SAN DIEGO COUNTY ECOSYSTEMS:

The Ecological Impacts of Climate Change on a Biodiversity Hotspot

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The Ecological Impacts of Climate Change on a Biodiversity Hotspot

This magazine serves as a summary of a report included in California's Fourth Climate Change Assessment.

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INTRODUCTION TO SAN DIEGO'S CLIMATE AND ECOSYSTEMS

by Amber D. Pairis, Udara Abeysekera, John M. Randall, Megan K. Jennings, Julie Kalansky, and Dan Cayan

The Mediterranean-type ecosystems of California, characterized by warm, dry summers and relatively cool, intermittantly wet winters, are some of the most ecologically diverse systems outside of the tropics (Cowling et al. 1996). The California Floristic Province (CFP), spanning from southwestern Oregon to northwestern Baja California, is largely coincident with this Mediterranean-type climate zone. The CFP is recognized as one of the world's biodiversity hotspots (Stein et al. 2000, Burge et al. 2016) with high species richness and diversity among both plants and animals. The focus of our study is the San Diego region's mountains, foothills, valleys, and coastal zone. The study area encompasses a complex overlay of topography from the Pacific coast to interior mountains. The area is characterized by highly variable precipitation, strong seasonality, and coastal low clouds and fog (CLCF)

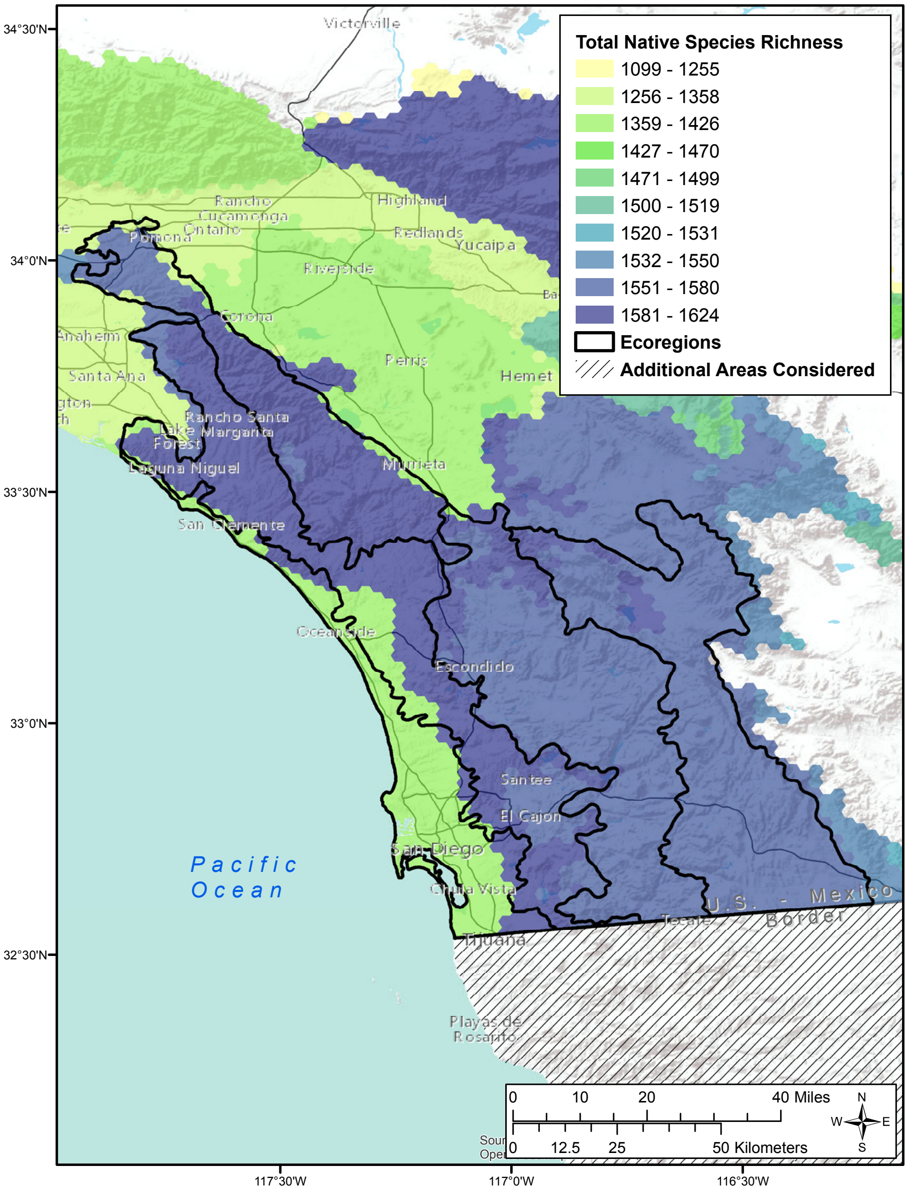


FIGURE 1: Map of overall species richness for all plant and vertebrate faunal taxa. Ecoregional subsection boundaries are displayed to identify how richness varies in San Diego's different ecosystems.

