently being treated received a score of 1 so they would influence the overall exposure and vulnerability scores. GIS analysis determined the cumulative exposure as a sum of scores of source potential within a 40 cell (1 kilometer) radius.

Further GIS analysis measured sensitivity as the maximum of the relative invasibility of land cover/use types, the degree of disturbance from human activities (roads, trails, runway, campground, and the pig fence [see feral pig section]), and recent fires that facilitate establishment of invasive plants. Invasibility has been defined "as the susceptibility of an environment to the colonization and establishment of individuals from species not currently part of the resident community" (Davis et al. 2005, p. 696).

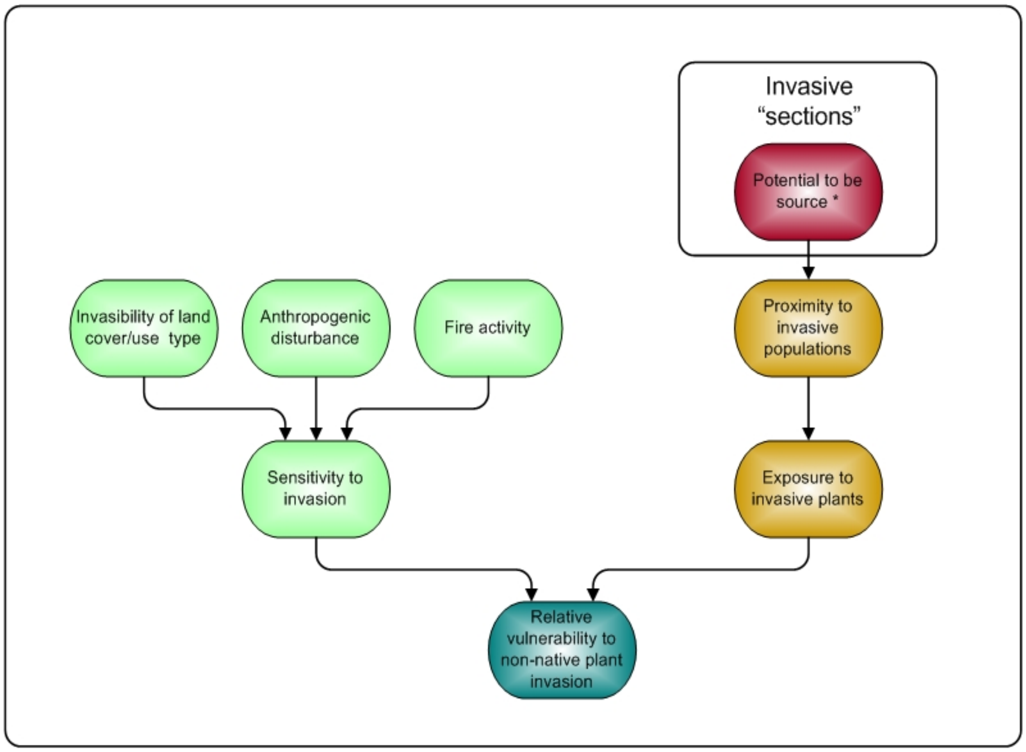

Figure 31. Conceptual GIS model of relative vulnerability to non-native plant invasions as the integration of exposure and sensitivity.

Table 19. Non-native invasive plant species (in alphabetical order) being treated at PINN. List indicates the species' priority ranking in the early detection program (Williams and Jordan 2010).

Common Name	Scientific Name	Code	List
giant reed	*Arundo donax*	ARDO	5.1
whitetop	*Cardaria draba*	CADR	
Italian thistle	*Carduus pycnocephalus*	CAPY	2
tocalote	*Centaurea melitensis*	CEME	3
yellow starthistle	*Centaurea solstitalis*	CESO	3
bull thistle	*Cirsium vulgare*	CIVU	3
poison hemlock	*Conium maculatum*	COMA	2
shortpod mustard	*Hirschfeldia incana*	HIIN	3
prickly lettuce	*Lactuca serriola*	LASE	3
horehound	*Marrubium vulgare*	MAVU	2
lanceleaf plantain	*Plantago lanceolata*	PLLA	3
Himalayan blackberry	*Rubus armeniacus*	RUAR	
curly dock	*Rumex crispus*	RUCR	3
blessed milkthistle	*Silybum marianum*	SIMA	3
common sowthistle	*Sonchus oleraceus*	SOOL	
saltcedar	*Tamarix ramosissima*	TARA	5.1
puncturevine	*Tribulus terrestris*	TRTE	3.1

Invasibility has been associated with land cover/use type and categorized through a literature review by Althoen et al. (2007) for Santa Monica Mountains National Recreation Area (SAMO) into high (grassland, riparian, oak woodland), medium (coastal sage scrub), and low (chaparral) classes. This categorization was judged to be adequate for PINN because these broad-level cover types are relatively similar to SAMO. These were scored as 20, 5, and 1 respectively for this assessment. Disturbance was scored as a decreasing function of distance from the constructed feature. The most recent burned areas received the highest scores, decreasing with time since last burn. Vulnerability was calculated as the product of exposure and sensitivity. Thus to be assessed as high vulnerability, a site must have many invasive plant species <u>and</u> be highly invadible and/or disturbed. See Appendix A for GIS layers generated for the assessment.

Data

<u>Park scale:</u>

Weed sections: PINN_invasive_Sections.shp shapefile from PINN, along with presence/absence data in tabular form for the invasive species treated by section.

Land cover: coverrid11c raster from PINN, mapped by the Wildlife Spatial Analysis Lab at the University of Montana in 2005 using IKONOS imagery from 2000.

Roads: streets_ac geodatabase, containing the 2003 Tele Atlas Dynamap Transportation version 5.2 product, extracted for PINN by the NPScape program. This was supplemented by a shapefile of dirt roads provided by PINN.

Trails: PINN supplied shapefiles of the hiking trails and Climbing Access trails.

Other disturbance layers: PINN supplied shapefiles of an airport runway, the pig fence, and campgrounds.

Fire perimeters: shapefile obtained from the California Department of Forestry and Fire Protection (California Department of Forestry and Fire Protection 2008). According to Pinnacles staff the database was current with respect to the fire history of the park. We extracted fires for individual years and converted them into a raster of years since last burn.

Status

<u>Park scale:</u>

Relative exposure to invasive plants tends to be greatest along roads, trails, and riparian areas where the invasive sections are most common (Figure 32a). Much of PINN is covered in chaparral, which is relatively insensitive to invasions. The most sensitive areas are linear features along roadways, trails, riparian areas, and in recent burn areas (Figure 32b). Because of this congruence of exposure and sensitivity, it is not surprising that the most vulnerable sites show a similar geographic configuration to the two factors (Figure 32c). Thus the invasive sections being treated in the Weed Control Program also appear to be the most vulnerable areas of PINN. If treatment can restore low levels of exposure, the overall vulnerability of PINN will be reduced. The most likely changes that would alter sensitivity to invasion would be new fires that temporarily affect invasibility and provide niches for pioneering invaders, and climate change that could cause a longer-lasting change in vegetation and fire regime.

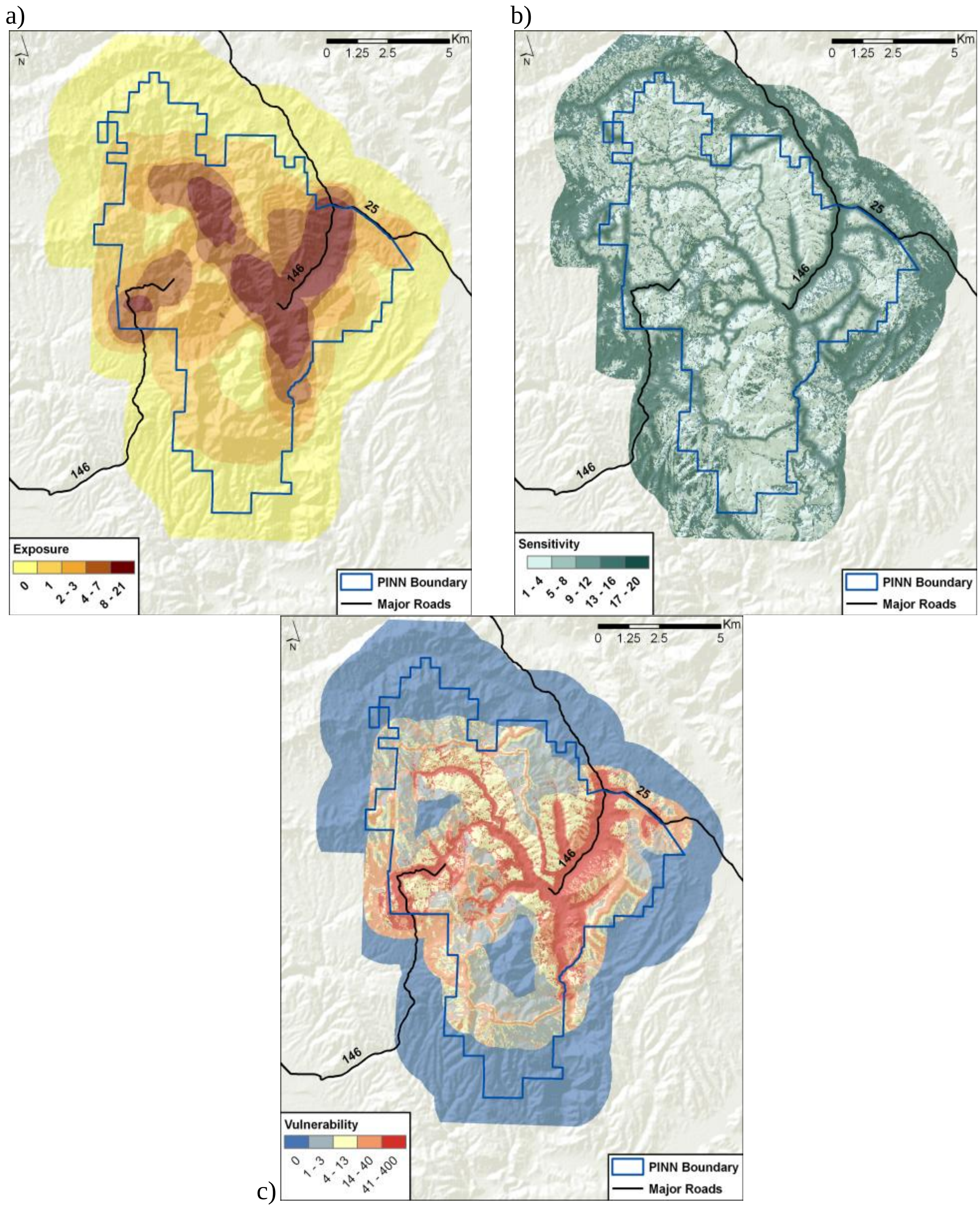

Figure 32. Maps of a) exposure to populations of invasive plants (0 – none, 20 = high), b) sensitivity to invasion (0 – none, 20 = high), and c) relative vulnerability to non-native plant invasion (0 – none, 400 = high).

Emerging Issues

Climate change can potentially influence the pattern and success of plant invasions in multiple ways. Shifting temperature and precipitation patterns can stress native plant communities and open opportunities for invaders. Climate-induced changes in fire regime can increase the frequency or severity of fire that would also provide disturbed niches for invaders. As discussed in the Climate indicator section, temperature is expected to increase substantially in any climate scenario, while the projections for precipitation are less consistent. The section below on Fire frequency and area burned in response to climate change and urban growth indicates that annual burned area is predicted to increase at PINN.

NPS must also remain vigilant to arrivals of new non-native plants with high invasion potential and to appearance in new locations. The Early Detection Monitoring Program within I&M is designed to periodically survey priority areas using staff and volunteers to detect new populations so they can be controlled before they have a chance to establish and spread.

Nitrogen deposition could increase the invasibility of barrens, which are shallow soil, rocky areas with low productivity and high relative cover of native forbs. Barrens can be found throughout the chaparral covered hillsides in relatively small patches. Their low productivity suggests that they could be especially sensitive to inputs from atmospheric nitrogen. Barrens also lack the shrub cover that precludes invasive species persistence in chaparral.

The newly acquired lands around the east entrance were not enclosed within the 2003 fence to exclude feral pigs. Most of these lands were enclosed within a new segment of pig fence in spring 2011. Following the logic of the conceptual model, the ground disturbance from installing and maintaining the new section of fence is expected to create an additional area of greater sensitivity to invasion and hence of vulnerability to invasion.

Data Gaps

Trend data are still too short and too geographically limited to determine whether non-native plants are expanding or whether recent control activities have had much impact on invasions. Consequently the trends in the exposure component are unknown. The sensitivity component of vulnerability should be easier to track at least periodically. Land use changes can be mapped and updated. Fire perimeters are compiled by the state and can be readily used to update the time since last burn factor.

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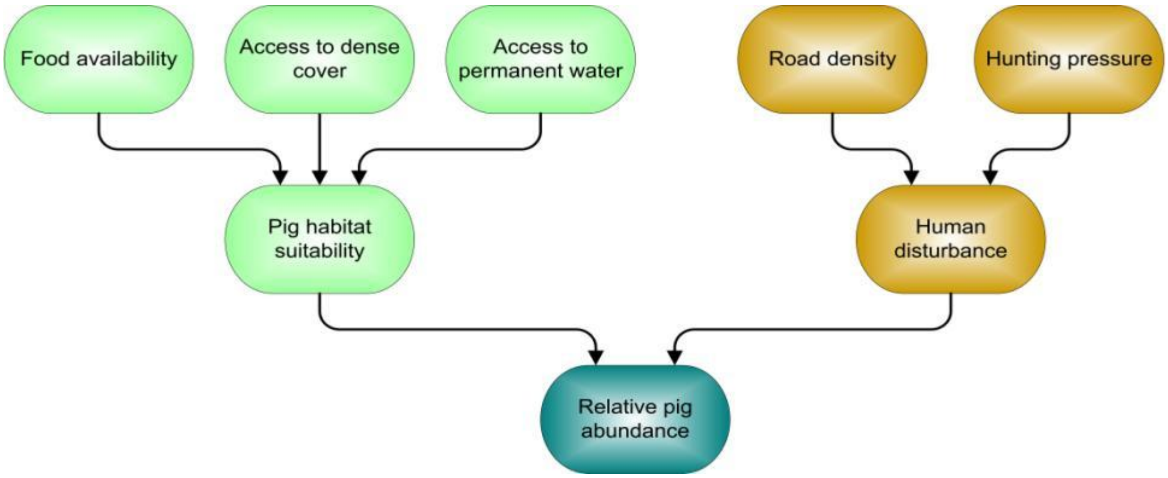
Biological Integrity—Invasive Species—Feral Pigs
Findings: Baseline only

The wild pig (*Sus scrofa*) was introduced into California in the 1700s when domesticated pigs escaped into the wild. European wild boar (also *S. scrofa*) was also introduced into Monterey County in the 1920s and interbred with the local feral pigs. They were first observed at Pinnacles National Monument in the late 1960s. The destructive foraging behavior of feral pigs poses a major threat to native plant communities, riparian habitats and species, water quality, and associated wildlife at PINN (Adams et al. 2006). After nearly two decades, PINN completed construction of a fence in 2003 to exclude wild pigs from a majority of the park area and then eradicated pigs inside the fence by 2006. GIS modeling generated a map of the potential relative abundance of feral pigs from which statistics within the park-and-buffer and park scales and inside the exclosure fence were derived. PINN contains highly suitable habitat for pigs with low human disturbance. If not for the exclosure fence, pig populations could be very dense and a significant stressor on other park resources. With the removal of the pigs, resources are expected to recover although monitoring results are not in yet. Some areas adjacent to PINN to the west and northwest have similar relative abundance values to the park. The newly acquired lands around the east entrance that were not enclosed within the 2003 fence have moderately high values. Most of these lands were enclosed within a new segment of pig fence in April 2011, and all pigs will have been removed by the end of 2012.

Approach

The I&M and vital signs programs do not currently monitor feral pig populations, nor are data of the population of wild pigs in and around PINN available from other sources for any time period, not to mention at multiple time periods. Therefore it was necessary to model relative abundance from a combination of pig habitat suitability and human disturbance to its habitat. Hollander (1998) developed a GIS model of relative abundance through judgment from pig experts (

Figure 33). Pig habitat suitability as per Hollander was modeled as the product of scores for the availability of food, cover, and water. Modeling the suitability of accessibility of dense cover and availability of food was modeled with a habitat map that depicts habitat types and cover density and the California Wildlife Habitat Relationships habitat suitability matrix for cover and feeding. Food and cover scores were based on a neighborhood average within a 1500 meter (~1 mile) radius, based on the opinion of the experts. Only perennial streams and springs and ponds with water in the summer dry season contributed to the water availability score, which diminished up to 1500 meters. Human disturbance to pig populations were derived from general human presence as measured by road density within a 1500 meter radius and hunting pressure. As modeled by Hollander (1998), hunting pressure was assigned categories of no pressure (state and federal parks), high pressure (BLM and National Forest lands), and moderate pressure (private and other public lands). Relative abundance was calculated as the product of suitability and disturbance scores, with the final index ranging from 0 to 100. From the experts polled by Hollander (1998), the spatial scale of habitat needs and disturbance occur within a 1500 meter radius, which implies that the relative abundance of pigs adjacent to PINN may have some effect on conditions within the park. Consequently, feral pig relative abundance was modeled and assessed at the park and the park-and-buffer scales but not at the regional scale. The mean, standard deviation, and maximum value were also calculated inside the pig fence to determine the habitat quality that the exclosure fence is protecting from pig invasion. All GIS data are from recent years, so there was no opportunity to assess trends in the modeled relative abundance. See



Appendix A for GIS layers generated for the assessment.

Figure 33. Conceptual GIS model of relative abundance of wild pigs (after Hollander 1998).

Data

- Food and cover— California Department of Forestry and Fire Prevention's Multi-source Land Cover Data, version 02_2, that depicts habitat types and cover density (http://frap.cdf.ca.gov/data/frapgisdata/download.asp?rec=fveg02_2) and the California Wildlife Habitat Relationships habitat suitability matrix for cover and feeding (http://www.dfg.ca.gov/biogeodata/cwhr/). The habitat map was compiled at a spatial resolution of 100 m, which was used for all pig modeling processes.

- Proximity to perennial streams and ponds that were extracted from the National Hydrography Dataset (NHD, http://nhd.usgs.gov/), and supplemented inside PINN with data compiled by Paul Johnson of the PINN staff from personal knowledge of the area.

- Roads: streets_ac geodatabase, containing the 2003 Tele Atlas Dynamap Transportation version 5.2 product, extracted for PINN by the NPScape program.

- Land ownership—the California Protected Areas Database, version 1.2, compiled by the GreenInfo Network (http://www.calands.org/). This was supplemented with military bases from the state's map of Public, Conservation and Trust Lands, version 05_2 (http://gis.ca.gov/ceic/showSourceXML.epl?id=31122;style=0).

The PINN GIS database includes a vegetation map with similar classes to the wildlife habitat types (but not cover density classes) used for the park-and-buffer scale analysis. Besides the absence of density data, this map does not encompass the entire jurisdictional boundary of PINN. Without this key GIS layer, a more detailed analysis of feral pigs was not performed. Instead, the relative pig abundance layer generated for the park-and-buffer scale was also summarized within the jurisdictional boundary of PINN and within the confines of the pig exclosure fence (supplied by PINN).

Status

Park-and-buffer scale: Relative pig abundance estimates the potential density of feral pig populations on a scale from 0 (none) to 100 (high) based on habitat suitability and human disturbance factors identified by wildlife experts. In general the Gabilan Range provides moderate to high scores for wild pigs, particularly west and northwest of PINN. The lower elevation grasslands and agricultural lands of the Salinas Valley and south of PINN received relatively low scores (Figure 34). On average within the 10 km buffer (including PINN) therefore, relative abundance is low (mean = 5, maximum = 67). In general, the lack of perennial surface water is the most limiting factor. In fact, scores more than 1500 meters from perennial water sources fall to zero in the model.

Park scale: PINN has highly suitable habitat for food and cover and relatively good access to year-round water. Moreover the park unit has low levels of human disturbance related to road access and hunting, which is not allowed in PINN. As a result, the average score for relative pig abundance inside the jurisdictional boundary is moderately high (mean = 14; Figure 34). The scores inside the pig exclosure fence were even higher than the park unit as a whole (mean = 19). Sites just inside the northern flank of the fence line are among the highest scoring lands in the area. Lands near the east entrance of PINN but outside the fence are also moderately rated, and therefore might harbor relatively dense populations of pigs. Of course, the exclusionary fence and the pig eradication program means that the actual population abundance is virtually zero within the fence.

Trends

As the assessment of feral pigs is based on current conditions of the suitability and disturbance factors, and in the absence of monitoring data on their populations or effects, little is known about trends in their relative or absolute abundance. The most likely factors that could influence relative abundance are fire, which may reduce the availability of dense protective cover, and climate change, which may alter the pattern and predictability of permanent water availability. Large fluctuations in pig populations would be expected in response to interannual variation in precipitation and oak masting.