> "In the near term, ecosystems in the region will be most threatened by landscape changes, disturbances, and fragmentation due to development and fire.
>
> In the longer term, climate variability will compound those stressors with significantly warmer temperatures, more variable precipitation regimes resulting in occasional high intensity flooding and more frequent and prolonged droughts, and more destructive fires due to drought and increased ignitions/fuel availability."

(Dettinger et al. 2011, Clemesha et al. 2016), which strongly influence the resident biological palette.

Ecologically, the County boasts more taxa of plants and mammals than any other in the United States (Rebman and Simpson 2014, Tremor et al. 2017), and is home to thousands of species (Figure 1) including ~200 taxa of plants and animals that are state- or federally-listed as threatened or endangered (California Department of Fish and Wildlife 2017). This high level of diversity is, in part, the result of the complex physiographic and climatic structure within the short distance from the sea to mountain crest. The distances between ecotones, or transitional regions between ecosystems, are relatively short, and modest climate changes could displace entire ecosystem zones. In the near term, ecosystems in the region will be most threatened by landscape changes, disturbances, and fragmentation due to development and fire. In the longer term, climate models indicate that climate change will compound those stressors with significantly warmer temperatures, more variable precipitation resulting in occasional high intensity flooding and more frequent droughts, and more destructive fires due to drought and increased ignitions/fuel availability. Although the region's species and ecosystems have adapted to a precipitation regime with greater year-to-year variability than nearly anywhere else in the United States (Dettinger et al. 2011), they will be challenged as average temperatures rise and the precipitation regime is propelled to even greater variability.

San Diego County's diverse ecological landscape is also home to a human population estimated at 3.3 million in 2015 (U.S. Census Bureau 2017). Most of the human population lives in the western third of the County, the majority of which falls within the San Diego metropolitan area. Situated immediately to the south is the metropolitan area of Tijuana, Mexico, which is home to another 1.7 million people (Secretaría de Desarrollo Social 2015). According to the decennial U.S. census, San Diego County's population has increased rapidly for over a century, growing at rates of 30% - 90% in every decade of the 20th century and of over 10% thus far in each of the first two decades of the 21st century.

The rapid development and growth in human population in San Diego County has degraded large areas of habitat, shifted land use patterns, and expanded development into San Diego's backcountry (Figure 2), which has imperiled many of the region's distinctive and endemic species. As a result, San Diego's communities of conservation planners, natural resource managers, and developers were among the first in the nation to come together to collaborate on the planning and implementation of a regional habitat conservation plan. This resulted in a strategy to create networks of linked conserved areas through federal Habitat Conservation Plans (HCPs), and state Natural Community Conservation Plans (NCCPs). Since the mid-1990s, most new land conservation efforts in San Diego

Recently updated climate models project yearly average temperatures increasing by about:

RCP 4.5
INTERMEDIATE EMISSIONS
// Consistent with future intensive efforts to reduce emissions

4 - 6°F

or

7 - 9°F

RCP 8.5
HIGH EMISSIONS
// Consistent with no future policy changes to reduce emissions

by the end of the century

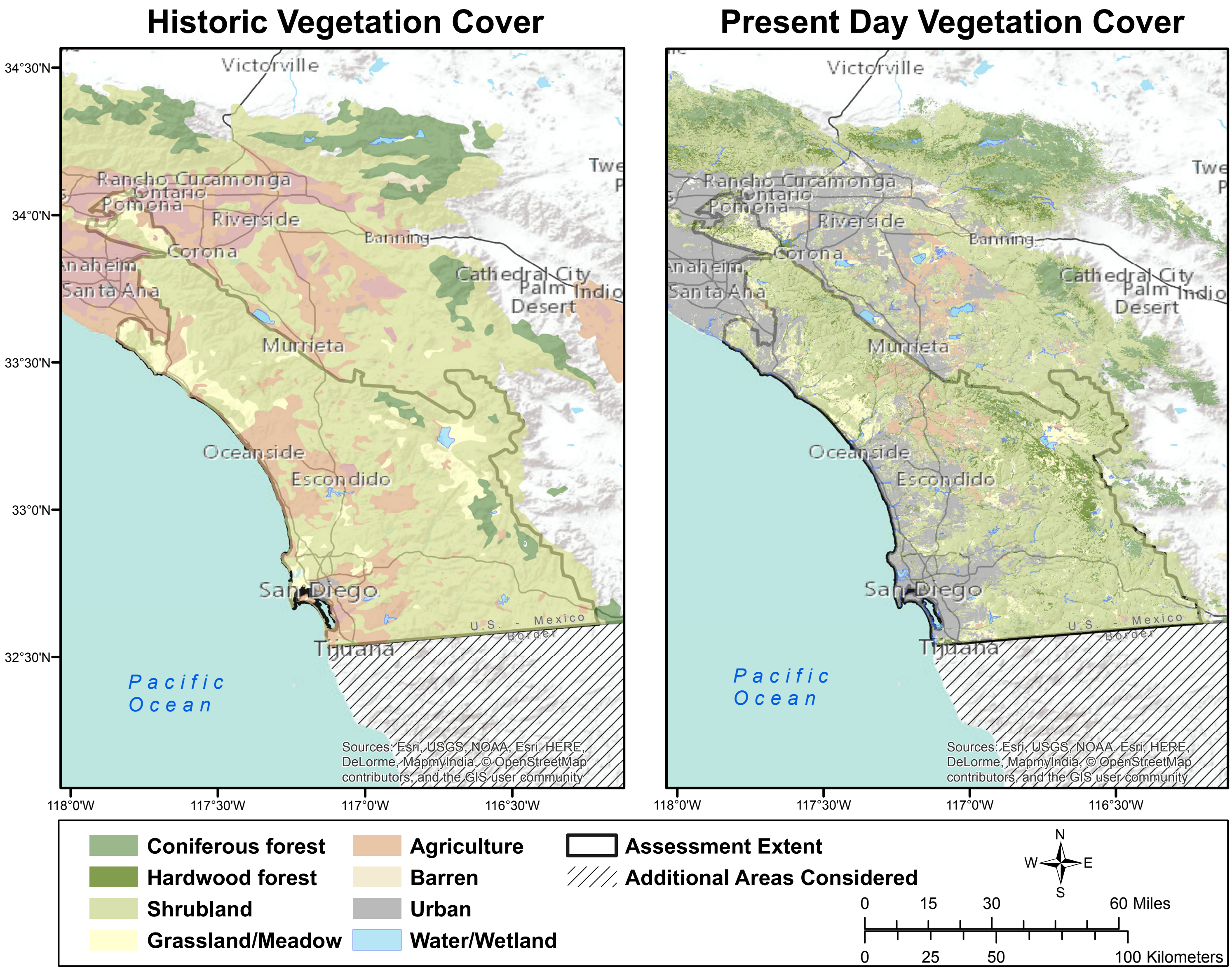


FIGURE 2: Change in distribution of urbanization, agricultural lands, and natural vegetation between the 1930s and present day.

County have been tied to these plans.

Given this history of conservation planning (Table 1), San Diego is uniquely poised to demonstrate how the intersection of monitoring, research, and combined efforts by scientists and planners can promote effective long-term conservation. Building resilience into San Diego's ecosystems is a challenge that will require collaborative efforts by policy-makers, planners, land managers, and the broader conservation community. Furthermore, it is becoming increasingly important for researchers to play a more prominent role in the dissemination of their research in ways that are actionable given the existing regulatory, economic, and social context in which land managers work (Enquist et al. 2017). In light of this, a group of ecologists and climatologists, under the umbrella of the Climate Science Alliance-South Coast, undertook this review of regionally-specific climate impacts. The overarching goal of this collaborative effort was to present an assessment of the San Diego region's ecosystems and natural resource futures, and to take stock of the implications of climate change in combination with other stressors.

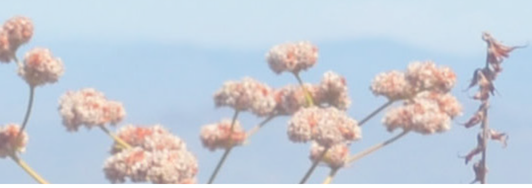
This review considers historical climate and environmental observations and plausible future climate in the San Diego region from: 1) Relative Concentration Pathway (RCP) 4.5, a moderately mitigated greenhouse gas (GHG) emission scenario, and 2) RCP 8.5, a business as usual scenario. The data presented in this report include those derived from an ensemble of 32 global climate models (GCMs) or those 10 models that have been selected by the California Fourth Climate Change Assessment (Cayan et al. 2018). The output from these models has been downscaled using the Localized Constructed Analogs (LOCA) statistical downscaling method (Pierce et al. 2014).

	Area (mi^2)	% Protected
Chaparral	1498.3	58.9%
Urban	783.0	2.4%
Coastal Scrub	546.8	16.4%
Grassland/Meadow	413.4	8.9%
Oak/Hardwood Forest	243.6	6.1%
Agriculture	156.1	0.7%
Riparian Forest	71.2	2.0%
Coniferous Forest	47.6	2.4%
Wetland	37.6	1.9%
Barren	20.7	0.4%

TABLE 1: Ten major vegetation/land cover types mapped in San Diego County.

The synthesis here is not fine-scale or focused on single-species issues and therefore, not meant to be prescriptive. However, we hope it can be used to help inform management targets and approaches to promote proactive management and planning for a range of climate scenarios. Each section describes future changes of important climate or climate-driven elements, and examines how and why these phenomena and other co-stressors might affect ecological factors. In gauging these effects, this assessment describes the region's unique diversity of ecosystems (Figure 3), habitats, plants, and animals, as well as their susceptibility to impacts from climate variability and relevant anthropogenic drivers that may be exacerbated by a changing climate (e.g., urban growth, land use shifts, and fire regimes).