Emerging Issues

Eliminating wild pigs from the majority of PINN and constructing a pig-proof fence to minimize their incursions has neutralized this stressor within the fenced area. The eastern entrance of PINN that lies outside the 2003 fence shows potential for relatively high pig densities (Figure 34) and their associated ecological impacts. The majority of this area was enclosed by additional fencing in 2011, and all pigs removed by the end of 2012.

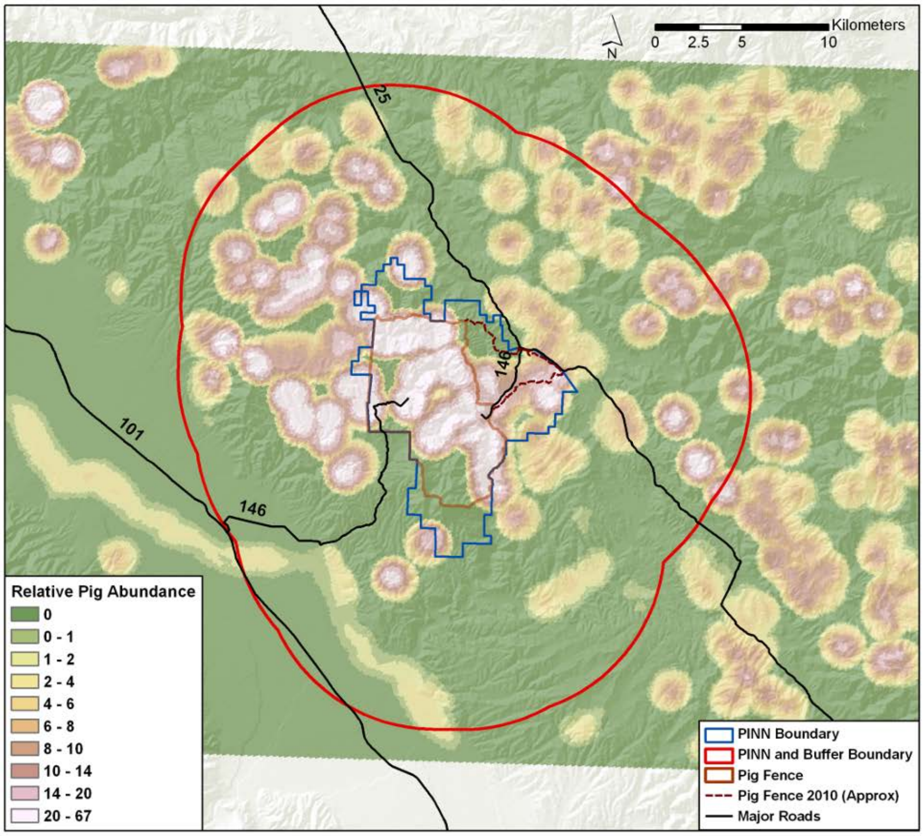


Figure 34. Map of the potential relative abundance of feral pigs at PINN.

Data Gaps

Some areas of PINN outside the pig fence were predicted to have high relative pig abundance. It is unknown what pig density occurs in these areas and the trend. Further monitoring is needed to determine if the pig removal program is achieving the desired level of restoration. Access to perennial water is a critical factor in the model, but stream and spring data outside of PINN are generalized. PINN staff members were able to delineate perennial water for specific stream segments in greater detail than was available from the NHD data inside PINN. Similar refinements are needed for areas outside of PINN.

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Biological Integrity—At Risk Biota—Prairie Falcon
Findings: No significant trend

Since 1989 there has been no statistically significant trend in the number of territorial pairs, nesting pairs, successful nests, or fecundity. Overall the prairie falcon population at PINN appears to be relatively stable.

Approach

Prairie falcon (*Falco mexicanus*) is one of the signature species of Pinnacles National Monument. This medium-sized raptor, which is listed as a species of concern by the Point Reyes Bird Observatory and as a species at risk by the California Natural Diversity Database, is a year-round resident that nests in cliffs within the park but forages over a much larger region, especially in grasslands, woodlands and shrublands to the west and southwest of the park (Buranek 2006).

Prairie falcons are widely distributed across PINN in what raptor biologists have categorized as core areas used by rock climbers vs. non-core areas with little or no climbing activity in the central western vs. northern or southern eastern parts of the park, respectively (Figure 35). Since monitoring began at PINN in 1984 the number of nesting pairs has averaged 9.5 pairs out of an estimated 300–500 nesting pairs in California (Anderson and Squires 1997).

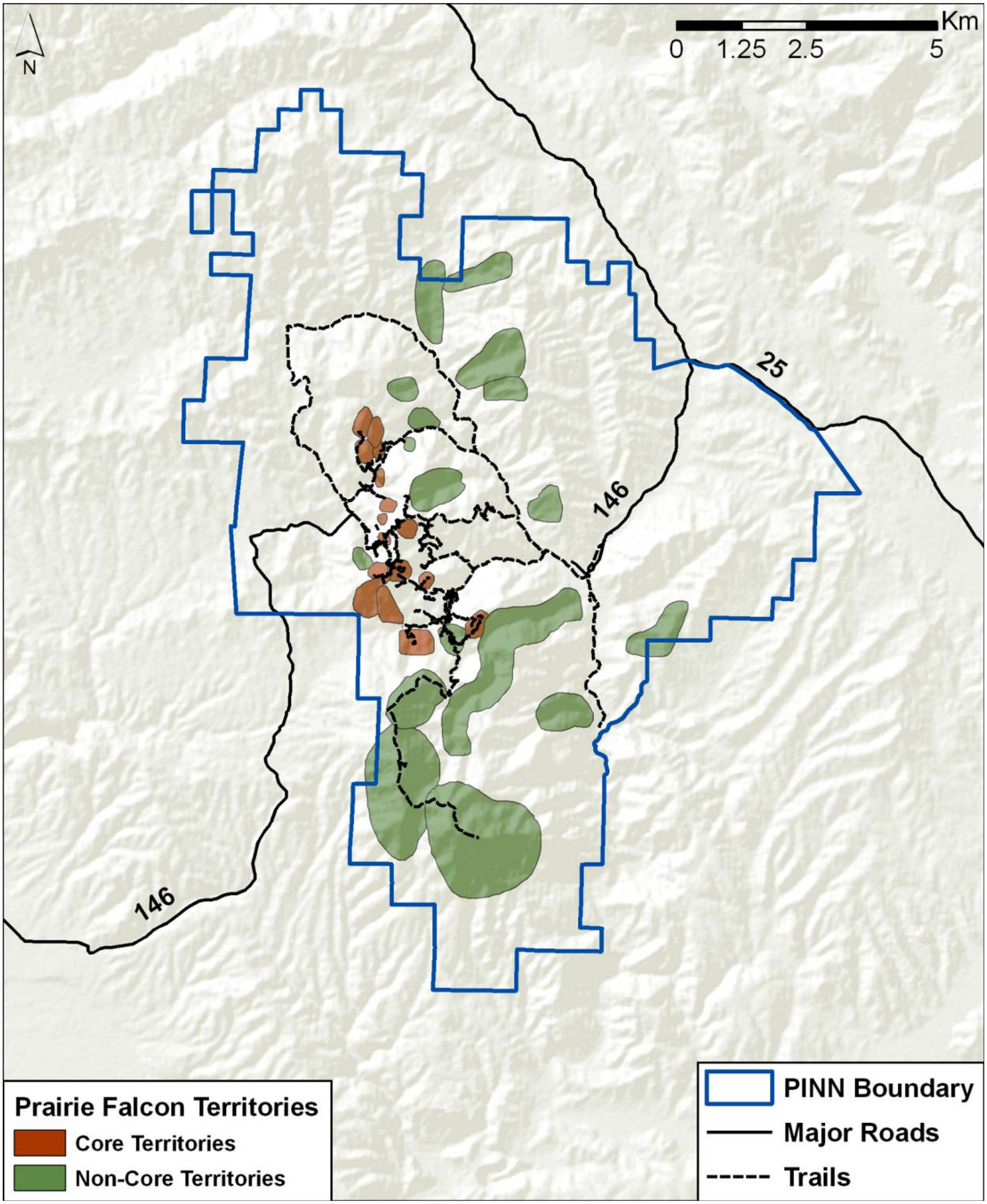

Figure 35. Map of prairie falcon core and non-core areas at PINN (source: Table SOP 5. in Emmons et al. 2010).

Prairie falcon population dynamics at PINN could reflect both regional changes in prairie falcon numbers (to the extent that local population size is affected by immigration and emigration) as well as variation in local birth and death rates. Unfortunately regional data are limited so it is not possible to formally estimate the degree to which population dynamics at PINN are influenced by large scale fluctuations and trends in falcon abundance. Breeding Bird Survey and Christmas Count data are not especially informative for species such as falcons and other raptors that generally occur at low densities (Farmer et al. 2007). Migratory counts at traditional watch sites have proven informative (Anderson and Squires 1997), and the autumn sighting counts for the Marin Headlands published annually in the Pacific Raptor Report provide some comparative data. Only data for the period 2001–2007 are available online (these show no obvious trend), so we did not pursue any formal analysis of the Marin Headlands count data. In the conceptual model shown in Figure 36 and in the analyses reported below we ignore influences of large-scale population trends on variation in prairie falcon abundance at PINN.

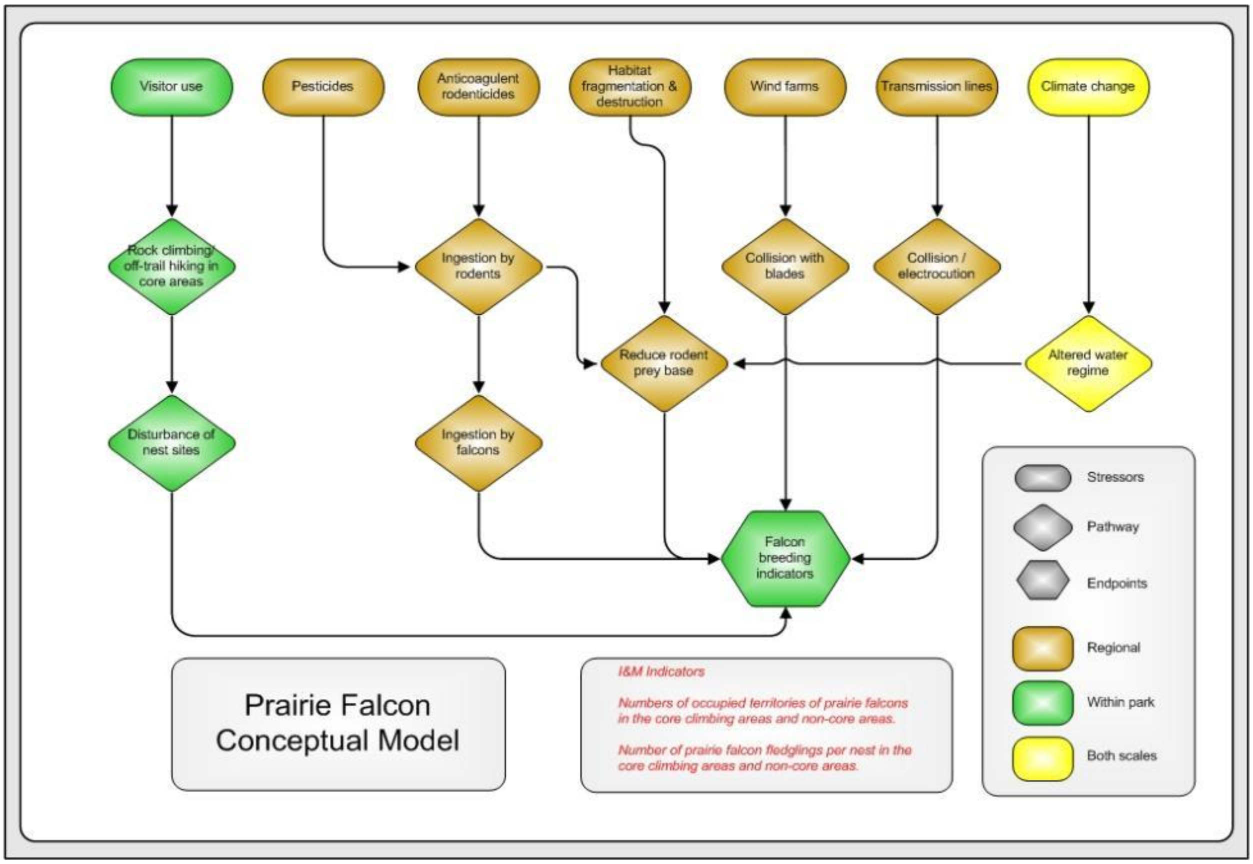

Figure 36. Prairie falcon conceptual model.

Based on available literature we hypothesize that prairie falcon abundance at PINN is most strongly influenced by the size of the prey base within foraging range, nesting habitat quality, and agents of mortality such as pesticides and wind turbines (Figure 36), as well as by endogenous factors such as density-dependent population growth. Monitoring of prairie falcon populations at the Snake River Birds of Prey Area in Idaho has documented strong association of reproductive success with regional prey abundance, in particular with ground squirrel abundance (Steenhof et al. 1999). Ground squirrel populations generally increase during wetter periods and decrease during drought, so falcon abundance should be indirectly tied to climate and climate change (Figure 36).

Prairie falcon reproductive success is also vulnerable to regional pesticide use. Bioaccumulation of organochlorine pesticides or pesticide by-products such as 1,l'-[dichloroethenylidene]bis[4-chlorobenzene] (DDE), polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB) has been documented in birds at PINN. DDE concentrations in eggs that failed to hatch during 1989–1991 nesting seasons were probably high enough to affect hatching success (Jarman et al. 1996).

In addition to influence from these regional drivers, nesting success may be affected by local disturbance by park visitors during the nesting season. Since 1988 a raptor advisory system has been in effect that requests climbers and off-trail hikers to avoid entering occupied areas during the falcon nesting season.

Data on territorial pairs, nesting pairs, successful nests, and fledgling per nest were analyzed for the period 1989–2010. We excluded 1985–1988 because surveys were not as extensive or consistent during those early years (Starcevich and Steinhorst 2010). We analyzed the monitoring data to answer these specific questions:

1) Is there a systematic trend in number of nesting pairs of falcons at PINN since consistent monitoring began in 1989?

2) Do population trends differ between core and non-core areas in PINN?

3) Is there a systematic trend in fecundity (# fledglings/nest) since 1989?

4) Does fecundity vary between core and non-core areas?

5) Is variation in fecundity trends related to climate variability?

Recently Starcevich and Steinhorst (2010) evaluated the power of PINN prairie falcon surveys to detect trends in occupancy and fecundity. They noted the challenge of determining true occupancy from simple detection and suggested that establishing true site occupancy requires multiple site visits within a year and evidence of territorial behavior. Based on this criterion the historical data analyzed here may inflate the actual territory occupancy rate, especially in non-core areas which were not surveyed as intensively or consistently. Based on analysis of 2008–2009 data for occupancy and 2002–2009 data for fecundity, Starcevich and Steinhorst (2010) concluded that annual surveys of 27 to 30 territories consisting of a census of the 18 core sites and 9 to 12 of the non-core sites for occupancy surveys and at least 10 occupied territories for fecundity surveys should provide power greater than 0.80 for trend detection. We plot nesting pair data for both core and non-core areas below but have not undertaken a formal trend analysis for non-core areas given the variation in monitoring effort.

Detecting and interpreting trends in population data remains one of the most challenging problems in ecology because of the interplay between environmental variation, population regulation by density-dependence and random fluctuations (Lundberg et al. 2000). Patterns are generally very sensitive to space and time scales of data collection. Moreover, population data are usually strongly autocorrelated in space and time, which complicates the use of inferential statistics. Starcevich and Steinhorst (2010) did not consider the issue of serial autocorrelation, but the presence of such autocorrelation—the tendency for fecundity (or other population measures) to be more similar in years that are closer together in time—can significantly impact the statistical power to identify real trends by reducing effective sample size and thereby widening confidence intervals (Bence 1995). There are a variety of ways to account for spatial autocorrelation in time series and regression analysis. We used a fairly simple and conventional approach of generalized least squares with an autocorrelated error term (Lundberg et al. 2000). This has the effect of preserving the relationship between dependent and independent variables but providing more reliable significance tests. All statistical analyses were conducted using R statistical software (packages **stats** and **nmle**).

Data

Regional scale: No regional scale data were available for analysis.

Park plus scale: No park-and-buffer scale data were available for analysis.

Park scale: Falcon census data and nesting productivity data for the period 1984–2009 were taken from the 2009 Raptor Breeding Season Report (http://science.nature.nps.gov/im/units/sfan/vital_signs/Raptors/Annual Reports/2009_SFAN_Raptor_AnnRep_2.pdf).

November-through-April rain-year precipitation data were produced by summing monthly rainfall data from concurrent years. Nesting data from year t+1 were compared to rainfall data that combined November and December rainfall from year t with January-April rainfall from year t+1.

Status

Park scale: Since 1989 the number of falcon territorial pairs at PINN has averaged 12 pairs and ranged from a minimum of 8 pairs to a maximum of 15 pairs in 2006 (Figure 37). On average, roughly 70–80% of territorial pairs nested in any given year, with the exception of 2008 when only 5 of 12 pairs nested. A high percentage (mean = 85%) of nests successfully fledged at least one chick during a given year.

Between 1989 and 2010 the number of nesting pairs in core areas averaged 6.5 pairs per year (Figure 37)The number of nesting pairs in core areas exhibits significant ($r=0.54$, $p < 0.01$) positive autocorrelation with the prior year ("first-order or lag-1 autocorrelation) and with two years previous ($r=0.47$, $p=0.01$) (Figure 38).

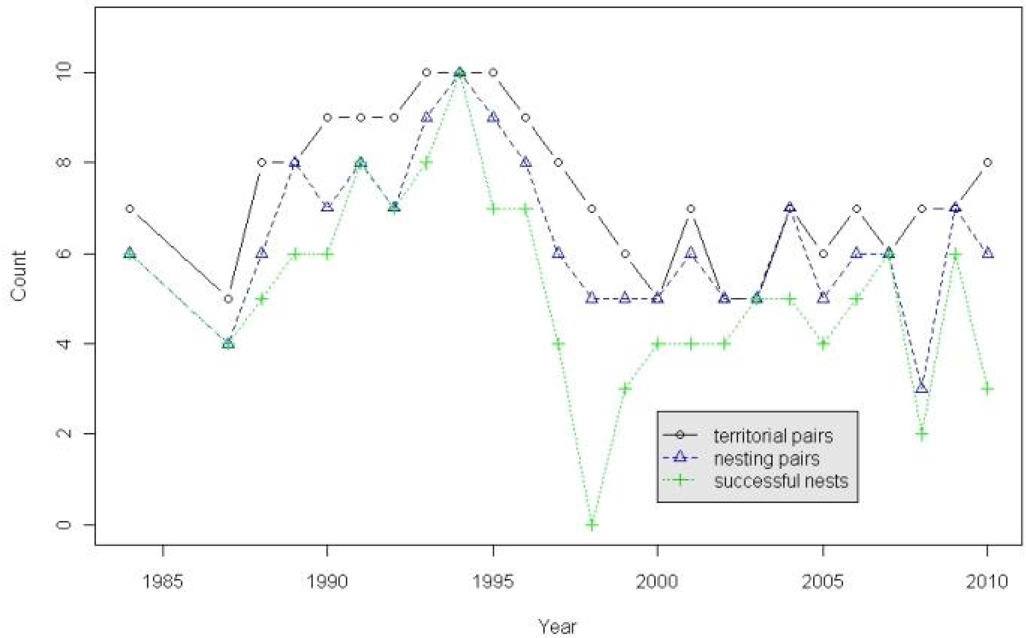

Figure 37. Annual counts of prairie falcon territorial pairs, nesting pairs and successful nests in core areas of Pinnacles National Monument, 1984–2010.