FIGURE 3: Photos from top to bottom: Coniferous and shrub habitat, montane chaparral habitat, oak grassland habitat, and riparian habitat. Photo credit: Megan Jennings



SUMMARY TABLE:

ECOLOGICAL IMPACTS OF CHANGING CONDITIONS

ANTHROPOGENIC OR CLIMATE DRIVERS OF CHANGE	***Projected shift***	***Confidence in shift ****	***Associated ecological impacts***	***San Diego or southern CA example***
Mean annual temperature	General increase	Very high confidence	Species range shifts, novel assemblages	Narrowly endemic, gabbro-associated plants may experience unsuitable temperatures where suitable soil conditions exist
Heat waves	Increase in frequency and severity	Very high confidence	Increased mortality, decreased reproductive success	Potential for exceeding thresholds for some species like the California owl (Strix occidentalis occidentalis) with known temperature thresholds
Spring drying	General increase	High confidence	Potential to affect biomass	Decreased reproductive success for species that breed in aquatic systems, e.g., arroyo toad (Anaxyrus californicus)
Precipitation variability	General increase	High confidence	Impacts to ephemeral and riparian environments - less stabilizing vegetation and increased erosion can increase allochthonous input	Decrease the shredder functional group of macroinverts reducing downstream detritus food sources for zooplankton and fish
Droughts	General increase	High confidence	Potential structural shifts in ecosystems	Oak tree (Quercus agrifolia) stress and die off during the 2012-2016 drought
Pests and pathogens	Increase for some pests and vectors	Medium confidence	Increased lethal and sub lethal effects	Bark beetle caused mortality in coniferous forest and riparian tree dieback caused by shothole borer and fusarium fungal pathogen
Land use change + habitat fragmentation	General increase	Very high confidence	Habitat degradation and loss of landscape connectivity	Disconnected habitats for species like the mountain lion leading to lack of gene flow and population declines
Fire frequency	General increase	High confidence - depends on urbanization combined with fire	Type conversion to non-native grasses	Reduced habitat for shrubland species like the CA gnatcatcher that has lost nesting habitat to repeated fires
Santa Ana winds	Unknown	More research needed	Plays a role in fire cycle	Longer dryness extending into Santa Ana Wind season may increase fires under dangerous fire weather conditions
Coastal low level clouds and fog	Unknown	More research needed	Future decreases in CLCF may result in shrub cover decrease and exotic grass cover increase degrading coastal sage scrub	Future decreases in CLCF could increase shrub seedling mortality during summer

TABLE 2: Summary of biodiversity drivers and climate impacts on San Diego's ecosystems. Examples are included as well as an assessment of the state of our knowledge about these impacts and management practices available to address each impact.

* Based on IPCC definitions of confidence

Availability of data/ info to understand ecological responses	*Existing management options or strategies*	*Suggestions for future management, research or monitoring?*
Low: strategic weather monitoring in complex topography and high gradient climatic settings and inconsistent information among species - need trend data	Habitat management for persistence, protection of regfugia, adaptation through connectivity or facilitated migration	Conduct trend monitoring for species of interest
Low: logistical and ethical issues for experimental studies of ecological response of fauna	Maintain adequate habitat to support populations that can persist. Provide connectivity for species to move to refugia.	Determine if analysis of existing data can provide insight into impacts on plant and animal populations. Model climate refugia and focus conservation efforts on those areas.
Low: insufficient long-term data to understand how a prolonged droughts over affect ecosystem structure	Monitoring of at-risk species and recovery efforts for those that have or can be hardest hit by spring drying.	Continuous long-term monitoring at a diversity of habitats.
Medium: Monitoring data can be synthesized to examine impacts of large interannual precipitation variability by using monitoring data over the last 7-10 years	The SWAMP includes targeted monitoring of streams. Existing focus on cataloguing changes to covered species and habitats.	Redesign of current monitoring plants to include indicator sites and species. Improved stream gauge monitoring.
Medium: Information from recent drought show vulnerabilities of a diversity of species. Thresholds that might trigger landscape changes are unknown.	Existing monitoring beyond rainfall tracking, is unknown	Climate-quality precipitation, wind, humidity, solar radiation and soil moisture observations in strategic locations and higher density array of precipitation gauges along topographic gradients in selected ecosystems in conjunction with habitat monitoring.
Medium: Information for some pests and pathogens are somewhat well studied, but potential for novel pathogens is unknown	Surveillance of known pests and pathogens in the region and use of earth detection and rapid response efforts to address outbreaks	Expand surveillance programs to include pathogens with high probability of reaching San Diego or with potential for significant impacts to humans or ecosystems.
High: Information on the effects of fragmentation on many spcies are known and many more are being researched to determine the population-level effects	Identification and preservation of connectivity across landscapes, including aquatic systems.	Identification of spatially-explicit linkage zones for functional connectivity. Linkages should be prioritized for conservation with multi-agency stakeholders and focus on land acquisition and mitigating barriers.
High: Existing data supports our understanding. The major unknown is degree of future population growth and land use change.	Coordinating of fire management with land management on conserved lands.	Increased efforts to track type conversion or areas at risk. Fire suppression and prevention efforts should be focused on these areas.
See fire	See fire	Same as fire
Medium: Knowledge can be gleaned from work in other regions of California (e.g. northern CA and the Channel Islands) but research linking to impact of CLCF to biodiversity is sparse.	Recent remote sensing work has made spatial CLCF data available, thus making investigating the effets of CLCF on San Diego ecosystems much more accessible.	Monitoring to determine if coastal plain with CLCF can act as a climate refugium.

TEMPERATURE AND TEMPERATURE EXTREMES IN THE SAN DIEGO REGION

by Megan K. Jennings, Kristen Guirguis, Dawn M. Lawson, Eric D. Stein, and Sula E. Vanderplank

San Diego County spans starkly different climate zones where desert conditions are found a short distance east of a mild coastal climate. The coastal zone is characterized by relatively cool days and mild nights. During summer, average daily maximum temperatures in the interior valleys are about 15°F hotter than at the coast. In some parts of the interior valleys average summer maximum temperatures exceed 95°F (35°C) while average coastal maximum temperatures are below 80°F (26.6°C). At night, the dry conditions in the interior valleys promote nighttime cooling, whereas coastal cloud marine layer and low clouds intercepts terrestrial radiation which keeps coastal temperatures mild.

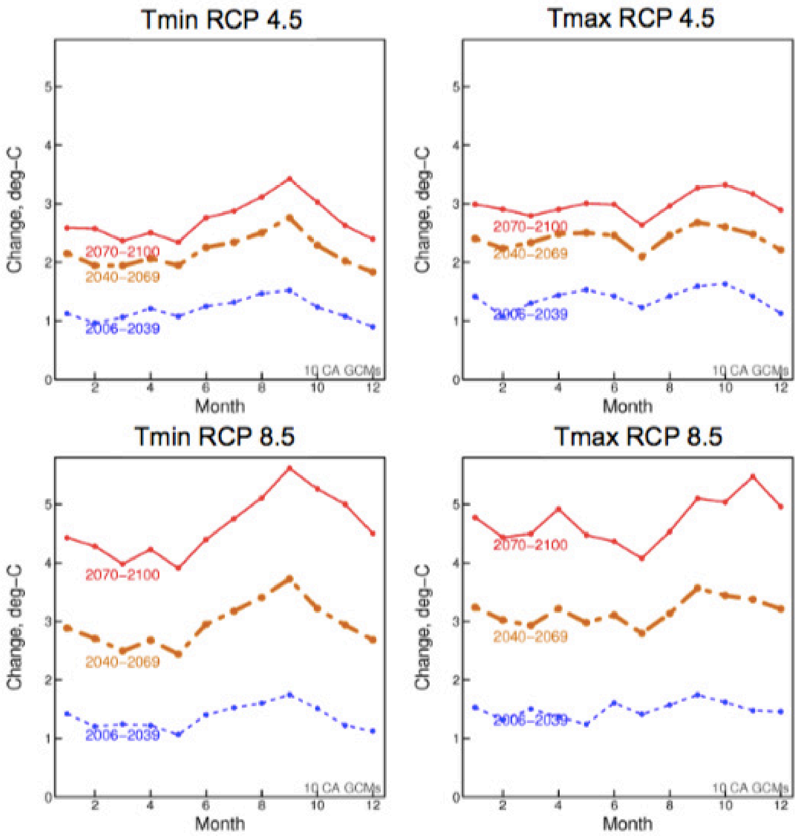


FIGURE 4: Projected shifts in temperature over the annual cycle displayed as minimum and maximum temperatures under RCP 4.5 and RCP 8.5 in three future periods: 2006- 2039 (blue dotted line), 2040-2069 (brown dashed line), 2070-2100 (red solid line).