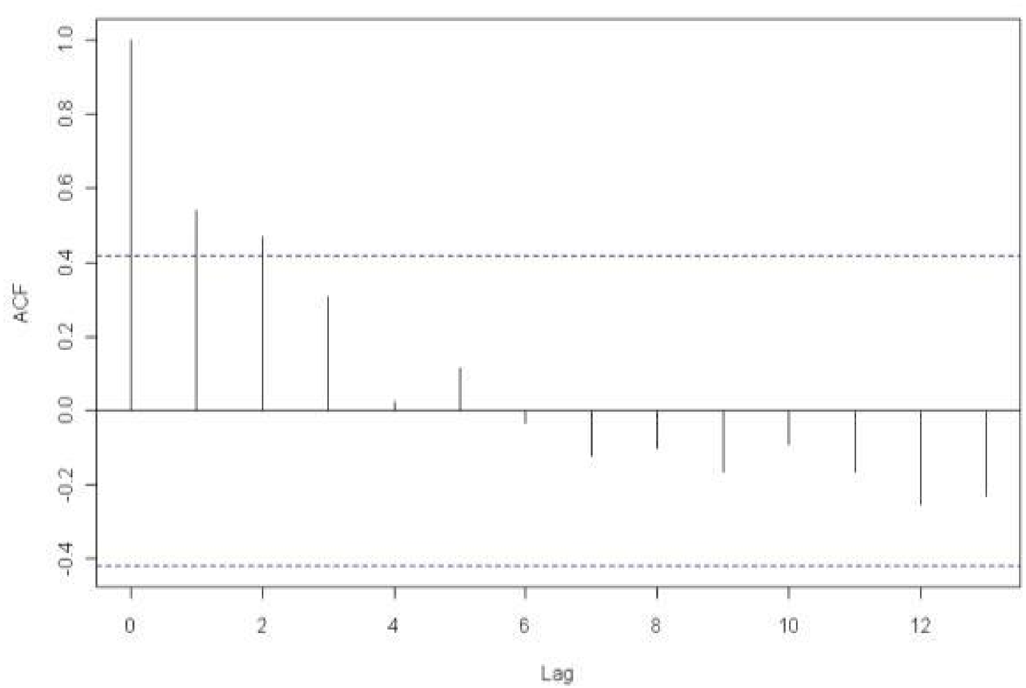

Figure 38. Correlogram showing the autocorrelation (ACF) as a function of time lag in years for the number of nesting pairs in core areas. Dashed blue lines are 95% confidence intervals.

Since 1984 the number of fledglings per nest has averaged 3.25 ± 0.8 (Figure 39). Fecundity dropped to zero during the strong El Nino winter and spring season, 1997–1998, presumably due to the powerful storms that lashed the park during the nesting season. For the period 1989–2009 annual fecundity did not vary between core and non-core areas (Mann-Whitney rank test, p=0.43), even after dropping the outlying 1998 El Nino year (p=0.40).

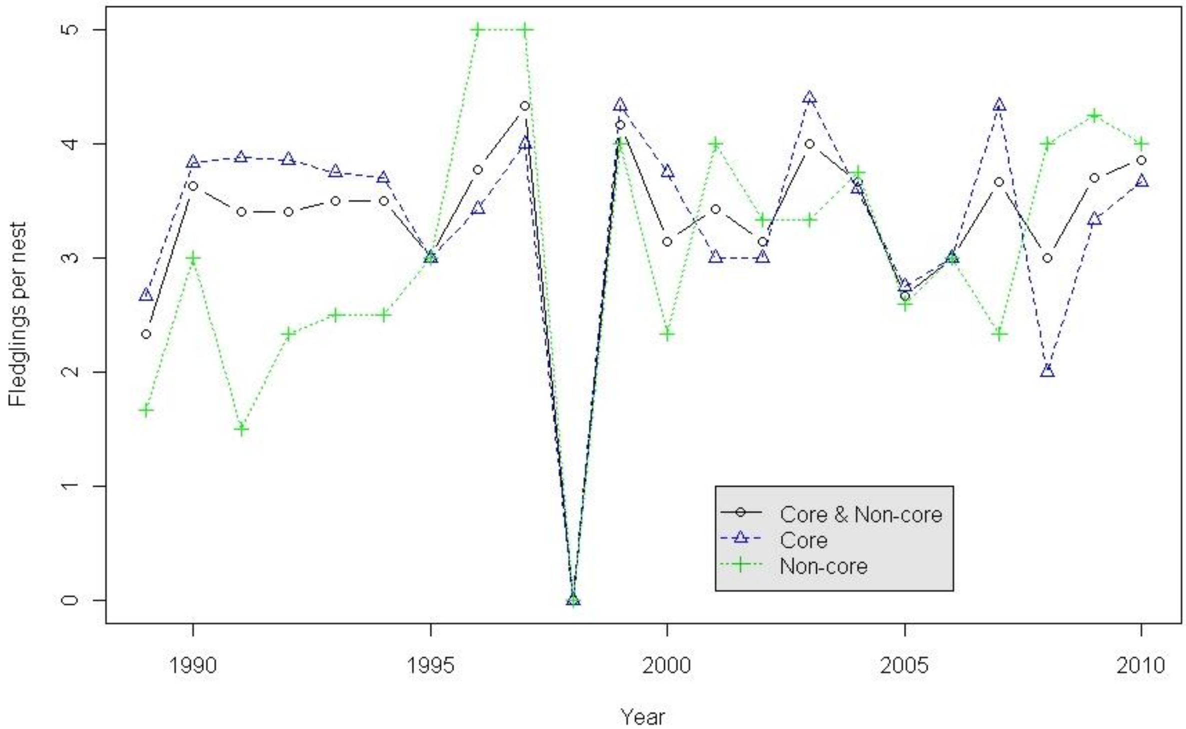

Figure 39. Prairie falcon fecundity (mean fledglings per nesting pair) for Pinnacles National Monument, 1989–2010.

Fecundity is moderately negatively correlated with fecundity in the previous year (r=-0.40, p=0.06) (Figure 40). Other than the extreme drop in fecundity during the extremely wet 1997–1998 El Nino year, falcon fecundity did not show any systematic relationship to rain-year precipitation, (adj. r^2 = -0.02, p=0.47,Figure 41). The lack of association held true after removing the outlying point for 1998 (adj. r^2 = -0.06, p=0.84). Fecundity was also unrelated to precipitation in the previous rain-year (adj. r^2 = -0.03, p=0.47). Comparable results were obtained for core areas and non-core areas.

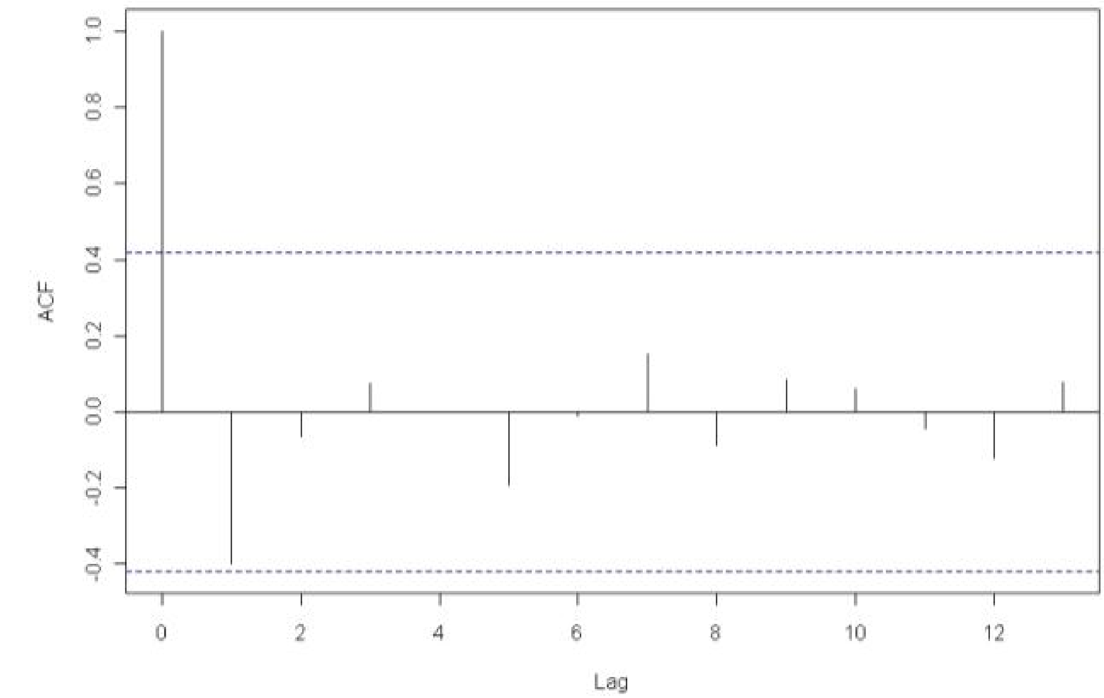

Figure 40. Correlogram showing the autocorrelation (ACF) as a function of time lag in years for prairie falcon fecundity at Pinnacles National Monument. Dashed blue lines are 95% confidence intervals.

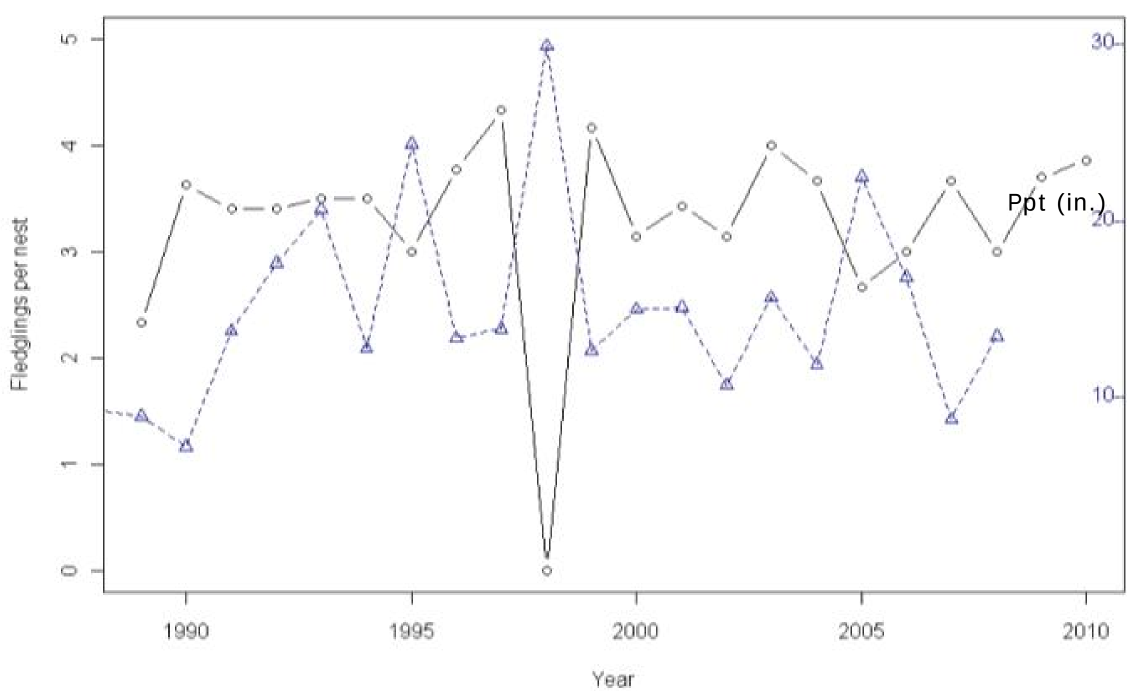

Figure 41. Co-variation of prairie falcon fecundity (solid black line) and precipitation (dashed blue line) at Pinnacles National Monument, 1989–2010.

Trends

Park scale: Since 1989 there has been no detectable trend in the number of territorial pairs, nesting pairs, successful nests, or fecundity. Overall the prairie falcon population at PINN appears to be relatively stable. The number of nesting pairs in core areas decreased slightly between 1989 and 2010. However, the slope term in a generalized least squares (GLS) trend model that included a first-order autoregressive error term was not significant (slope = -0.097, p=0.43).

Emerging Issues

We are unable to explain the significant 1–3 yr autocorrelation in falcon nesting pairs but suggest it is related in part to the fact that falcons require 2 years to reach reproductive maturity. More data are also needed to confirm possible longer-term 10–12 year cycles in falcon nesting population size and core area fecundity detected through autocorrelation analysis. We suspect that these longer cycles are a transient dynamic.

Over the range of weather conditions in this assessment, we found no relationship of precipitation with fecundity. The climate change assessment above showed that future climate may shift outside the range of historic variability, creating new conditions for falcons and their prey, which could change the nature of the relationship with weather. Warmer conditions as predicted in all models may cause a gradual shift from shrubland to more grassland, increasing habitat for ground squirrels within the foraging range of PINN’s falcons. This could either increase the density of falcon pairs or the fecundity of nesting pairs or both. Forecasts in precipitation are less consistent, but changes in annual rainfall or in the interannual variability may have effects on falcon population and fecundity.

Renewable energy development is gaining momentum throughout California. Small areas near PINN, within foraging range of the falcons, have modest potential for wind farms. Development is not imminent but is a non-zero probability. In fact, a winery near Gonzales, CA, recently proposed two wind turbines (Thorngate 2007). Concerns about raptor collisions with wind turbines, as shown in the conceptual model (Figure 36), could pose an additional threat to those already encountered by prairie falcons at PINN.

Data Gaps

Numerous scientific publications have suggested that closures and advisories can serve as an effective management tool for protecting cliff-nesting raptors (Fyfe et al. 1976; Olsen and Olsen 1978; Becker and Ball 1980; Suter and Joness 1981; Porter et al. 1987; Holthuijzen 1990; Cade et al. 1996; White et al. 2002). The 26-year raptor monitoring program began at the same time that raptor advisories were put into effect, so no pre-advisory data exist for comparing raptor fecundity before and after institution of the advisory program. PINN has not had the high staffing levels required for consistent monitoring of visitor use in core areas in order to conclusively confirm full visitor adherence to raptor advisories. Without these data it is not possible to entirely rule out cliff-nesting raptor nest failures due to human disturbance, although circumstances of nest failures usually suggest natural causes. The recent development of inexpensive remote video monitoring devices could fill this data gap.

Compilation of regional data sets on prairie falcon trends would also be valuable for evaluating potential larger-scale environmental controls on prairie falcon abundance as well as the possible influence of immigration on population dynamics in the park.

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Thorngate, N. 2007. Presence and movements of California condors near proposed wind turbines. Final report prepared for HT Harvey and Associates. Salinas, CA, Ventana Wildlife Society.

Landscapes (Ecosystem Pattern and Processes) Level 1 Category

Landscapes—Fire and Fuel Dynamics—Fire Regime
Findings: No significant change

Since 1950, the modern fire regime in the park and buffer area has been similar to that of the Interior Coast Ranges in general. Most fires were started by humans and 90% of acres burned in the months of June through October. Thirty-six mapped fires ≥ 170 ac have burned 45,626 ac (18,472 ha) or 22% of the undeveloped portion of study area; 12,630 ac burned inside the park boundary. This rate of burning yields a fire rotation period of 265 years to burn the 208,132 ac analysis area. Fire regimes are comparable inside the park and in the landscapes neighboring the park. Fire size distributions suggest a small decrease in fire sizes for the period 1980–2008 compared to 1950–1979.

The fire regime of the Pinnacles area has been strongly influenced by human cultures for thousands of years and has changed considerably over the past two centuries. Pre-European fire frequency is not well documented, but California Indian peoples may have burned grasslands and oak woodlands annually and chaparral less frequently (perhaps every 10–30 years); landscape fire rotation periods were much shorter, probably on the order of one-to-several decades. With the expansion of Mexican livestock ranching in the early 19th century, fire frequency probably decreased in grasslands and oak woodlands but increased in chaparral and coastal sage scrub. Fires remained common and the frequency of large accidental wildfires increased during the latter half of the 19th century, associated with increased economic activity and Anglo-American traffic in the region. Since the second quarter of the 20th century active fire suppression has lengthened mean fire-free periods in all vegetation types compared to the 19th century and Pre-European fire regimes. Reduced frequency of fire in the region has been associated with a reduction in grassland accompanied by expansion of chaparral and coastal scrub (Keeley 2002, 2005).

Approach

Fires in the Gabilan Ranges are generally smaller than those of the Santa Lucia Ranges (Davis and Borchert 2006). To avoid analyzing a mixture of fire regimes, we did not analyze the larger regional scale, restricting our analysis of wildfire trends to the park and adjacent landscapes within the 10 km buffer.

Greenlee and Moldenke (1982) provide a detailed fire history of the park through 1980. Our analysis considers large (>170 ac) wildfires recorded since 1950 in the fire perimeters database maintained by the California Department of Forestry and Fire Protection. We do not consider many small spot fires and control burns recorded in and around the park, as they account for a small fraction of the burn acreage.

We analyze time-since-fire distributions and fire-size distributions, comparing the time since fire distribution inside the park to that of the park-and-buffer buffer area. We compare fire size distributions for the period 1950–1979 vs. 1980–2008. See Appendix A for GIS layers generated for the assessment.

Data

Park-and-buffer scale:

Fire history data were obtained from the California Department of Forestry and Fire Protection (California Department of Forestry and Fire Protection 2008). According to PINN staff the database was current with respect to the fire history of the park. The fire perimeters include both public and private lands and are consistently recorded for fires larger than 300 ac. The database is considered much less complete prior to 1950, especially for private lands. (Note: updated fire history data became available after the completion of project analyses via the NPS San Francisco Bay Area Fire Network).

Status

Park-and-buffer scale:

Thirty-six mapped fires ≥ 170 ac were recorded in the fire perimeters database. These fires burned 45,626 ac (18,472 ha) or 22% of the undeveloped portion of study area (Figure 42). This rate of burning yields a fire rotation period of 265 years to burn the 208,132 ac analysis area. Pre-European fire frequency is not known, but the Ohlone culture may have burned grasslands and oak woodlands annually and landscape fire rotation periods were much shorter, probably on the order of one-to-several decades (Greenlee and Moldenke 1982, Greenlee and Langenheim 1990, Keeley 2002). Omission of numerous small burns between 1950 and 2008, for example controlled burns in the early 1980's (Pinnacles National Monument 2007), has little effect on the total acreage burned and does not affect our general conclusions.

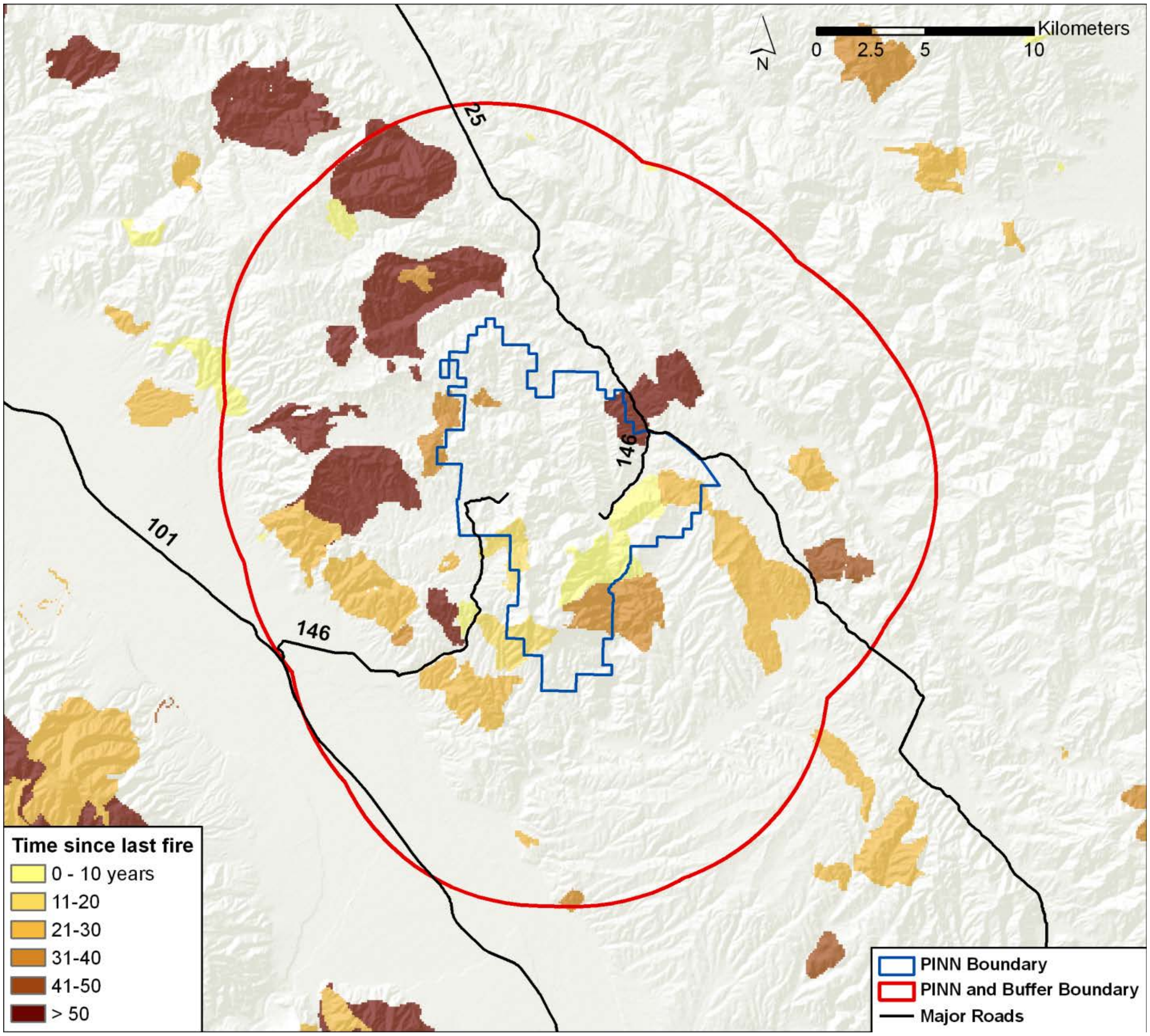

Figure 42. Time since fire map showing all fires recorded between 1950 and 2008 in the CDF&FP fire perimeters database (California Department of Forestry and Fire Protection 2008).