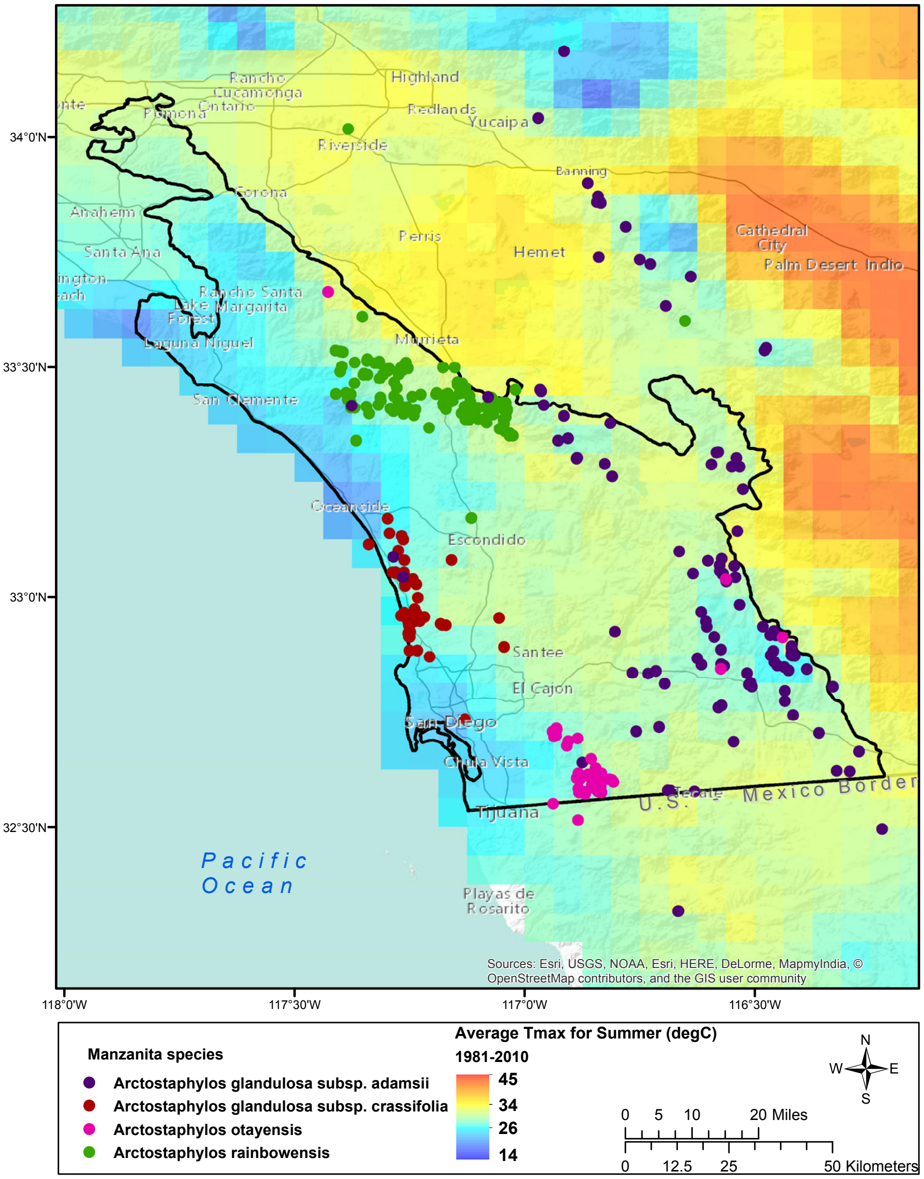
Recent climate models project that, by the end of the 21st century, annual average temperatures will increase by about 4-6°F under the RCP 4.5 scenario, or 7-9°F under RCP 8.5 (Figure 4; Cayan et al. 2013, Pierce et al. 2013, Pachauri et al. 2014). Although there is still uncertainty about how individual species might respond to a warmer climate, observations from other settings suggest that warming will shift species to ranges higher in elevation and northward in latitude and shift flowering times and other phenological stages earlier in the year (Hughes 2000, Cayan et al. 2001, Walther et al. 2002, Parmesan and Yohe 2003).

Temperature, particularly mean minimum temperature of the coldest month and mean maximum temperature of the warmest month, has been identified as a key factor in determining the distribution of shrubland community species (Figure 5; Franklin 1998, Riordan and Rundel 2009). Model projections for the coastal sage scrub vegetation types common in coastal San Diego County include large scale declines in species richness (Riordan and Rundel 2009). Increased air temperatures also result in higher water temperatures for streams and estuaries, affecting their biological communities, particularly in regions like San Diego where relatively shallow systems are more susceptible to heating. Many cold-water-dependent species may already be at the limit of their habitat ranges in the study area. Examples include the California newt (*Taricha torosa*), found only in stream segments with relatively persistent water.

Range shifts may lead to changes in biotic interactions that can have synergistic effects that are important to consider (Russell et al. 2012), particularly when individual plants or vegetation communities are altered. Shifts in environmental conditions can change the availability and suitability of habitat for animal species, especially habitat specialists that rely on particular plant species or assemblages. These species may lose habitat, be forced to follow the shifting ranges of the plants they need, or both.

Certain life history characteristics will make some

FIGURE 5: Extent of suitable habitat for four species of manzanita (*Arctostaphylos glandulosa ssp. glandulosa, A. g. ssp. adamsii, A. otayensis, and A. rainbowensis*) in the San Diego region with respect to the distribution of maximum temperatures during the warmest months



species more susceptible to the negative effects of climatic variability than others. For short-lived plants, reproductive rates may be most impacted, whereas for animals, decreased survival and reproductive rates are expected under extreme climatic variability (Morris et al. 2008). In the San Diego region, this could be particularly significant for rare and federally listed species that are short-lived such as the Laguna Mountains skipper (*Pyrgus ruralis lagunae*) and Hermes copper butterfly (*Lycanea hermes*), or annual plants that are narrow endemics such as the San Diego thornmint (*Acanthamintha ilicifolia*). The impacts to some annual plant species may be buffered by long-lived seed, such as the population of Orcutt's spineflower (*Chorizanthe orcuttiana*) which was rediscovered on Point Loma after 20 years (Lawson unpublished data).

Hot temperature extremes are also expected to increase (Gershunov and Guirguis 2012, Gershunov et al. 2013). Background climate warming will increase the frequency, duration, and intensity of heat waves, as measured against historical thresholds. Climate model projections indicate that the number of heat wave days will likely increase by more than three-fold by 2050 and considerably more than that, especially under high greenhouse gas emissions, by 2100. These extreme events (i.e., heat waves) may exceed physiological thresholds for temperature tolerance for some species. Although there is far less evidence about the direct or indirect impacts on plants and animals than humans, animal populations are expected to have similar responses to heat waves. Extreme temperatures can result in direct mortality, particularly to more sensitive segments of populations such as young and old age classes with the former having a greater effect on population trends as reproductive rates and survival to reproductive age may be limited or significantly reduced by these events.

For the big-eared woodrat (*Neotoma macrotis*), habitat modeling suggest both winter minimum and summer maximum temperatures may severely limit suitability in the future (Lawson unpublished data). The in-stream environment is another location where temperature thresholds for various species have been documented in Southern California. For the federally endangered arroyo toad (*Anaxyrus californicus*), estivation, or burrowing, is a common response among adults to avoid high temperatures and desiccation during hot, dry summers (Ramirez 2003). However, because the species breeds in relatively shallow, slow-moving streams, eggs or tadpoles may be more susceptible to early heat waves (Perry et al. 2012) that can quickly raise the temperature in shallow water beyond lethal levels or cause premature drying of the stream.

Shifts in temperatures and temperature extremes may also result in altered timing of ecological phenomena like flowering, emergence of insects, and onset of breeding for many species. Over the last several decades, the arrival of migratory songbirds to breeding habitats and onset of nesting has trended earlier elsewhere in California (Macmynowski et al. 2007, Socolar et al. 2017). For many aquatic species, the onset of breeding is typically

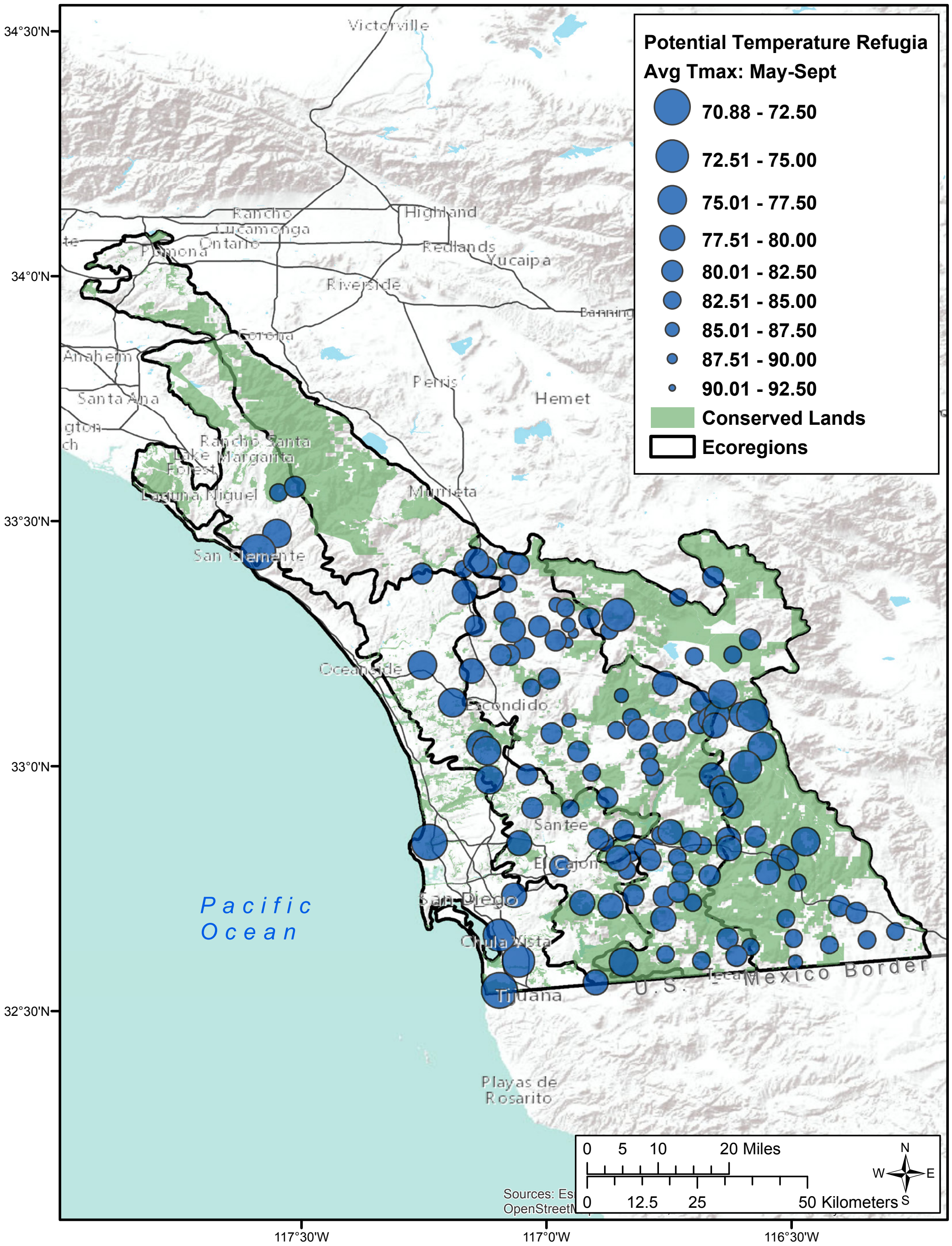


FIGURE 6: Map of potential temperature refugia based on historic records of more localized temperatures as recorded at weather stations across the region. Larger circles indicate areas more likely to act as a temperature refugium.

triggered by warming temperatures that reach a minimum threshold. Advances in spring warming and other timing changes can trigger earlier emergence of insect larvae and more prolonged and extensive algal blooms, both of which can influence overall productivity of instream communities (Poff et al. 2002, Hamilton et al. 2008).