Our estimate of fire rotation period is biased upward by the relatively short period of analysis and the incomplete fire history record. The largest recorded wildfire in the park in August 1931 burned nearly 30,000 acres outside the park as well as the eastern half of the park. Had our analysis included this earlier period our estimate of the fire rotation period would have been reduced to around 130–150 years, still considerably longer than reconstructed pre-European fire rotation periods. Greenlee and Moldenke (1982) reported a 40-year fire return interval for the park between 1900 and 1979, which is much lower than our empirical estimate for the period 1950–2008.

Fire occurrence inside the park is slightly higher than outside the park but the percent of the landscape in different time-since-fire classes is roughly comparable (Figure 43). Roughly 53% of the park has not burned since 1950 compared to 78% of the park-and-buffer.

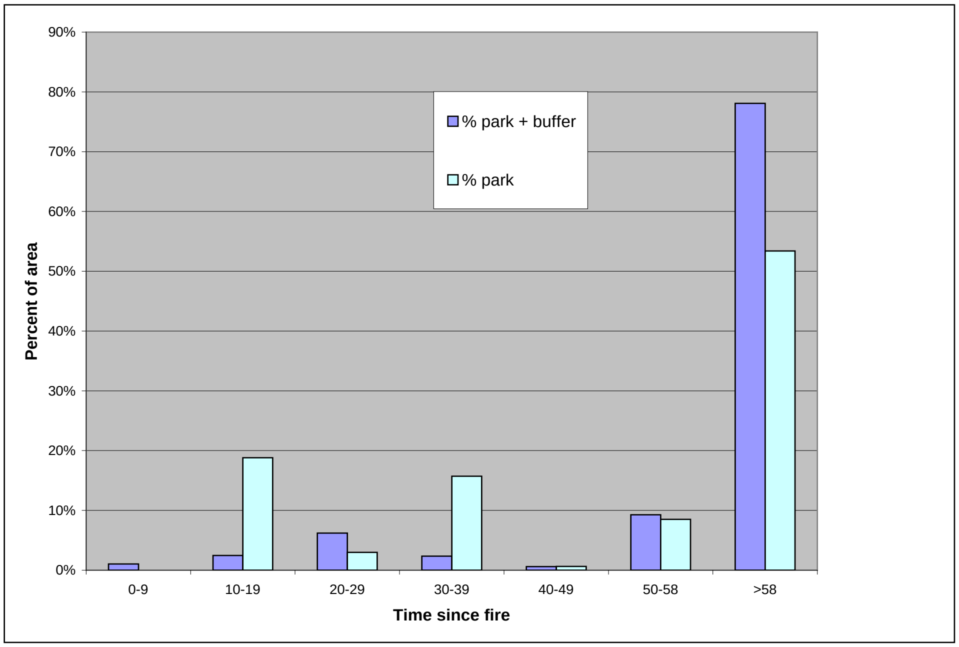

Figure 43. Comparison of time-since-fire distribution of the park versus the park-and-buffer.

Trends

There is some evidence that fire sizes have decreased over the past several decades (Figure 44), although the fire size distributions are not significantly different between the two periods (Wilcoxon rank test, $p = 0.23$). In East Bay counties (Contra Costa, Alameda, Santa Clara), Keeley (2005) reported a steady increase in fires < 4 ha and decrease in fires > 4 ha between 1945 and 2005, reflecting the effectiveness of fire suppression efforts in controlling increasing numbers of ignitions from a growing human population in the region.

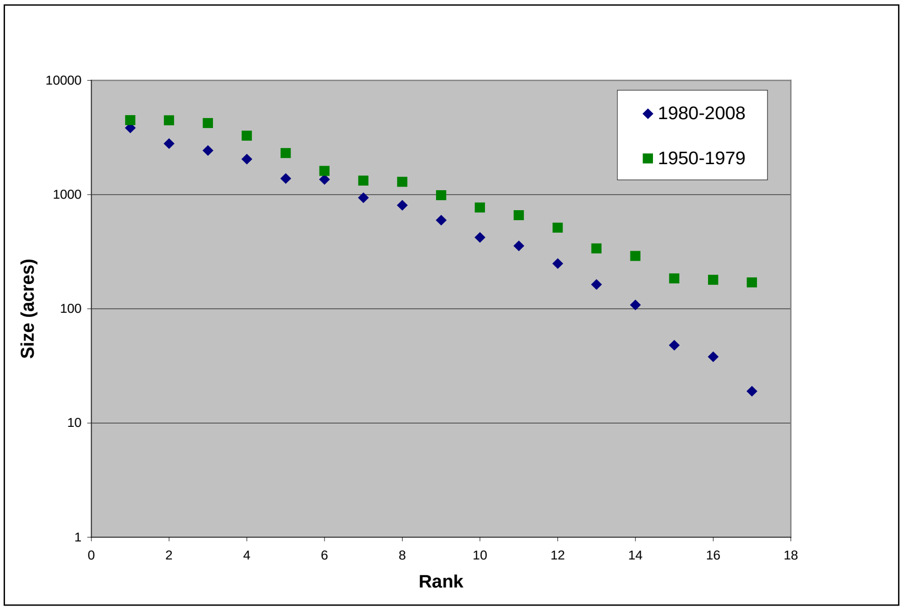

Figure 44. Ranked fire size from largest to smallest fire versus log (fire size) for the periods 1950–1979 and 1980–2008.

Emerging Issues

Twentieth century trends suggest a relatively weak relationship between warming, drought and wildfire risk in this region compared to forested regions of the Sierra Nevada and northern California (Keeley 2005, Westerling and Bryant 2008). Nevertheless, climate change (Westerling and Bryant 2008) and exurban development (Moritz and Stephens 2008) will probably combine to increase both the risk and cost of wildfires in the area. Expansion of shrublands into areas formerly occupied by grasslands could increase fire severity.

Data Gaps

Maintenance of a geospatial database on location and origin of all ignitions and spot fires not only in the park but in the buffer area is needed to monitor trends in regional fire regime.

Key References

California Department of Forestry and Fire Protection. 2008. Mapped fire history database for California; public version and detailed methodology.

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Moritz, M. A., and S. L. Stephens. 2008. Fire and sustainability: considerations for California's altered future climate. Climatic Change 87:S265–S271.

Pinnacles National Monument. 2007. Fire Management Plan.

Westerling, A. L., and B. P. Bryant. 2008. Climate change and wildfire in California. Climatic Change 87:S231–S249.

Wildfire is highly dependent on climate and on the vegetation associated with that climatic regime. Thus climate change is likely to affect the probability of fire occurrence and the area burned annually. Westerling et al. (2009, in review) modeled the response of wildfire to climate change scenarios in California over a representative range of emissions scenarios, global climate models, and shifts in vegetation caused by climate and urban development. Their results were summarized for PINN and its surrounding reference regions for three time periods out to the end of the 21st century relative to a 30 year reference period (1961–1990). For the model combinations we assessed, burned area per year in PINN is expected to increase 21–68% by the end of the century. Even greater rates of increase are predicted for the park-and-buffer and regional scales. Countering the potentially significant impact of increased fire on ecosystem resources and processes may require substantial increases in fire management resources or advances in fire-fighting technology.

Approach

Westerling et al. (2009, in review) modeled the probability of large wildfires and predicted burned area under a variety of climate change scenarios to capture the range of uncertainties about future wildfire regimes in California. They used both the A2 (medium-high emissions trajectory) and B1 (low emissions) scenarios from the IPCC (Nakićenović and Swart 2000) as adapted to California and three global climate models (GCM)— CNRM CM3, GFDL CM2.1 and NCAR PCM1 (see Cayan et al. 2009 and Chapter 3 for details on GCMs and scenarios). Climate variables were downscaled to 1/8 degree cells over a range of time scales (30 year averages, previous two years, current year, and seasonal variations), incorporating both longer-term conditions that control the amount of fuel and shorter-term variations affecting their flammability. Westerling et al. used the interaction between actual evapotranspiration and moisture deficit as a proxy for vegetation and fuel loading that could simulate shifts in vegetation cover with climate change. As urban development also changes the vegetative cover, they incorporated development patterns from EPA’s Integrated Climate and Land Use Scenarios consistent with the A2 (high growth and high sprawl) and B1 (low growth and low sprawl) (U.S. EPA 2008). Using historical data on fire perimeters, they developed a logit model of the probability of a wildfire > 200 ha occurring, which they applied with all the climate scenarios to bracket the range of plausible futures at three 30 year time periods centered on 2020, 2050, and 2085. Probability of wildfire was also translated into predicted area burned per year within each cell and compared to the 1961–1990 reference period.

The conceptual model underlying the logit model developed by Westerling et al. (in review) is depicted in Figure 45. The basic drivers of the model are landscape scale urban growth and increasing global GHG emissions. The former removes wild vegetation (i.e., reduces the vegetation fraction) and increases fire ignitions. The latter is expected to alter key climate variables that would impact fire-vegetation interactions on two time scales. The long-term climate affects the growth of vegetation and hence the fuel load. Shorter-term climate controls the moisture deficit that determines the flammability of existing fuels. Ecosystems may be energy-limited, where fuels are sufficient to support large fires but flammability is low except in dry years, or fuel-limited, such as grass and shrublands that can be highly flammable but have relatively lower fuel loads. Greater fire frequency can stimulate the invasion of non-native plants that may increase the flammability of the ecosystem. Fire management can adapt to increasing fire risk by applying greater fire-fighting resources or more effective technology. Neither invasive plants nor adaptive fire management were incorporated in the Westerling et al. model, however.

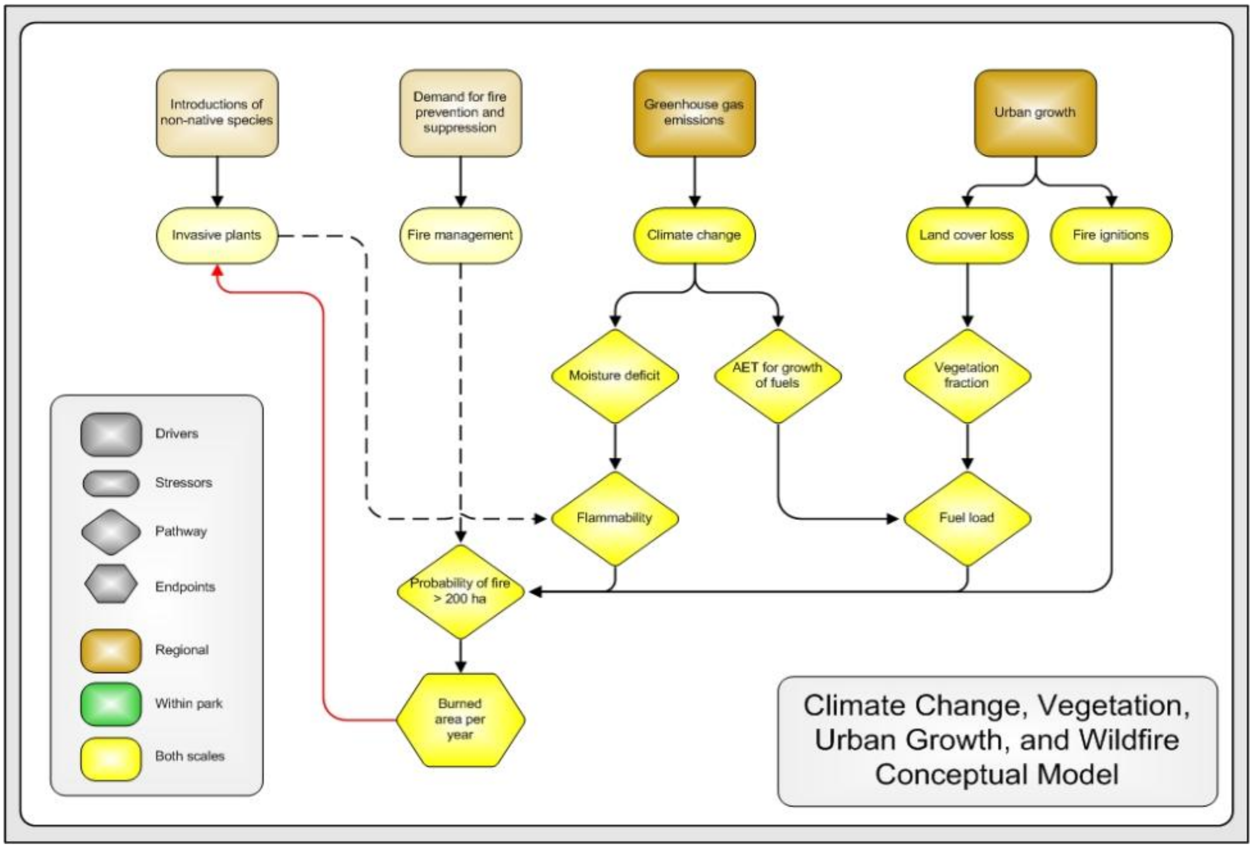

Figure 45. Conceptual model of the response of wildfire to climate change and urban growth in the model of Westerling et al. (in review). Lighter colored icons and dashed arrows represent potential drivers and stressors that are not included in the current version of the Westerling model. The red arrow to invasive plants indicates potential feedback of wildfire on fuels, although this was not included in the Westerling model.

For the PINN condition assessment, the predicted changes in annual burned area and frequency of fires > 200 ha from Westerling et al. (in review) were summarized over the scenarios and reported at the regional, park-and-buffer, and park scales. The Westerling et al. paper analyzed 264 combinations of emissions, climate models, urban growth scenarios, rate of vegetative adaptation to climate change, and three time periods. This would be too much information for this condition assessment, so we limited the analysis for PINN to the two emissions scenarios with their associated urban growth scenarios, the three global climate models, over the three future time periods. The assumption that vegetation adapts or migrates with climate change is constant among the combinations reported here. In short, the results were averaged spatially across all 1/8 degree cells within each reference region for a scenario, and then averaged over the three climate models.

Data

- Shapefiles of 1/8 degree cells in California with predictions of burned area and fire frequency for 264 combinations of emissions scenarios, global climate models, urban growth scenarios, and assumptions about the rate at which vegetation adapts to climate change (Westerling et al. 2009, in review) available at http://ulmo.ucmerced.edu/data/scen08/.

Predicted Trends

The average rate of burned area in the two 1/8 degree cells containing PINN was approximately 6 hectares per cell. This is nearly twice the average for the park-and-buffer region and statewide and more than twice the rate of the overall reference region. All three GCMs lead to similar forecasts of increasing future burned area for a given emissions scenario (Table 19). The GFDL CM21 GCM consistently predicts the highest rate of increase in both emissions scenarios. On average across GCMs, the modeling predicts a 58% increase in annual burned area within PINN by the end of the century under the A2 emissions scenario, ranging from 40–68% among GCMs (Figure 46). B1 emissions scenarios lead to a prediction of a 36% increase, ranging from 21–54%. The frequency of wildfires > 200 ha follows an almost identical rate of increase as burned area.

Table 20. Predicted area burned (in percent of area burned 1961–1990) by time period and global climate model within PINN for the A2 and B1 emissions scenarios. Statewide averages include all combinations of urban growth and vegetation adaptation assumptions.

	1961–1990	2005–2034	2035–2064	2070–2099
A2 emissions scenario				
CNRM CM3	100	125	126	140
GFDL CM21	100	130	152	168
NCAR PCM1	100	107	131	166
Mean	100	120	136	158
Statewide average of all A2 scenarios (Westerling et al. in review)		119	133	172
B1 emissions scenario				
CNRM CM3	100	115	130	121
GFDL CM21	100	137	147	154
NCAR PCM1	100	113	118	132
Mean	100	122	132	136
Statewide average of all B1 scenarios (Westerling et al. in review)		119	128	136

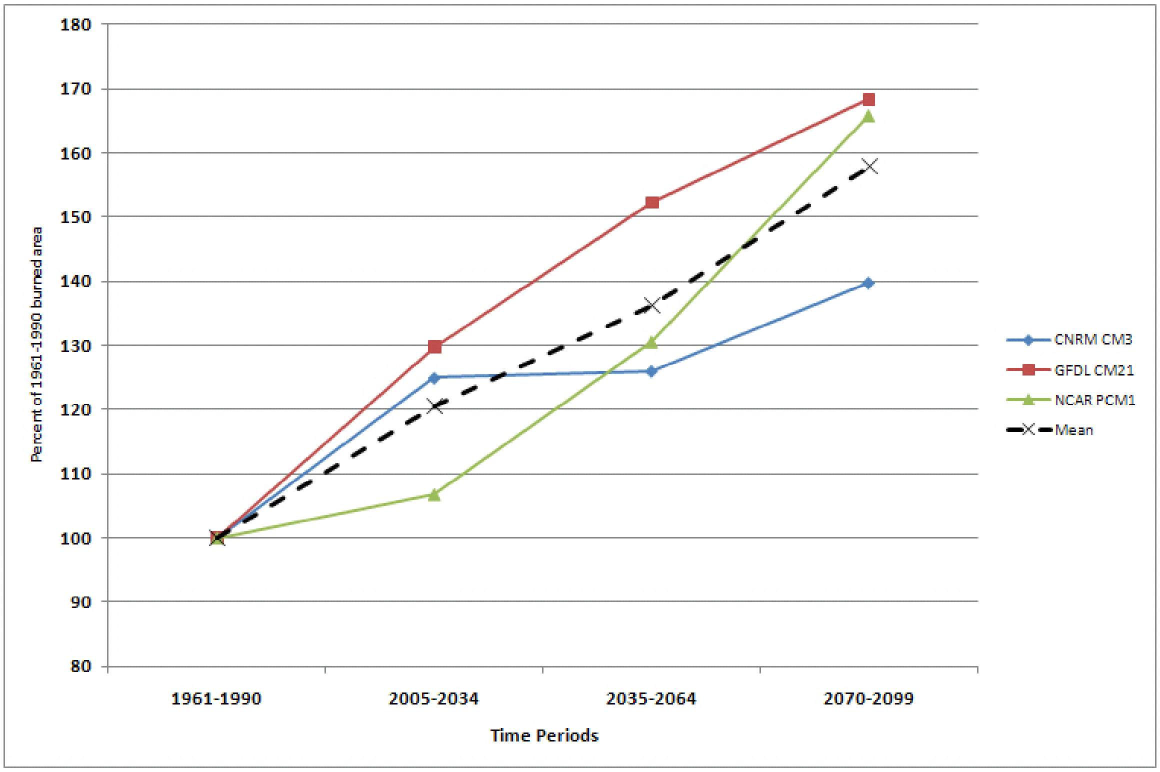

Figure 46. Graph of predicted burn area in PINN for the A2 emissions scenario with different global climate models as a percentage of the 1961–1990 reference period (derived from data from Westerling et al. (in review). The logit model estimated the annual burned area for 1961–1990 in PINN at ~6 hectares per year per 1/8 degree cell in all three climate models.

Although PINN has a rate of burned area nearly twice that of the park-and-buffer scale and more than twice that of the reference region, the rate of increase is quite similar across scales within each emission scenario (Table 20). Perhaps most alarming is the near doubling of burned area predicted in the park-and-buffer vicinity of PINN by the end of the century under an A2 emissions scenario (51% increase under B1).

Table 21. Predicted mean area burned (in percent of area burned 1961–1990) by time period within PINN and reference regions for the A2 and B1 emissions scenarios, based on the means of the three GCMs. Statewide averages include all combinations of urban growth and vegetation adaptation assumptions.

	1961–1990	2005–2034	2035–2064	2070–2099
A2 emissions scenario				
PINN	100	120	136	158
Park-and-buffer	100	121	144	191
Region	100	121	138	178
Statewide average of all A2 scenarios (Westerling et al. in review)		119	133	172
B1 emissions scenario				
PINN	100	122	132	136
Park-and-buffer	100	123	138	151
Region	100	122	133	138
Statewide average of all B1 scenarios (Westerling et al. in review)		119	128	136

Emerging Issues

Wildfire is an important process in the ecosystems at PINN. The fire dynamics section above reported that fire frequency has declined since the early 19th century with an associated shift from grassland and woodland to more chaparral and coastal scrub. The decline was caused by an aggressive fire suppression management strategy that extinguished fires before they got large. Climate change forecasts lead to relatively consistent predictions of increased fire frequency and burned area throughout the 21st century under many varying assumptions. These increases would likely have important effects on ecosystem resources and processes that are of concern to PINN managers. For instance, the combination of climate and wildfire frequency may convert chaparral and woodland to grassland and promote invasions by non-native plants. Attempting to mitigate those changes could require substantial increases in fire management resources or advances in fire-fighting technology. Therefore it is disturbing that observed emissions growth for 2000–2007 exceeded the most fossil fuel-intensive scenario from IPCC (Science Daily 2008), meaning that projected increases in fire frequency may be underestimated.

Data Gaps

The Westerling et al. database contains many additional scenarios that were not assessed here. We believe, however, that the scenarios in our assessment are illustrative of the range of expected and plausible responses of wildfire to climate change and urban growth. Westerling et al.'s modeling was based on historical wildfires with associated management. Therefore potential changes in management strategies, technology, or resources were not considered. They also did not model fire severity. It is possible that climate change and increased fire frequency may cause a shift from chaparral to grassland and thus reduce fire severity.

Key References

Westerling, A. L., and B. P. Bryant. 2008. Climate change and wildfire in California. *Climatic Change* 87:S231–S249.

Westerling, A. L., B. P. Bryant, H. K. Preisler, H. G. Hidalgo, T. Das and S. R. Shrestha. 2009. *Climate Change, Growth, and California Wildfire.* CEC-500-2009-046-D. Sacramento, California Energy Commission.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das, and S. R. Shrestha. Submitted. Climate change and growth scenarios for California wildfire. *Climatic Change*.

A functional network of connected wildlands is essential to the continued support of California's diverse natural communities in the face of human development and climate change. The California Department of Transportation and California Department of Fish and Game commissioned the California Essential Habitat Connectivity (CEHC) Project to delineate Essential Connectivity Areas that link Natural Landscape Blocks throughout the state. PINN and adjoining lands form one of these blocks, which is linked by an Essential Connectivity Area with the Pancho Rico Valley to the south. NPS management is already geared toward maintaining the ecological integrity of a natural landscape block. However, maintaining the park unit's habitat value will depend in part on the functioning of the connectivity area, which almost exclusively crosses private land. PINN managers may want to be alert for land use proposals that could degrade the connectivity value and to participate in more detailed design of habitat linkages for focal species of importance to the park unit.

Approach

Habitat connectivity is a critical landscape property at all spatial and temporal scales, whether between stopovers on migratory flyways, corridors between summer and winter range, foraging throughout the home range of a large predator, gene flow between populations, access to different life history requirements, or wetlands and uplands (Crooks and Sanjayan 2006). At a regional scale, connectivity can be disrupted by stressors such as intensive land uses and road construction. Spencer et al. (2010), with extensive stakeholder involvement including David Graber and Ray Sauvajot of the NPS, conducted a comprehensive GIS assessment of "essential connectivity areas" for the State of California. The CEHC Project first delineated Natural Landscape Blocks (NLBs) for which connectivity areas were to be modeled. These NLBs were identified primarily by large, contiguous areas (greater than 2,000 acres) in good ecological condition. The Ecological Condition Index (ECI) was developed by Davis et al. (2006) based on maps of land conversion, housing density, road effects, and forest structure. The CEHC Project set thresholds in the ECI specific to conditions in ecoregions for delineating NLBs. These initial areas were supplemented with protected areas and areas of high biodiversity where not already included by the ECI criterion. PINN and adjacent lands forms one of these NLBs (Figure 47). Identifying Essential Connectivity Areas (ECAs) required two basic steps. First a GIS layer of resistance or "cost" to wildlife movement was developed. The most important input to the resistance layer was a score based on land cover, with natural cover types having low resistance and human-modified types having higher resistance. Management status such as protected area had a minor influence on resistance value (Figure 47). Then a least-cost corridor analysis was run for each pair of NLBs, which finds the path of least resistance. Statewide, the CEHC Project identified 192 ECAs. Note that the resistance value used to model ECAs is very generic and was not based on a particular species. Thus the ECA might be considered an antidote to general habitat fragmentation rather than as a migratory or dispersal route for any individual or group of species.

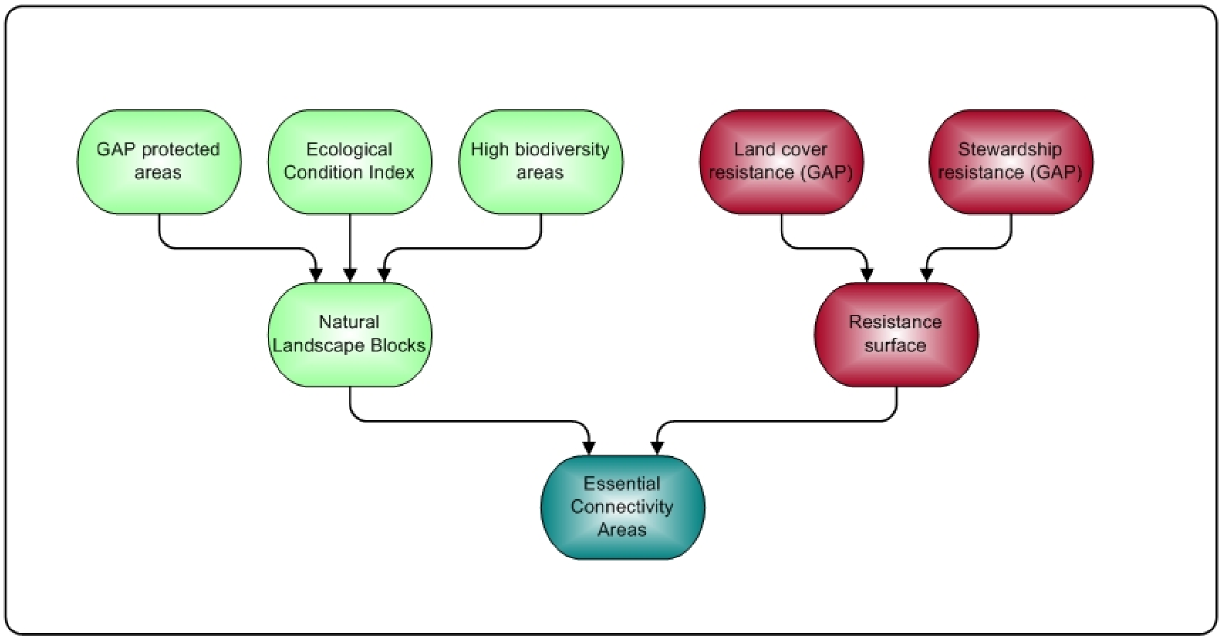

Figure 47. GIS conceptual model of California Essential Connectivity Areas (after Spencer et al. 2010).

For the PINN condition assessment, the proportions of Natural Landscape Blocks and Essential Connectivity Areas are reported at the regional, park-and-buffer, and park scales.

Data

- California Essential Connectivity Areas
  ftp://ftp.dfg.ca.gov/BDB/GIS/BIOS/Habitat_Connectivity/

Status

Much of the higher elevations of the Central Coast were incorporated into NLBs, including one that contains most of the administrative boundary of PINN (Figure 48). The primary ECA involving PINN links it with the Pancho Rico Valley roughly 50 km to the south. From there, other ECAs connect to the Los Padres National Forest in Big Sur and to the interior Coast Ranges. The CEHC analysis found that the ECA is 99% privately owned and bisected by State Highway 198. Roughly one-quarter of the ECA overlaps with Critical Habitat (3 species) and Essential Habitat (2 species) identified by the US Fish and Wildlife Service. This ECA overlaps substantially with a focus area identified by the California Rangeland Conservation Coalition (Cameron 2007) and with an Important Bird Area (National Audubon Society 2008).

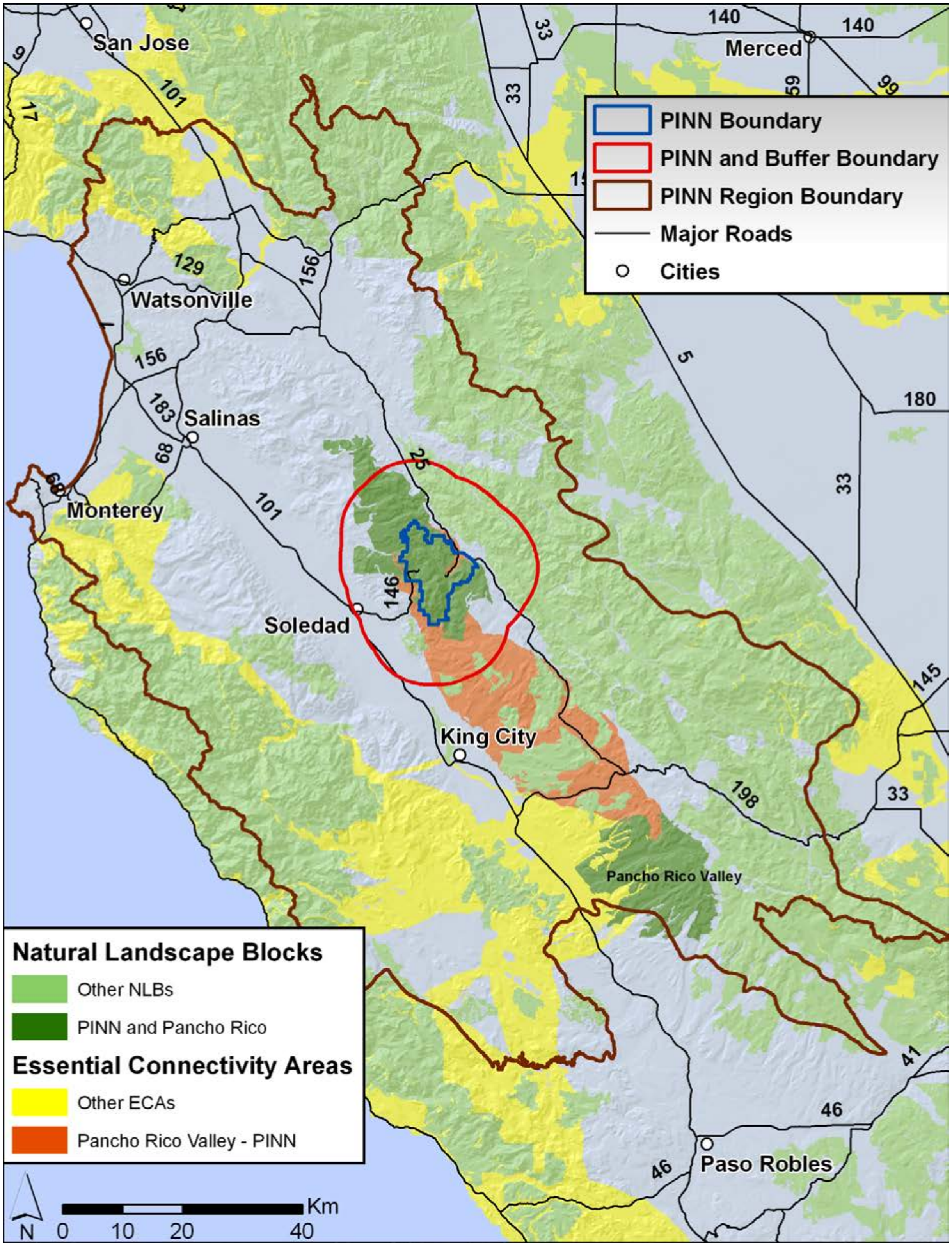

Figure 48. Map of the Natural Landscape Blocks (NLB) and Essential Connectivity Areas (ECA) between them (Spencer et al. 2010) for PINN and surrounding regions.

Tabulating percentages of area in NLBs and ECAs quantifies the visual impressions from looking at the map in Figure 48. Essentially the entire boundary of PINN is within an NLB (Figure 49). The park-and-buffer scale is more the half within NLBs, with 14% in the ECA to Pancho Rico Valley and intermediate unnamed NLBs. Just under half of the region is in NLBs with a quarter in ECAs.

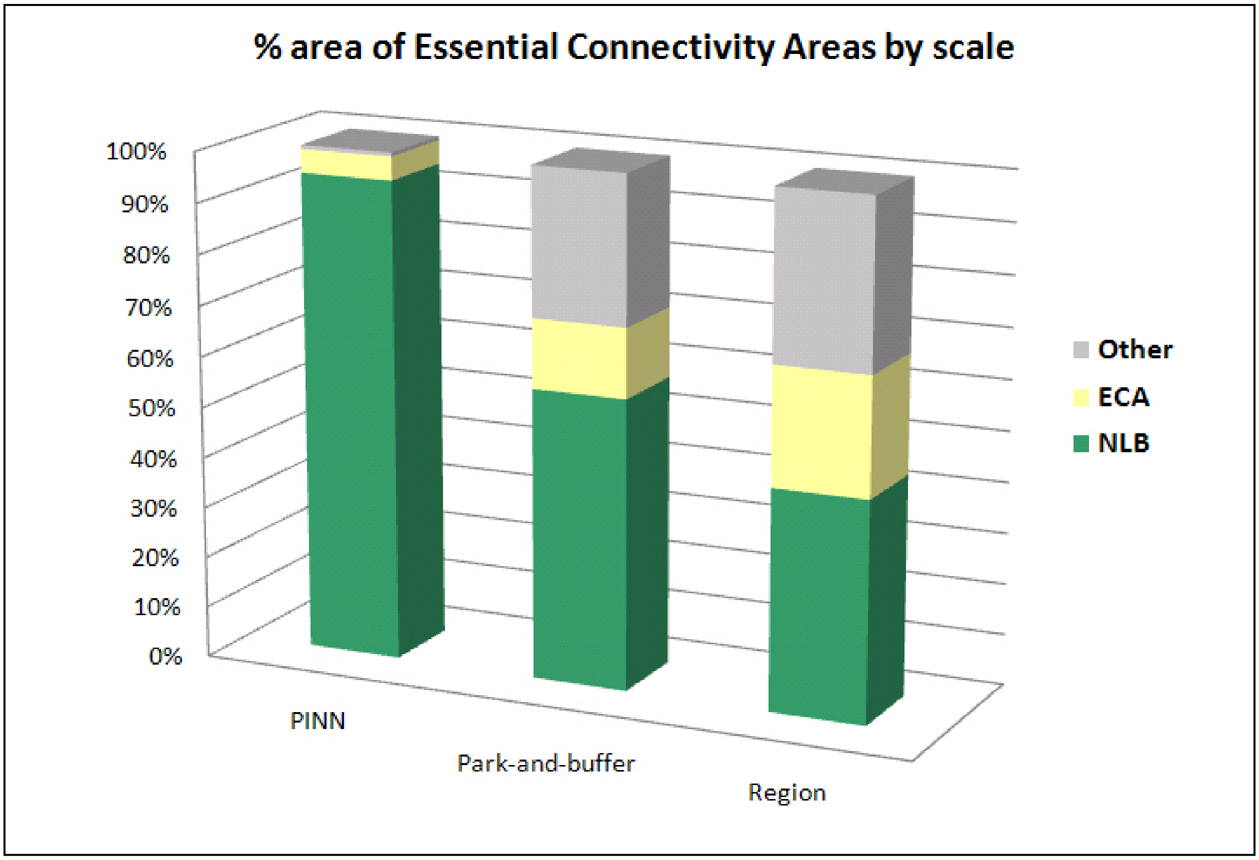

Figure 49. Bar graphs of the relative percentage of Natural Landscape Blocks (NLB), Essential Connectivity Areas (ECA), and all other lands for PINN, the park-and-buffer landscape, and the region.

Trends
The CEHC Project was based on current ecological conditions both to generate NLBs and ECAs. Thus no temporal trends in connectivity were addressed. Other sections of this condition assessment report show that ecological conditions have declined around PINN over previous decades. We may speculate that the size of NLBs tends to be relatively smaller now than they would have been in the past, and perhaps some potential ECAs have been lost. Fortunately, PINN is still linked by an ECA to the network of natural areas remaining in the state.

Emerging Issues
The CEHC Project underscores the growing awareness of the need to manage landscapes for habitat connectivity at scales larger than individual managed areas. PINN for instance has been shown to be a key NLB in the network of connectivity areas or green infrastructure of the state. Management objectives at PINN already strive to maintain conditions compatible with the criteria for NLBs. However, the habitat value of PINN depends in part on its continued

connectivity to NLBs to the south and east. Park managers should be vigilant for land use proposals that might degrade the value of the ECA and work with land owners to mitigate further fragmentation in the connectivity area.

The CEHC report provides guidelines for the local design of linkages (Spencer et al. 2010). One of the first proposed tasks is to work with stakeholders to identify the set of focal species or ecological processes for which corridors will be modeled. Each would have its own resistance surface. Corridors for individual species then need to be merged to identify the overall linkage. Conducting such a design process for the Pinnacles—Pancho Rico Valley ECA was beyond the scope of this condition assessment. Managers at PINN may want to consider initiating or participating in this design exercise with other stakeholders and land owners in the future. One such planning process, the Wildlands Conservation Plan for the Central Coast Region (Thorne et al. 2002) conducted a corridor analysis based on the specific habitat and spatial requirements of four focal species. That plan identified corridors not included in the more general CEHC Project that connect PINN northward to the Santa Cruz Mountains and westward across the Salinas Valley to the Santa Lucia Range.

Data Gaps

The CEHC Project identified broad connectivity areas deemed essential across the State of California. The process of necessity used spatial data that were statewide in coverage, and thus could not incorporate more detailed information for specific locales. Moreover the process was of necessity quite generic and did not address distributions or needs of particular species.

Key References

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Spencer, W. D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi and A. Pettler. 2010. California Essential Habitat Connectivity Project: A Strategy for Conserving a Connected California, Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration. Available at http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=18366 (accessed April 2011).

Landscapes—Landscape Dynamics—Habitat Connectivity for American Badger (Demonstration of a Modeling Approach)
Findings: Baseline only

Habitat and habitat connectivity are species-specific constructs both in terms of how habitat is defined and the spatial scale at which they are measured. For this reason the generic wildland habitat connectivity assessment described in the previous section is somewhat simplistic and difficult to interpret ecologically. In this section we demonstrate an approach for mapping and monitoring species-specific habitat connectivity using available, satellite-derived land cover data, the California Wildlife Habitat Relationships database, and the connectivity analysis package Circuitscape.

Approach

Circuitscape uses circuit theory to predict population or genetic connectivity in spatially heterogeneous landscapes (McRae and Shah 2009). The landscape is modeled as a conductive surface with high conductance (low resistance) assigned to habitats that are most conducive to movement and low conductance assigned to poor dispersal habitat or to movement barriers (Figure 50). Flows are modeled between specified points or regions of interest, for example between areas of core habitat or between the edges of the study landscape. Resulting patterns in current flow can then be related to ecological processes, such as individual movement and gene flow (McRae 2006, McRae et al. 2008).

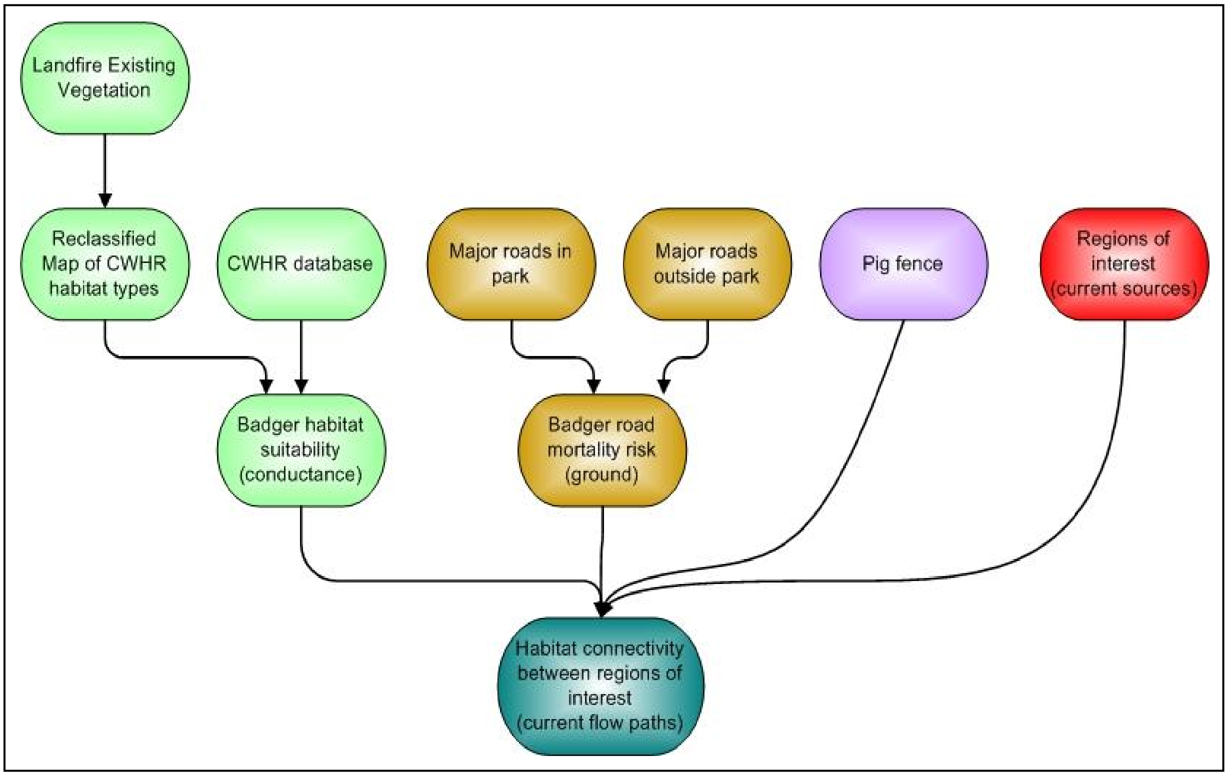


Figure 50. GIS conceptual model of connectivity modeling for American badger.

Because the PINN land cover map does not cover sufficient extent needed for a landscape scale assessment of connectivity, we compared several available, recent regional landcover maps including 30 meter data from the Gap Analysis project, 30 m data from the Landfire Project, and 100 m data from the California Department of Forestry and Fire Protection. Based on comparison to the vegetation map for Pinnacles and to recent air photos we selected the Landfire map and manually reclassified 63 Landfire existing vegetation types into 16 CWHR habitat types (Figure 50 and Figure 51). Each habitat type was assigned a badger "conductance" score based on the CWHR database using the geometric mean of habitat suitability across all structural stages of that habitat type (highest = 100, lowest = 0). Thus we assumed that badgers would move most freely through habitat that was rated as highly suitable for foraging, cover and reproduction, would be less likely to move through less suitable habitat types, and would not move through unsuitable habitats such as urban areas or oak forest. Although CWHR rates irrigated cropland as low suitability for reproduction and cover and medium suitability for foraging, for the demonstration here we considered cropland unsuitable due to risks from persecution, pesticides and other mortality factors.

The buried fence used to exclude pigs from PNM could also serve as a barrier to badger movement in and near the park. To explore the possible effects of the fence we re-scored cells traversed by the fence to a conductance value of zero, treating the fence as an impenetrable barrier, and re-ran the analyses.

Road kill is a major source of mortality for badgers, which appear to have little fear of roads and may even be attracted to them because roadsides can harbor large populations of prey species such as ground squirrels (Messick and Hornocker 1981). To account for mortality risk associated with road crossing, we assigned a high mortality risk to major public roads outside the park and a much lower risk to roads inside the park, where we assumed traffic volume and vehicle velocities would be lower. In Circuitscape the roads were represented as current "grounds" that would draw down current flowing near them (i.e., cause badger mortality and disrupt movements accordingly). An alternative approach is to assign roads high resistance, but there is no empirical evidence to suggest that badgers are deterred by roads. Sensitivity of the results to incorporation of roads was tested by running the model with and without roads.

To identify areas of relatively high importance for badger movement within and across the park, we created linear "regions of interest" to evaluate movements from northwest to southeast along the Gabilan Ranges and from southwest to northeast across the Gabilan Range between the Salinas Valley and Diablo Range (Figure 51 and Figure 52). Based on estimated badger home range size of 1.4–3.7 sq. km (0.4–1.5 sq. mi.), this park-and-buffer analysis is at a scale commensurate with within-population badger dispersal over one-to-several generations, as opposed to movement of individual animals in a home range or rare gene flow events associated with long distance immigration of individuals into the area.

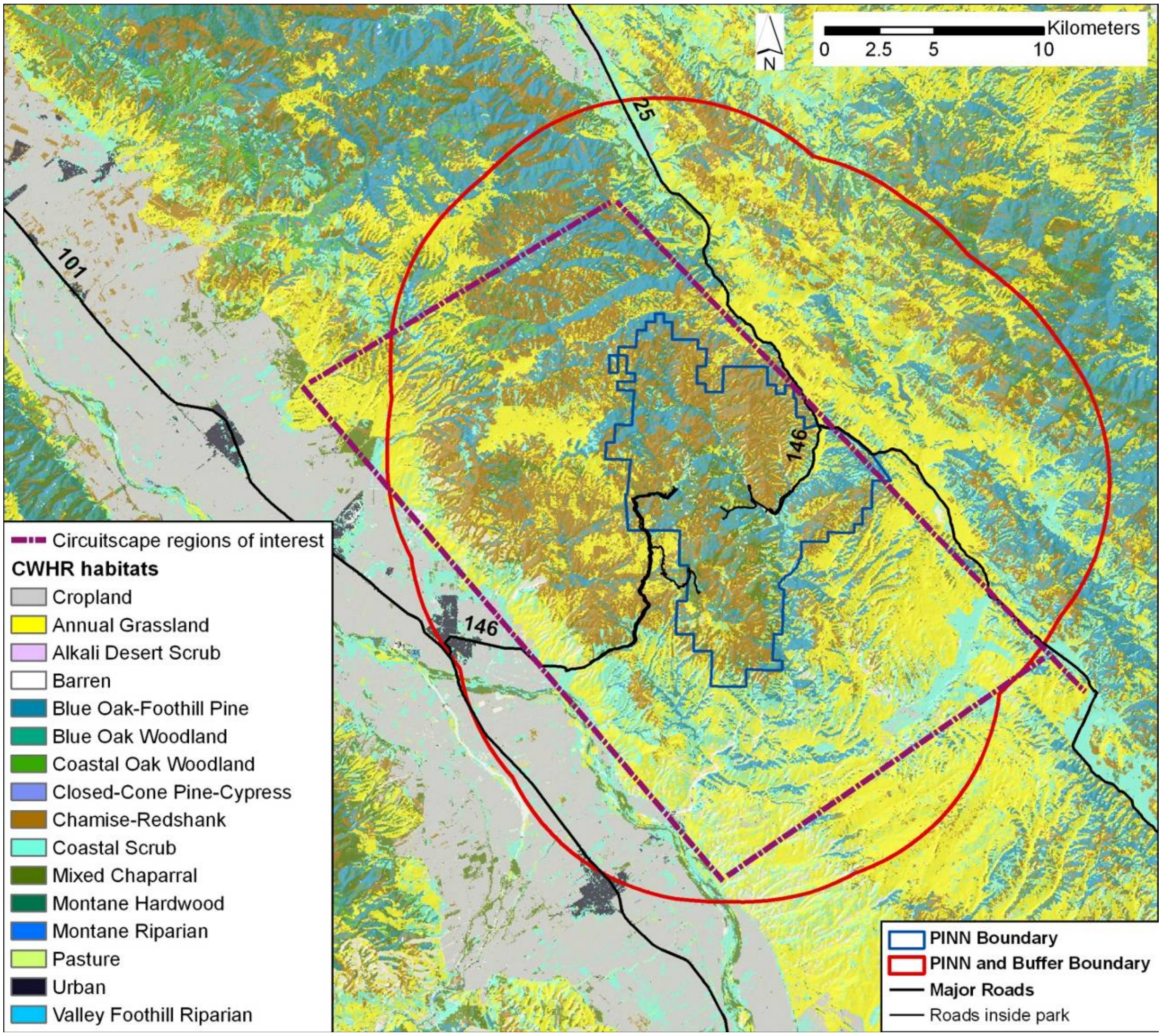


Figure 51. Map of CWHR wildlife habitat types derived from existing vegetation types as mapped by the Landfire Project. Important badger habitat types include annual grassland, and to a lower degree chamise-redshanks chaparral, mixed chaparral and irrigated cropland.

Data

- Landfire Existing Vegetation Type, http://www.landfire.gov/NationalProductDescriptions21.php
- California Wildlife Habitat Relationships database; http://www.dfg.ca.gov/biogeodata/cwhr/
- Roads; PINN GIS database

Status

Most of the highest suitability badger habitat (grassland) occurs outside the park. Inside the park, grassland habitats are patchily distributed in a matrix of chaparral vegetation, which is rated low-to-medium suitability for badgers (Figure 52).

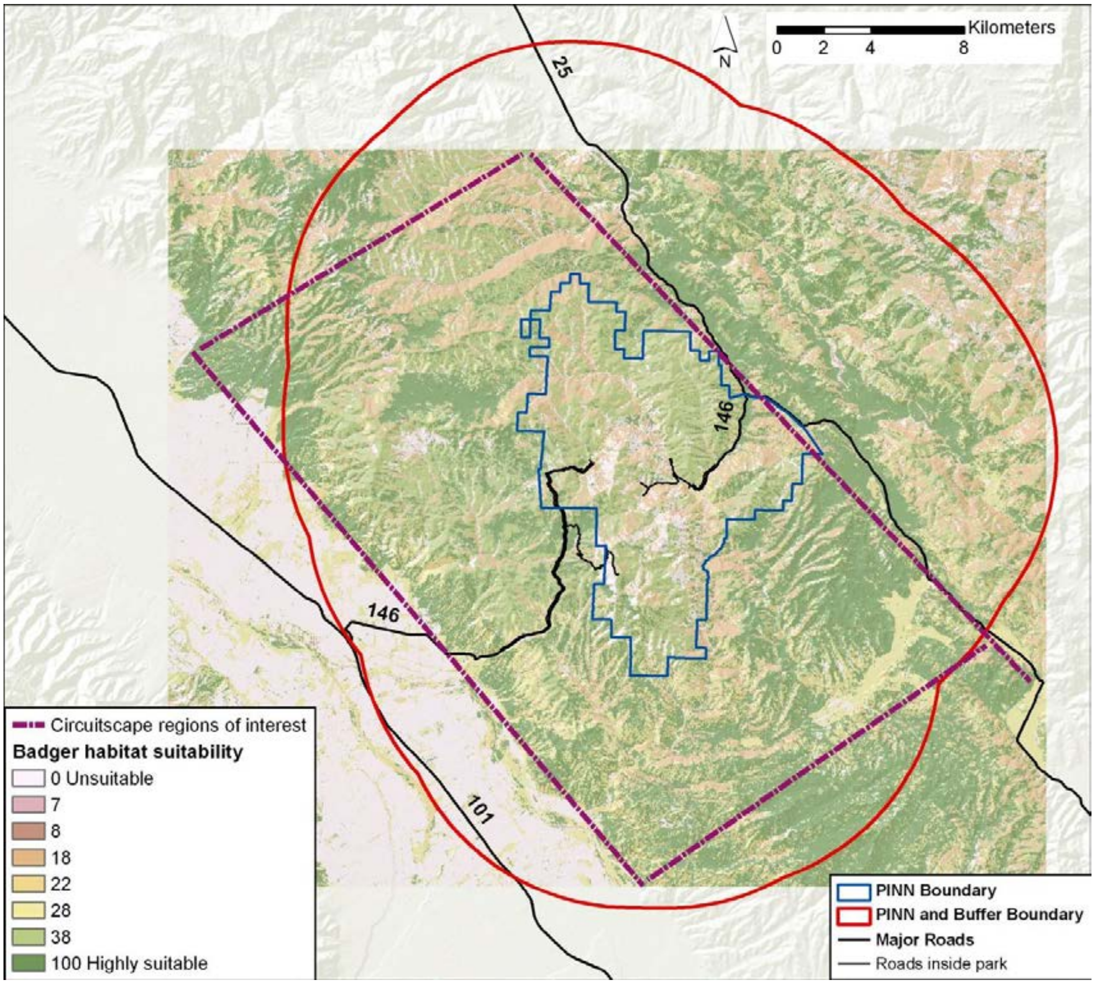


Figure 52. Map of habitat suitability or conductance for American badger derived from the map of CWHR habitat types in Figure 51.

If road risk and the fence barrier are ignored, badger habitat appears to be relatively well-connected from northwest to southeast along the foothills of the Gabilan Range outside of the park (Figure 53). Flow paths are concentrated along the northeast and western sides of the park and at the grassland-cropland interface along the western edge of the Salinas Valley. Well-defined flow paths occur just outside the northeastern park entrance and just inside the southwestern park entrance (Figure 53b and c.)

Lowest flow values inside the park occur in the central region. Some well-defined northwest-southwest and east-west flow paths are apparent, especially in the southern-central portion of the park (Figure 53). These are areas where medium-to-high suitability habitat is bounded by unsuitable or low-suitability habitat.

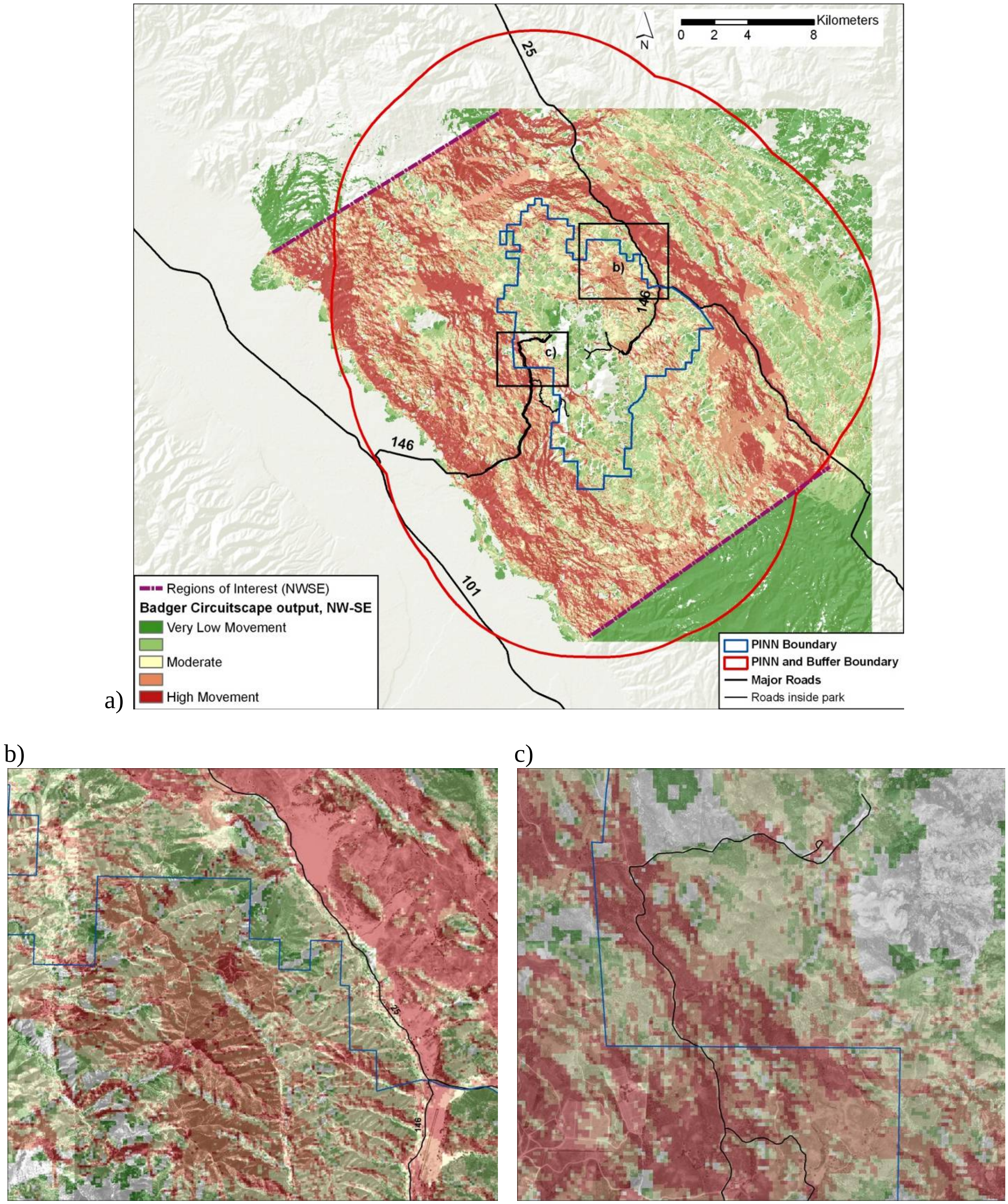


Figure 53. (a) Current map predicting areas of highest and lowest badger movement along a northwest to southeast axis across a. Pinnacles National Monument between linear regions of interest. (b) overlay of current map on 1 m orthophoto along northeastern corner of the park. (c) overlay of current map on 1 m orthophoto near western park entrance.

Southwest-northeast (Figure 54) flow paths across the park are less concentrated than those in the northwest-southeast direction (Figure 53). The main routes along this orientation occur along the northern edge of the park and immediately southeast of the park.

The pig fence presumably confines any badgers living inside the fenced area, except where the fence is interrupted by entry roads. However, most badger habitat lies outside the fenced portion of the park. Thus northwest-southeast connectivity is not much affected by the fence other than some concentration of movement paths around the fence in the northeastern and southern portions of the monument (Figure 55a). Similarly, southwest-northeast movement pathways are disrupted across the central portion of the monument, and pathways at the northern and southern ends of the monument are predicted to increase in relative importance (Figure 55b). The pig fence has been extended around newly acquired lands at the east entrance, which may alter movement patterns further.

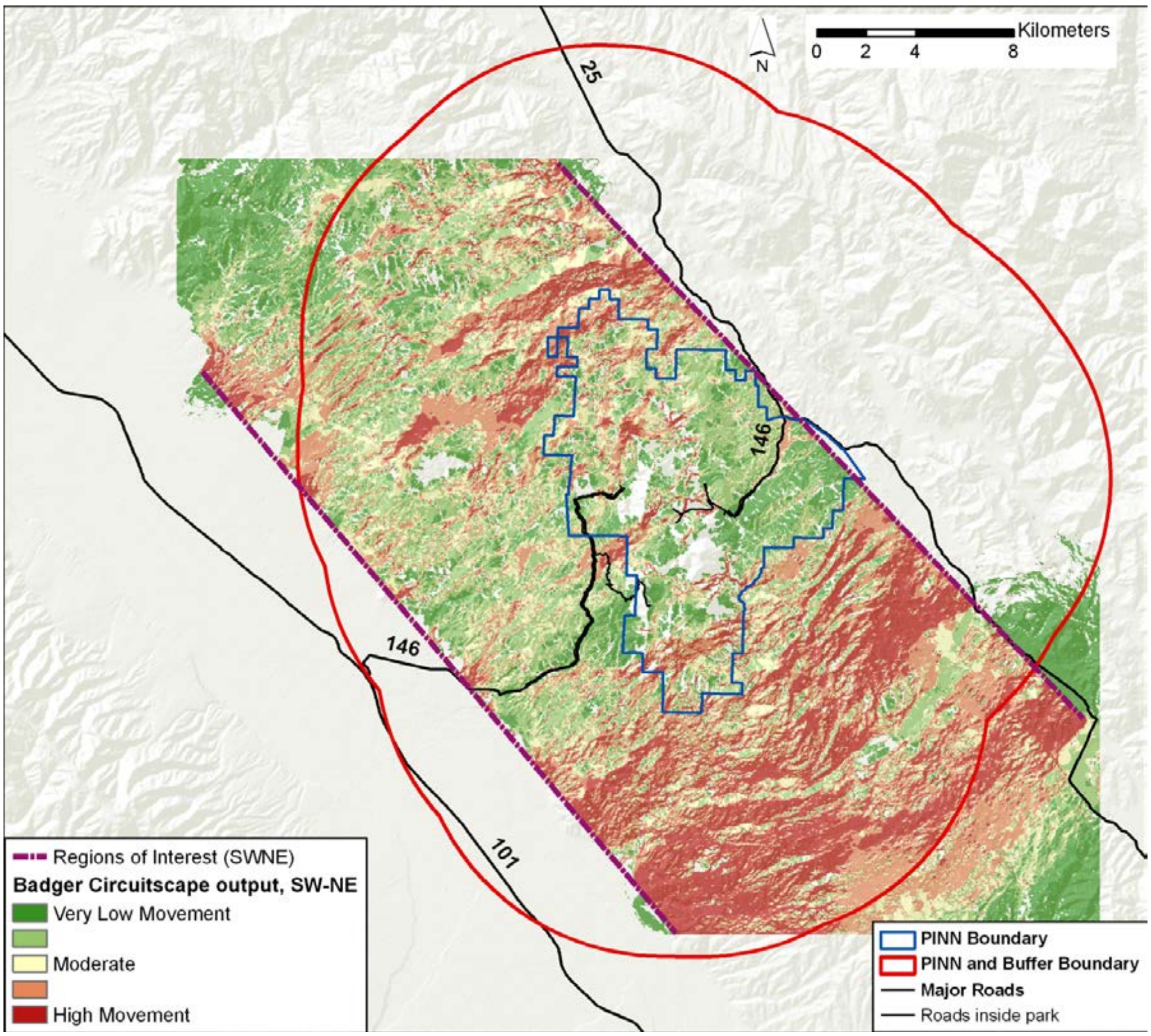
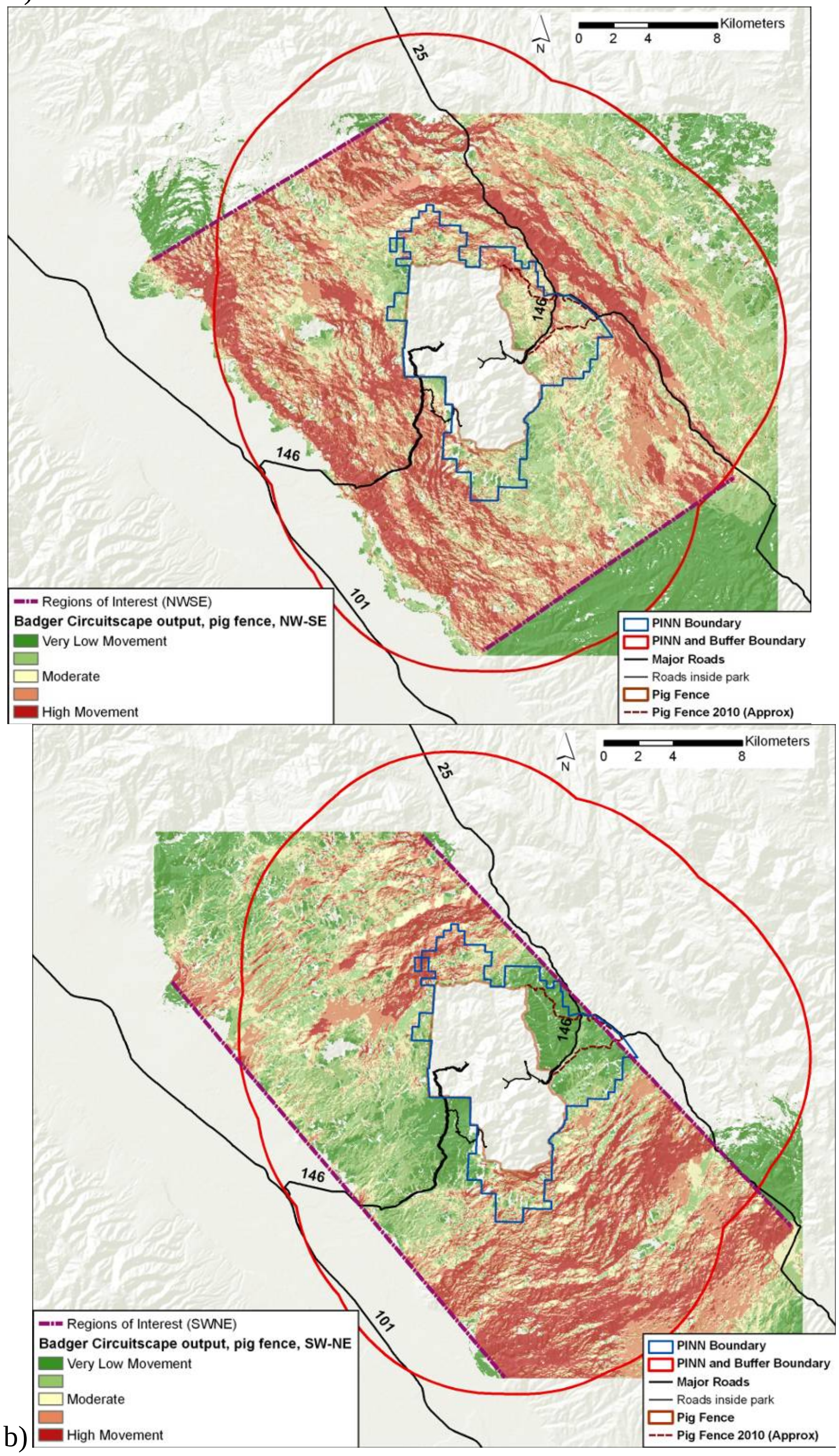


Figure 54. Current map predicting areas of highest and lowest badger movement along a southwest to northeast axis across Pinnacles National Monument between linear regions of interest. Darker areas are pinch points in the landscape where movements are predicted to be concentrated.

a)



b)

Figure 55. Current maps predicting areas of highest and lowest badger movement between linear source regions in (a) northwest-southeast and (b) southwest-northeast directions, assuming that the pig fence is impenetrable to badgers.

If roads are treated as grounds in the analysis, predicted movement patterns from northwest to southeast along the Gabilan Range are quite different than those in the absence of roads, especially along the northeast corner of the park, where movement patterns are disrupted by State Highway 25 (Figure 56). The road here divides high quality grassland habitat and parallels an area of predicted high movement. Similarly, flow patterns are strongly affected by Highway 146 southwest of the park. These results show the sensitivity of modeled movement pathways to whether road networks are included or not included in the analysis. They also suggest that, depending on traffic volume and road effects on badger behavior, roads could represent a significant influence on badger distribution in and around the northeastern and southwestern portions of the park.

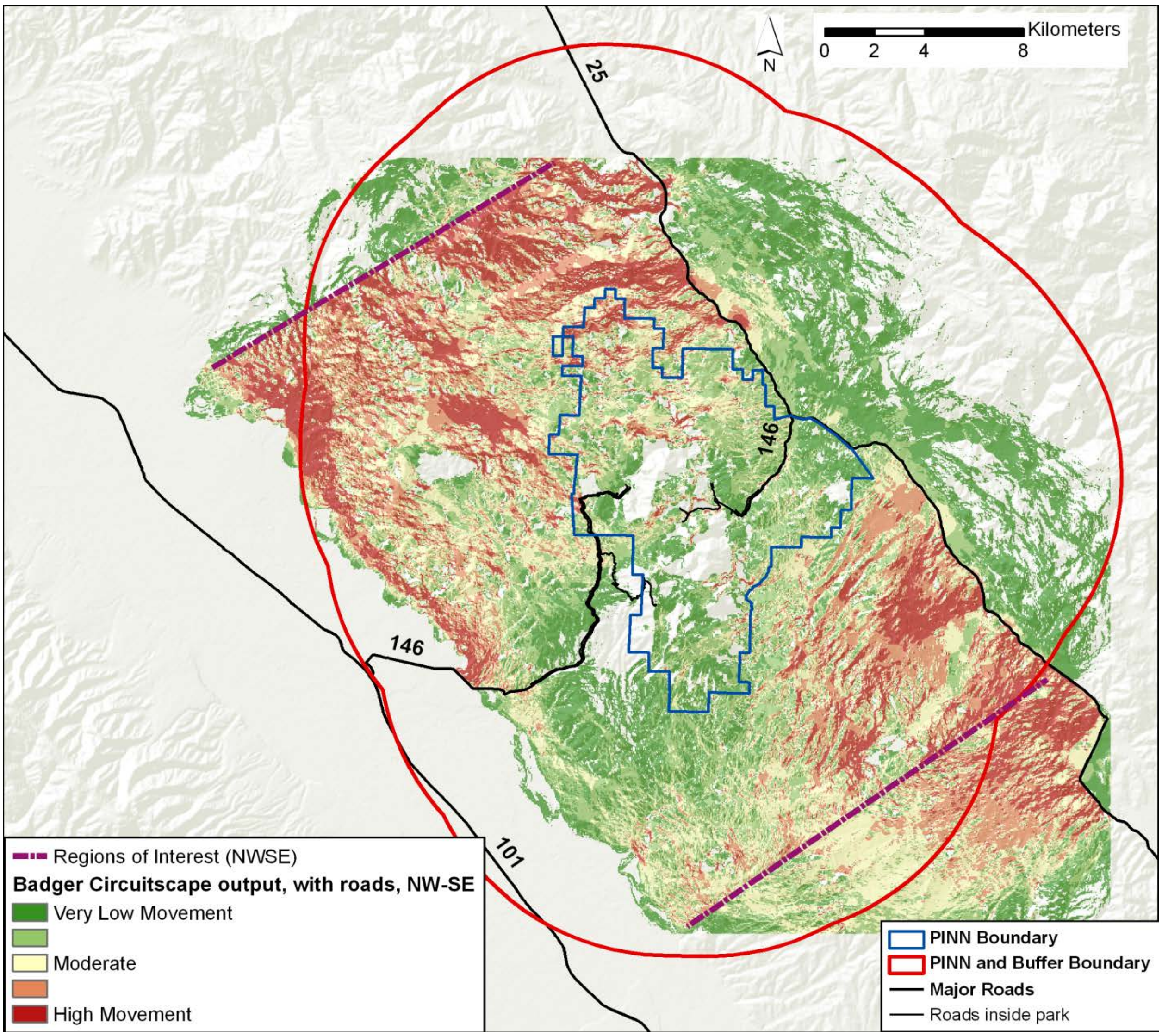


Figure 56. Current map predicting areas of highest and lowest badger movement along a northwest-to-southeast axis across Pinnacles National Monument between linear regions of interest. In this analysis local roads were treated as weak grounds and major roads treated as strong grounds.

Emerging Issues

The pig fence has been extended around newly acquired lands at the east entrance, which may alter movement patterns further.

Data Gaps

Data on multi-generational dispersal of badgers in this area is not available. Modeling relied on expert opinion about conductance of habitat types, roads, and the pig fence. The latter two features were modeled with and without considering them as barriers to movement.

Key References

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McRae, B.H., and Shah, V.B. 2009. Circuitscape User Guide. ONLINE. The University of California, Santa Barbara. Available at: http://www.circuitscape.org (accessed April 2011).

Messick, J.P. and M.G. Hornocker. 1981. Ecology of the badger in southwestern Idaho. Wildlife Monographs 76:3–53.

Landscapes—Viewscapes—Dark Night Sky
Findings: Baseline only

PINN has been popular with stargazers for its relatively undisturbed night skies with low "astronomical light pollution." Chronic skyglow from urban lights, as well as direct glare and intermittent lights such as car headlights, can also create "ecological light pollution" that is known to affect behavior, navigation, reproduction, communication, competition, and predation in some species (Longcore and Rich 2004). The monument lies to the south of the heavily populated Bay Area and east of moderate-sized cities of Salinas and Monterey. A model based on population in 1990 quantified the impact of city lights on skyglow in the monument. At that time, the skyglow was still relatively minor, relative to conditions before human settlement (Albers and Duriscoe 2001). However, the biggest source of light pollution at PINN is probably Soledad Prison, which was not accounted for in the model. The model has not been applied with more current census data to identify trends in skyglow, but the number of housing units within PINN's surrounding region increased 11% from 1990 to 2000. Therefore we would expect that the skyglow has increased as well.

Approach

Skyglow is the light reflected back from the night sky (Longcore and Rich 2004). Albers and Duriscoe (2001) modeled skyglow for the United States. The model predicted the skyglow contribution of each city as a function of its population size in the 1990 census and its distance from each location. Overall light pollution or skyglow at each location was calculated as the sum of the maps of skyglow produced by every city, and the sums were then categorized into classes on the Schaaf scale from 1 (most polluted) to 7 (no light pollution; Figure 57). Thus regional urban development is the ultimate driver of light emissions, which are propagated to PINN by atmospheric scattering. This scattering is modulated by air quality and weather conditions, which can also be modified by human activities. Local effects from lighting in campgrounds and similar sources are not incorporated in this assessment.

Data

Regional scale: Albers and Duriscoe (2001) summarized the proportions of major national park units in each of the seven Schaaf classes. We include this in the regional scale assessment because the source of the light pollution is from the external region rather than generated within the monument itself.

Park scale: Data were not available on permanent lighting within PINN or on intermittent light from vehicles.

Status

Regional scale: As can be seen in figure 57Figure 57, PINN was just beyond the main skyglow impact of the San Francisco and Monterey Bay areas in 1990. Virtually all of PINN was in class 6 at that time (Albers and Duriscoe 2001). The study also computed the proportions of other parks by Schaaf class. Some park units in California had less skyglow (e.g., Death Valley, Lassen Volcanic, Redwood, Yosemite, and Sequoia-Kings Canyon), some were very similar (e.g., Joshua Tree, and Channel Islands), but others had considerably more (e.g., Point Reyes, and Santa Monica Mountains).

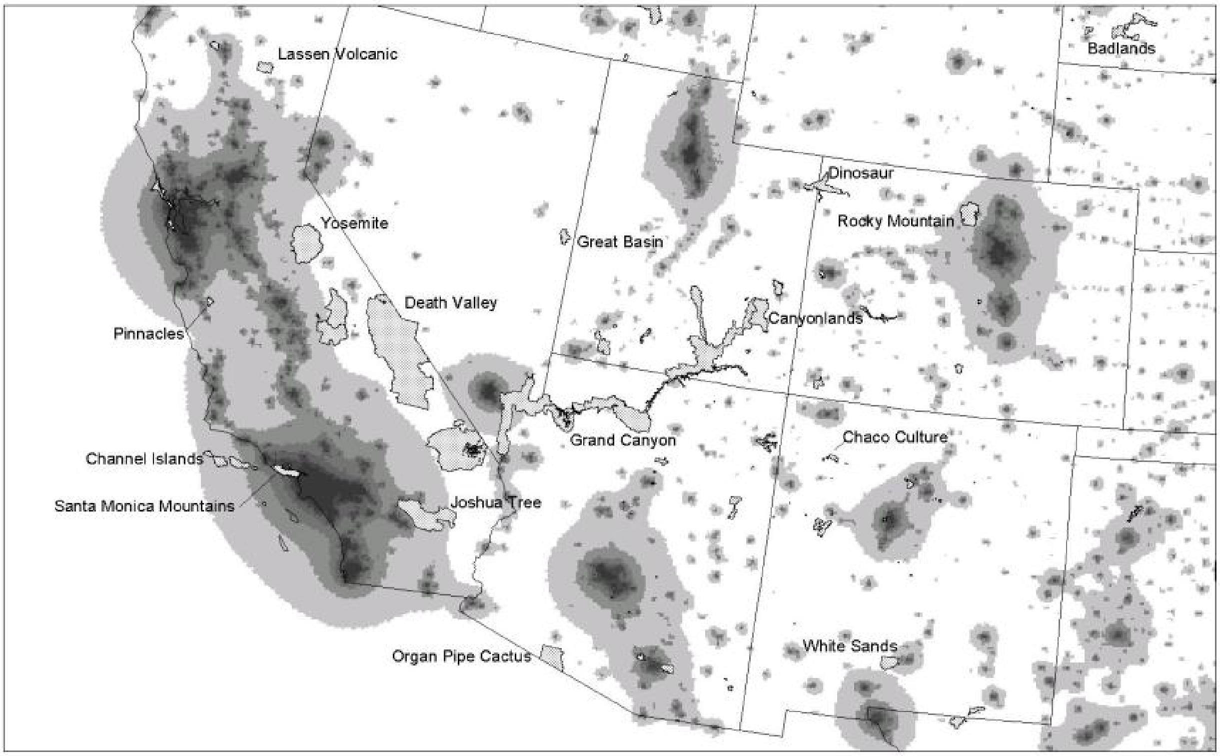

Figure 57. Map of Schaaf scale of light pollution in 1990 in relation to major national park units. Darkest shading is Schaaf class 1 (most impacted) and white is class 7 (no artificial light). *Source*: Albers and Duriscoe 2001.

Trends

Regional scale: Data are currently only available on skyglow for 1990. The model has not been run again with the 2000 census data or intra-decadal population projections or with future population projections. We know from the housing assessment in this report that the number of housing units in the PINN region has increased steadily by about 0.3% per year since 1940 to 2000, and population change will be at a similar rate. The effect on light pollution will depend on the relative distance of population growth from PINN.

Emerging Issues

Astronomical light pollution is currently not a major concern. As the Salinas Valley, Monterey Bay, and southern San Francisco Bay continue to develop, however, the amount of skyglow is likely to increase. Similarly, ecological light pollution may emerge as a more significant stressor as this emerging branch of ecology expands. Species experiencing the compound effects of multiple stressors may be most vulnerable as regional population grows. Lighting in the campground and at Bear Gulch Headquarters is suspected of increasing the effectiveness of predation on California red-legged frog. Other candidate taxa to be vigilant about include nocturnal moths (and the plants they pollinate) and owls.

Data Gaps

The primary data gap about light pollution as a stressor is the absence of model results for 2000 or a more recent population estimate so that the trend can be assessed. The model of skyglow used in Albers and Duriscoe (2001) assumed that population was concentrated at the center point of each city, and does not account for effects of low density sprawl, Soledad Prison, or lighting for nighttime harvesting of vineyards immediately east and west of the PINN boundary. Rural residential development has been increasing near PINN. Its lights may not be significant in terms of skyglow but can have significant effects on animal behavior. The world atlas of artificial nighttime sky brightness overcomes many of the limitations of this population-based model by combining observation data of nighttime top-of-the-atmosphere artificial radiance with scattering models that propagate the light through the atmosphere (Cinzano et al. 2001). This approach should give more accurate results than the population-based modeling. Unfortunately, the atlas website (http://www.lightpollution.it/worldatlas/pages/fig1.htm) has only published maps for the late 1990s, and they are only graphic files not suitable for analysis within parks.

The NPS Night Sky Team (http://www.nature.nps.gov/air/lightscapes/team.cfm) was formed in 1999 by PINN employee, Chad Moore. This team collects field measurements of light pollution and identifies sources (Moore 2001). Data have been collected for many national park units, but none are available online (http://www.nature.nps.gov/air/lightscapes/monitorData/index.cfm) yet for PINN.

For animals that avoid bright lights, light pollution can disrupt their movement patterns. Nocturnal predators such as owls can lose their night vision and be forced to hunt elsewhere. Very little is known about the ecological impacts of skyglow and direct lighting on the species and communities that inhabit PINN.

Key References

Albers, S. and D. Duriscoe. 2001. Modeling light pollution from population data and implications for National Park Service lands. George Wright Forum 18: 56–68.

Longcore, T. and C. Rich. 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2: 191–198.

Moore, C. A. 2001. Visual estimation of night sky brightness. The George Wright Forum, 18(4):46–55. Available at http://www.georgewright.org/184moore.pdf (accessed April 2011).

Summary of Resource Assessments

The status and trends of resource condition indicators is summarized below (Table 21). The summary also includes indicators and data collected for the vital signs monitoring program separately from the condition assessment. Vital signs measures are indicated with a “VS” in the Measures column followed by a number of the data source. The trend indicator icons reflect the trend of the indicator and not a positive or negative resource outcome.

Table 22. Summary of status and trends of resource condition and vital signs indicators.

INDICATORS	MEASURES	RECENT DATA	REFERENCE CONDITIONS	STATUS	TREND
0AIR AND CLIMATE					
Air quality	Ozone trend (VS, 1) Nitrogen deposition Sulphur deposition Visibility Clean Days and Dirty Days (VS, 1)	1.00 ppb/yr (0.00 p-value) Visibility Clean Days: -0.09 dv/yr (0.27 p-value) Visibility Dirty Days: -0.05 dv/yr (0.55 p-value)	75 ppb (EPA); <= 60 ppb is "good condition" (NPS) 0.25 kg/ha/yr is natural background; <1.0 kg/ha/yr is "good condition" (NPS standards); 5.5 kg/ha/yr is considered the critical load for lichen communities in California chaparral. 0.25 kg/ha/yr is natural background; <1.0 kg/ha/yr is "good condition" (NPS standards) 8 deciviews (5 year average deciview values minus estimated deciview values in the absence of human caused degradation)	Recent ozone concentrations are near the EPA non-attainment standard. Nitrogen and sulfur deposition rates are relatively low. However, chronic low level nitrogen loading could result in changes in lichen species over time.	
Climate	Minimum temperature of the coldest quarter Maximum	-0.26ºC (average in PINN, 1971–2000)	15ºC (mean annual temperature of past 50 years)	There were no directional trends in climate factors at PINN from 1948 to 2001. Minimum winter temperatures are projected to increase by 2.0– 2.7ºC	

INDICATORS	MEASURES	RECENT DATA	REFERENCE CONDITIONS	STATUS	TREND
	temperature of the warmest quarter Temperature seasonality (standard deviation of monthly temperatures) Growing degree days above 5ºC Mean annual precipitation	33.8ºC 27.4 3521 447.9 mm	432 mm (average of past 50 years)	while maximum summer temperatures are projected to increase by 3.7–4.0ºC. Seasonality is projected to increase by 7–16%. Precipitation projections are variable, either increasing or decreasing depending on the global climate model.	
WATER					
Water quality	pH Level (percent samples exceed standards) (VS, 5) Dissolved Oxygen in mg/L (percent samples exceed standards) (VS, 5) Water Temperature in Celsius (VS, 5) Total coliform MPN/100 mg/L (percent samples exceed standards) (VS, 5) Nutrients—Total Kjeldahl Nitrogen mg/L (VS, 5)	6.11–8.26 (53%) 2.3–13.86 (31%) 4.7–27.1 160–41,000 (8 %) 0.18–3.00	7.0–8.5 (CCRWQB) > 5.0 mg/L <log mean of 200 (minimum of not less than five samples for any 30- day period), nor shall more than ten percent of total samples during any 30- day period exceed 400/100 ml)	Water quality ranks among the most important indicators of ecosystem health. A large number of water quality indicators were sampled at eight sites in PINN in 2007 and 2008. In general, water quality indicators met regional standards, but there were occasional exceedances at some sites such as for E. coli bacteria. Emerging issues include aerial drift of agricultural pesticides, nitrogen deposition from expanding human activities, and the effects of climate change.	

INDICATORS	MEASURES	RECENT DATA	REFERENCE CONDITIONS	STATUS	TREND
	Nutrients—Nitrate (NO3) mg/L (VS, 5) Conductivity—Micro-Seimens (µS) per cm (VS, 5)	0.1–1.22 155–6,710			
Stream flow	Base flow turbidity measured as Nephelometric Turbidity Unit (NTU) (VS) Total annual discharge (cubic feet per second) (VS) Mean Daily Discharge (cfs) (VS) Peak flow event (cfs) (VS) Low flow event (cfs) (VS)	TBD TBD TBD TBD TBD			
BIOLOGICAL INTEGRITY					
Invasive plants	Number of List 1 and 2 priority invasive species detections (VS, 7) Number of subwater-sheds with invasive species (VS, 7)	List 1: 0 of 9 species List 2: 2 of 7 species List 1: 0 of 7 sub-water-sheds List 2: 4 of 7 sub-water-sheds	List 1: 0 of 9 species List 2: 0 of 7 species List 1: 0 of 7 sub-watersheds List 2: 0 of 7 sub-watersheds	About 140 of approximately 675 plant species are nonnative. Several of these species are invasive, with the potential for creating serious ecological damage. Areas of highest exposure to invasions in weed control zones coincide substantially with land cover types that are most sensitive to invasion that occur along roads and trails.	
Feral pigs	Mean relative abundance score (inside PINN, scale 0–100)	13.76	Pigs are not native to PINN, so the reference condition would be none.	Relative pig abundance is relatively low at the park-and-buffer scale. Habitat within the PINN boundary is moderately suitable for feral pigs, but they have	

INDICATORS	MEASURES	RECENT DATA	REFERENCE CONDITIONS	STATUS	TREND
	Mean relative abundance score (inside pig fence) Mean relative abundance score (park-and-buffer)	18.98 4.76		been exterminated inside the pig fence. Lands within PINN that are outside the pig fence are also suitable habitat and may therefore harbor dense populations of pigs.	
Prairie falcon	Number of occupied territories (in core area) (VS, 3) Number of fledglings per nest (in core area) (VS, 3)	7 2	Given the lack of trend and relative stability of the population, the mean occupancy rate and mean nest fecundity since 1989 is a reasonable reference condition.	Since 1989 there has been no statistically significant trend in the number of territorial pairs, nesting pairs, successful nests, or fecundity. Overall the prairie falcon population at PINN appears to be relatively stable.	
Raptors	Species Richness (of nesting raptors) (VS, 3)	9		Nesting raptors are documented during the prairie falcon monitoring season.	
Landbirds	Species Diversity (VS, 2) Species Richness (VS, 2) Index of Abundance (VS, 2)	10.83 12.34 7.42		Inventories of landbird density and species diversity have been conducted. Monitoring has not yet started but is being considered.	
Amphibians	California Red-Legged Frogs, Relative Abundance (VS) California Tiger Salamander, #of breeding sites (VS)	TBD TBD			
Reptiles	Coast Horned Lizard, Number of occupied sites	TBD			
Bats	Species Diversity (VS, 4,6)	14		Inventories have been conducted and may be repeated in the future.	

INDICATORS	MEASURES	RECENT DATA	REFERENCE CONDITIONS	STATUS	TREND
Lichens	Species Diversity (VS)	TBD			
Bird habitat	TBD (VS)	TBD			
Fish habitat	TBD (VS)	TBD			
Wetland communities	TBD (VS)	TBD			
LANDSCAPES					
Fire regime	Fire rotation period (inside PINN)	265 years	Chaparral vegetation is maintained by moderate fire return frequency of 20–80 years. Grassland and oak woodland community types may have experienced shorter return periods (10–25 years historically). Burning typically occurred between June and October.	The fire rotation period is 265 years. Fire regimes are similar inside PINN and the surrounding landscape. Fire-size distributions suggest a small decrease in fire sizes for the period 1980–2008 compared to 1950–1979.	
Future fire regime	Area burned in PINN in 2070–2099 as percent of 1961–1990 period—mean of 3 GCMs for A2 emissions scenarios —mean of 3 GCMs for B1 emissions scenarios	158% 136%	NA	Wildfire is sensitive to climate change and urban growth. Modeling predicts a marked increase in burned area by the end of this century in all scenarios at all three scales of analysis. Countering the potentially significant impact of increased fire on ecosystems may require substantial increases in fire management resources.	
Habitat connectivity	NA	NA	NA	PINN is contained in a Natural Landscape Block identified by the California Essential Habitat Connectivity Project, which is linked by an Essential Connectivity Area to another block at Pancho Rico Valley.	
Habitat connectivity—badgers	NA	NA	NA	Most of the highest suitability (grassland) habitat for badgers occurs outside PINN. Depending on traffic volume and effects on badger behavior, roads could represent a significant influence on badger distribution in	

INDICATORS	MEASURES	RECENT DATA	REFERENCE CONDITIONS	STATUS	TREND
				portions of PINN.	
Dark night sky	Mean Schaaf class	5.99	7 (no artificial light)	Skyglow as modeled from 1990 population data was relatively minor at PINN. Skyglow was less than Point Reyes and Santa Monica Mountains, but more than remote park units such as Death Valley and Yosemite. Local light sources such as campgrounds may have localized impacts on behavior of nocturnal predators and prey.	
Plant community change	Percent of plots with Priority 1 or 2 invasive species. Ratio of native:exotic species (VS) Species Richness (VS)	TBD TBD TBD			
Sudden Oak Death	Percent of plots with disease present Percent cover (VS)	TBD TBD			
Landscape	Amount of major land cover types within 30 km of monument	TBD			

 = baseline only  = no significant trend = increasing trend

Data sources for vital signs: 1) NPS 2007, 2) Humple and Gardali 2005, 3) Emmons 2008, 4) Heady 2005, 5) Skancke and Carson 2009, 6) Sue Smith (pers. communication to Paul Johnson), confirmed *Myotis volans*, 7) Williams and Jordan 2009 and updated with 2010 field season results.

Chapter 5. Discussion and Conclusions

Answers to Management and Research Questions

The staff at PINN and the SFAN I&M program identified a set of management and research questions (listed in Chapter 3). This NRCA has made progress in answering some of them and identified the limits of our current knowledge. Here we provide brief summaries of what was found.

1. *What is the significance of natural fires to the ecosystem in and around the park? What are the ecological effects of long-term fire suppression in PINN and in the region? How important is it to reintroduce this management tool and on what frequency?* These questions involve a number of cause-effect relationships that are beyond the typical scope of NRCA's. The fire regime of PINN and surrounding area has been strongly influenced by human cultures for thousands of years, so the concept of "natural fire" may no longer have much utility. Since the second quarter of the 20^{th} century, active fire suppression has lengthened mean fire-free periods in all vegetation types. The rate of burning since 1950 yields a fire rotation period of 265 years, with a slight decrease in fire size in the past three decades. Reduced frequency of fire in the region has been associated with a reduction in grassland accompanied by expansion of chaparral and coastal scrub. At the same time, exotic annual grasses have taken a solid foothold in this region of California and dominate areas cleared of chaparral (by mechanical means or by fire).

2. *What are the effects of non-native species invasions (plants and animals) along with disease?* The primary invasive species of concern at PINN are non-native plants and wild pigs. This NRCA focused on the potential vulnerability caused by both exposure to invasive species and sensitivity of the landscape to invasions. Quantitative data on the effects of invasives are not available. Qualitatively, invasive plants degrade habitat quality for many plants and animals, and they may increase the flammability of the landscape and hence fire frequency or severity. Wild pigs churn up soil as they root with their snouts in the ground for food, altering plant communities and facilitating the spread of non-native plants. Pigs eat acorns, which both restricts the number of oaks that can regenerate and reduces food for native wildlife. Rooting may alter nutrient cycles and dry the soil of water necessary for plant growth. They increase nutrient and bacterial levels in streams. On the Central Coast, Sudden Oak Death is rapidly and drastically altering plant communities through high mortality of susceptible species. These species tend to be relatively uncommon at PINN, however.

3. *What are the expected changes in visitation patterns based on census and economic data (e.g., will rock climbing become a bigger management issue for the park and breeding raptors)?* A growing regional population would be expected to increase demand for outdoor recreation at PINN. NRCAs primarily assess current conditions or recent trends if temporal data are available, rather than projecting future levels of drivers and stressors. We did not address possible population trajectories and associated levels of demand for rock climbing or other forms of recreation. Without data on the effects of nest disturbance by climbers and off-trail hikers on Prairie falcon fecundity it was not possible to test the effectiveness of PINN's raptor advisory system in the core areas.

4. *What have the changes in climatic factors been over the last 100 years (temperature, precipitation)?* Reliable climate data only start in 1948. Linear regressions of daily climate data conducted for this NRCA found no directional trends in minimum temperature of the coldest period, annual growing degree days above 5ºC, or annual precipitation at PINN from 1948 to 2001.

5. *What are the potential effects of changing climate in this region (e.g., rain, temperature, flooding, drought patterns), and how may this affect vegetation and wildlife communities (especially those important to the park)? What are the other implications for the park (e.g., to fire frequency)?* Climate models are relatively consistent in their projections of temperature factors by 2100 at PINN: 32–38% increase in growing degree days, 2.0 – 2.7ºC increase in minimum winter temperatures, 3.7–4.0ºC increase in maximum summer temperatures. Precipitation projections are more variable, either increasing or decreasing depending on the global climate model. Climate can affect species distributions and ecological processes directly through changes in temperature and precipitation and indirectly through changes in species interactions. The combination of large projected increases in temperature and relatively modest changes in precipitation can be expected to reduce the growth and recruitment of many plant species at PINN. For instance, California Buckeye and Valley Oak are limited to relatively cool and wet sites. Projected distributions based on climate models indicate that their probability of occurrence will decrease further, and that they will become increasingly isolated from populations outside the park. These changes could result in decreased cover and forage for the many bird and mammal species that rely on these trees. Our analysis of recent modeling of wildfire response to climate change found that burned area is expected to increase 21–68% within PINN by the end of the 21st century relative to the 1961–1990 reference period and depending on the emissions scenario, global climate model, and other parameters.

6. *What are potential impacts of regional agriculture and pesticide use to sensitive park resources (e.g., amphibian populations)?* Millions of kilograms of pesticides are applied annually to crops in the Salinas Valley, placing downwind aquatic ecosystems of PINN at risk of pesticide exposure. Upwind pesticide use is a significant factor in declines of some amphibian species in California including several occurring PINN. Pesticides can also cause declines in phytoplankton and zooplankton at low concentrations, disrupting aquatic ecosystems and increasing amphibian mortality. The proportion of pesticides being applied aerially, however, is quite low. This NRCA found no direct evidence at PINN of either pesticide loading in aquatic ecosystems at or of impacts on amphibians. Anticoagulant rodenticides are a class of pesticide used primarily to kill rodent pests such as ground squirrels, which are a major food source for Prairie falcons. These rodenticides can cause disease and mortality in raptors, meso-carnivores, and other non-target organisms

7. *What are the effects of air quality (e.g., pollutants) on the park's natural resources?* The NRCA found no direct evidence of damage to natural resources at PINN from air quality parameters. However, ozone and nitrogen deposition levels at PINN do raise concerns for several resources. Three ozone sensitive plants are susceptible to foliar damage, although damage has not been documented in the field as of 2001. Current nitrogen deposition

rates can adversely affect stream nitrate levels, with subsequent impacts on stream biota. Streams at PINN seem well-buffered and are not expected to suffer detrimental impacts. Although nitrogen deposition rates are relatively low, these rates are associated with changes in lichen community composition elsewhere in California. Nitrogen deposition could increase the invasibility of barrens, which are shallow soil, rocky areas with low productivity and high relative cover of native forbs. Visibility levels are degraded sufficiently to affect the visitor experience.

General Themes of the Assessment

Three fundamental themes permeate this condition assessment: 1) the pervasive ways that anthropogenic drivers affect the key resources at PINN, 2) the interconnectedness of resources, and 3) the inevitable trade-offs and conflicts in resource management. This final chapter synthesizes these themes from the individual resource assessments, highlights some key emerging issues and data gaps, and concludes with some recommendations for further study.

The human enterprise has continued to expand and intensify in the region surrounding PINN. Urban growth has crept further down the Santa Clara Valley from San Jose and throughout the Salinas Valley. Agriculture too has become more intensive, with greater application of pesticides. This expanding human population generates a litany of stressors. More people means more demand for outdoor recreation at PINN and associated infrastructure. Heavier use of PINN potentially causes more disturbance of wildlife, particularly nesting prairie falcons, and increases the risk of wildfire ignitions. Roads and infrastructure reinforce the impacts of development to fragment habitats, tending to isolate PINN from its broader landscape. As development increases and moves closer to PINN, its emissions of air pollutants, pesticides, and skyglow become greater stressors on the resource endpoints. Globally, the rapid increase in greenhouse gas emissions is projected to lead to profound changes in the local climate.

PINN's unique landscape was largely formed by the interacting forces of climate, wildfire, and geology. This condition assessment discovered that ecologically-relevant climate factors and fire regime have been relatively stable over the past five or six decades at PINN. Modeling predicts that growing degree days and temperature at PINN will become similar to current conditions in the southern San Joaquin Valley. Minimum winter temperatures in particular are forecasted to increase. Models are less consistent in forecasting precipitation changes. Most ecological resources in PINN would be affected by these changes in climate. The assessment found that the frequency of wildfire and the area burned annually will almost certainly increase, with consequent effects on invasive plants and wildlife habitats. Climate change is likely to have direct effects on other resources or processes such as plant-pollinator phenology, range shifts of plant and animal species, and added stress on amphibians with changing precipitation and less reliable runoff patterns. Two tree species characteristic of PINN, Valley oak and California buckeye, appear highly vulnerable to climate change. The variability of weather also has dramatic influences. For instance, prairie falcons produced no fledglings in 1998. This was a record rainfall year in which the ground squirrel population, a primary prey source for the falcons, also was decimated. In the context of the conceptual models used to frame this assessment, such interactions are illustrated by the inclusion of resource indicators along ecological pathways to other resources.

Resource management is largely an exercise in balancing competing social objectives. This condition assessment has discussed several of these in a stressor-endpoint framework, but now let us reconsider several examples as competing objectives. Society demands food and authorizes controlled application of pesticides to maximize yields and quality. Some of these pesticides are harmful to amphibians if they enter their aquatic habitats, such as by drifting from aerial spraying. The regional loading of pesticides is relatively high and steadily increasing. The extent to which they are polluting wetlands in PINN is not clear. Accommodating recreational use is a key mission of PINN. Yet the presence of rock climbers and off-trail hikers in core areas during prairie falcon nesting season is believed to disturb the birds and risk nest failure. An advisory system that requests visitors avoid occupied nesting areas was implemented in hopes of minimizing disturbance. Feral pigs are highly destructive to vegetation and wetlands, and so to protect these resources at PINN, a pig-proof fence was installed around a large proportion of the park unit, and pigs inside the fence were exterminated. Although this action is permitting recovery of damaged habitats, the fence itself has potential effects on other resources. As a linear disturbance, the fence may be facilitating cross-country access and dispersal of non-native invasive plants. As a final example, the land surrounding PINN has some potential for renewable energy development, particularly wind. Low-carbon power would have positive benefits by reducing greenhouse gas emissions. On the other hand wind farms could pose a risk to species managed within the park such as raptors, bats and the federally endangered California condor that would need to be carefully evaluated during an environmental review.

Key Emerging Issues and Data Gaps

Climate change will be the overarching issue for the future. As we have seen, climate factors influence almost all key resources at PINN. The direction, speed, and magnitude of change in the means, extremes, variability, and timing of these factors will shift into unprecedented conditions that are beyond our experience. Therefore, many of the consequences on species, vegetation communities, and ecological processes are predictable only with large uncertainties. These uncertainties span the gamut from future emissions trajectories to climate response to emissions to the ecological responses to novel climatic conditions to the complex interactions among resources. Monitoring resource endpoints for signals of climate change impacts will be vital to providing managers timely information.

Other emerging issues are related to chemical contaminants, potential loss of connectivity in the larger landscape, and skyglow from regional metropolitan areas. The biological resources of PINN are exposed to a variety of contaminants. Fuel combustion in the region leads to nitrogen deposition, with current deposition levels at PINN equivalent to levels known to cause negative effects on lichens elsewhere in California. Pesticides known to have negative effects on amphibians are being increasingly applied to farmland in the region encompassing PINN. It is unknown how much of these chemicals are migrating (particularly from aerial drift) into the habitats of amphibians in the monument. Anticoagulant rodenticides are also being applied near development in the region to control rodents such as ground squirrels. Predators and scavengers who consume dead rodents then accumulate this toxin, which combined with other stressors, can have lethal effects. Raptors such as prairie falcons that nest in PINN forage far enough from the monument to be exposed. As development expands in this region, this issue may become more pronounced. Because of the low intensity of use of the landscape surrounding PINN, habitat connectivity remains relatively high. Park managers should be proactive in engaging and finding common ground with neighboring land owners and agencies to ensure that such connectivity is not degraded from new activities. Metropolitan areas that have been growing also tend to emit more skyglow that brightens the nighttime sky. Increasing skyglow can contribute to the cumulative stresses on some organisms. Local light sources such as at campgrounds are suspected of increasing the effectiveness of predation on California red-legged frog, which is a federally threatened species. Amphibians collectively are an emerging issue because of global and regional declines in many populations.

The report identifies data gaps that, if filled, would improve the usefulness of the stressor or resource condition indicators assessed in this report. These data would either improve the accuracy of the indicator value or in many cases provide trend information where only baseline values are currently known. Key data gaps include:

- Pesticides—the volumes applied on agricultural lands are known but the amounts transported into PINN such as by aerial drift and the levels in aquatic habitats, and subsequently bioaccumulated into amphibians have not been inventoried or monitored. The role of the amphibian chytrid fungus and the degree to which its effects are amplified by pesticide-related stresses is unknown at PINN.

- Rodenticides— the volumes applied on agricultural lands are known, but the main use occurs around structures, which is not reported to the California Department of Pesticide Regulation. Moreover the levels accumulating in PINN predators foraging beyond the boundary is unknown.

- Air quality—the effects of low but chronic levels of nitrogen deposition on the diverse assemblage of lichens and plants are not well-understood.

- Non-native invasive plants—trend data are still too sparse and geographically limited to determine whether these plants are expanding or what is the level of success of control efforts.

- Feral pigs—pigs were exterminated within the 14,500 acre pig fence completed in 2003 and in progress for the pig fence expansion of 2011, but the abundance and density of pigs in high suitability habitat in the unfenced portions of PINN are not well known. The extent to which the pig fence may also be a barrier to native wildlife (e.g., American badger) and a facilitator for human access into the backcountry and its associated impacts (e.g., invasive plants) is unknown.

- Prairie falcons—without data on nest disturbance by rock climbers and off-trail hikers, it is not possible to test the success of the raptor advisory system on prairie falcon fecundity in core areas. Compilation of regional data sets on prairie falcon trends would also be valuable for evaluating potential larger-scale environmental controls on prairie falcon abundance as well as the possible influence of immigration on population dynamics in PINN.

- Fire regime—maintenance of a geospatial database on location and origin of all fire ignitions and spot fires in and around PINN are needed to monitor trends in regional fire regime.

- Habitat connectivity—statewide connectivity modeling needs to be supplemented with species-specific modeling that accounts for their individual habitat affinities. Knowledge of these affinities needs to be compiled through literature review and consultation with species experts.

Recommendations

The assessment leads to a number of recommendations for future analyses that were beyond the scope of this initial effort.

- Conceptual models developed for the assessment have highlighted the complex interactions of stressors on resource indicators plus the effects of changes in one indicator on another. Most of the analyses in the assessment are either simple GIS models of suitability or statistical models of time-series data that do not capture these synergies among stressors. The Human Footprint attempts to perform this synthesis by aggregating models of multiple stressors into an overall spatially-explicit representation of degree of human impact. The assessment also extracts data for PINN from a statewide model of the response of fire regime to climate (another resource indicator) and urban growth (a stressor). This level of synthesis is challenging both in the structure of the model and in quantifying the parameters of the interactions. Therefore the choice to extend modeling to this level must be made judiciously where the resources are high priority and the potential management actions are likely to be controversial.

- Habitat connectivity has been identified as important at multiple scales. A couple of studies have shown PINN to be a core area of a regional set of linkages or corridors. We recommend that park planners be engaged to find common ground with adjoining land owners and agencies to maintain healthy habitat connectivity that decreases the landscape resistance outside the monument.

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Appendix A. GIS data layers created for the assessment

Indicator theme	GIS layer topic	GIS layer name	Layer type
Stressor: Housing Development	Housing density 1940	pbg00	shapefile
Stressor: Housing Development	Housing density 2000	census2000	shapefile
Stressor: Road distance and accessibility	Distance to nearest road	Dist2rds	raster
Stressor: Road distance and accessibility	Travel time from park entrance	Ttime_min4	raster
Stressor: Pesticides	Pesticide use 2007	pss_pest	shapefile
Stressor: Rodenticides	Rodenticide use 2007	pss_rcide	shapefile
Biological Integrity—Invasive species—Non-native invasive plants	Exposure to populations of invasive plants	exposure	raster
Biological Integrity—Invasive species—Non-native invasive plants	Sensitivity to invasion by invasive plants	sensitivity	raster
Biological Integrity—Invasive species—Non-native invasive plants	Vulnerability to non-native invasive plant invasion	vulnerability	raster
Biological Integrity—Invasive species—Feral pigs	Relative abundance of feral pigs	Rel_pig_abun	raster
Landscapes—Fire and fuel dynamics—Fire regime	Years since last burn	tsf_regnodev	raster

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 114/122356, September 2013

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