Planning for refugia is an oft cited strategy for designing conservation and land management strategies that will be resilient to climate change. Coastal low clouds and fog may buffer warming along the coast, but in inland regions, we can examine past climate records for potential temperature refugia. In Figure 6, we identify potential refugia where microclimates may provide some relief from shifting temperatures. These locations are based on averaged minimum temperature in the coldest period as well as maximum temperature during the warmest period between 1990 and 2015. Identifying such local-scale temperature refugia may be beneficial for planning and management efforts.

PRECIPITATION AND DROUGHT IN SAN DIEGO COUNTY

by Julie Kalansky, Dan Cayan, Dawn M. Lawson, Eric D. Stein, and David W. Pierce

Plant and animal communities of San Diego County are adapted to thrive in highly variable climates. The Mediterranean-style climate is characterized by extreme intra and interannual variability in rainfall. Approximately 80% of rainfall occurs between November and April with the remaining months being hot and dry. In addition to this markedly seasonal structure, the year-to-year variability in Southern California is higher than anywhere else in the continental United States fluctuating between droughts, extremely wet years and periodic floods (Dettinger et al., 2011). The frequency and intensity of rare, extremely high precipitation events determine if a given year will be wet or dry. Large spatial variability adds to the complexity of the climate regime in the region. The mean annual precipitation ranges widely, between approximately 8-36 inches, with most differences resulting from topographic influences. Shrublands, the most common terrestrial community, use both drought avoidance (e.g., deciduous leaves and extensive root systems) and drought tolerance (e.g. stomatal control and post-fire germination) strategies to survive under these constantly changing conditions. Riparian communities rely on seasonal peak flows that can vary by over 50 fold during the course of a year, and several hundred percent between years, to support breeding and rearing habitat. Periodic scouring flows are important to prevent senescence, clean spawning gravels, and import fresh sediment, and promote habitat complexity.

By mid-21st century, climate model simulations indicate the number of dry days will increase, and the occasional periods of rain of higher intensity than current typical conditions. The driest 5 years (also driest 1, 3 and 7 years, not shown) in a 31-year moving window are projected to become drier, especially under the higher RCP 8.5 GHG scenario. The intensification of dry spells is driven by an increase in the number of individual dry years, shown in Figure 7 - Top. Exacerbating the increased dryness caused by changes in precipitation and temperatures are very likely to increase throughout the 21st century and would increase losses of moisture from the land surface (Cayan et al. 2010, Diffenbaugh et al. 2015, Ault et al. 2016).

Extreme drought has the potential to change ecological community composition and structure at the landscape scale in part because drought operates at a larger spatial scale than other disturbances such as fire. In addition to shifting habitat suitability to favor deeper rooted and more drought tolerant species, drier conditions may increase susceptibility of plant communities to pests or pathogens. Combined with increased fire frequency, this may result in shifts to early successional and generalist species at the expense of endemic communities. For example, recently observed oak mortality is thought to be a result of drought-induced weakening combined with secondary attack by wood borers and ambrosia beetles (California Forest Pest Council 2015, Lawson et al. 2017a,b). Conversely, many of the annual

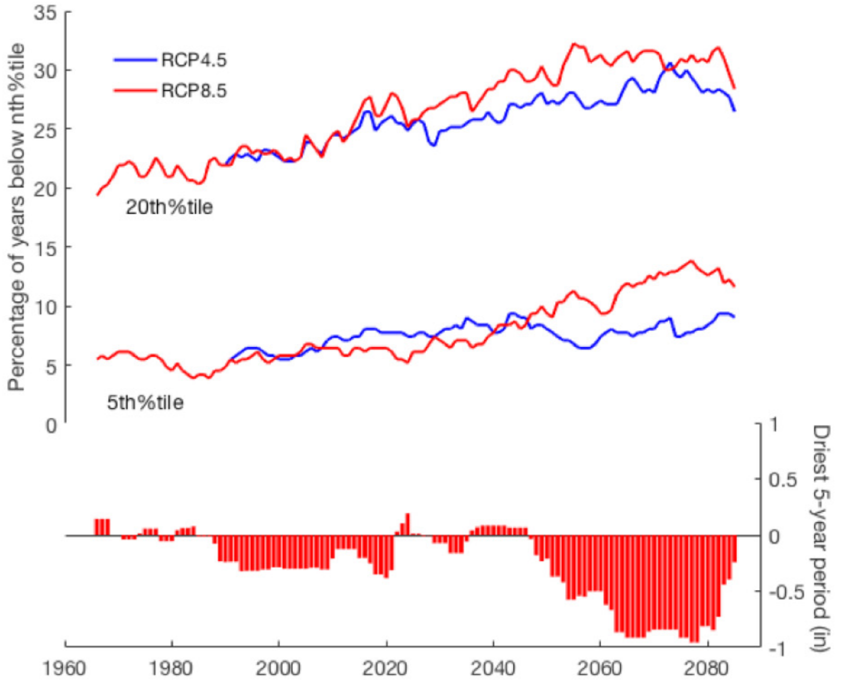
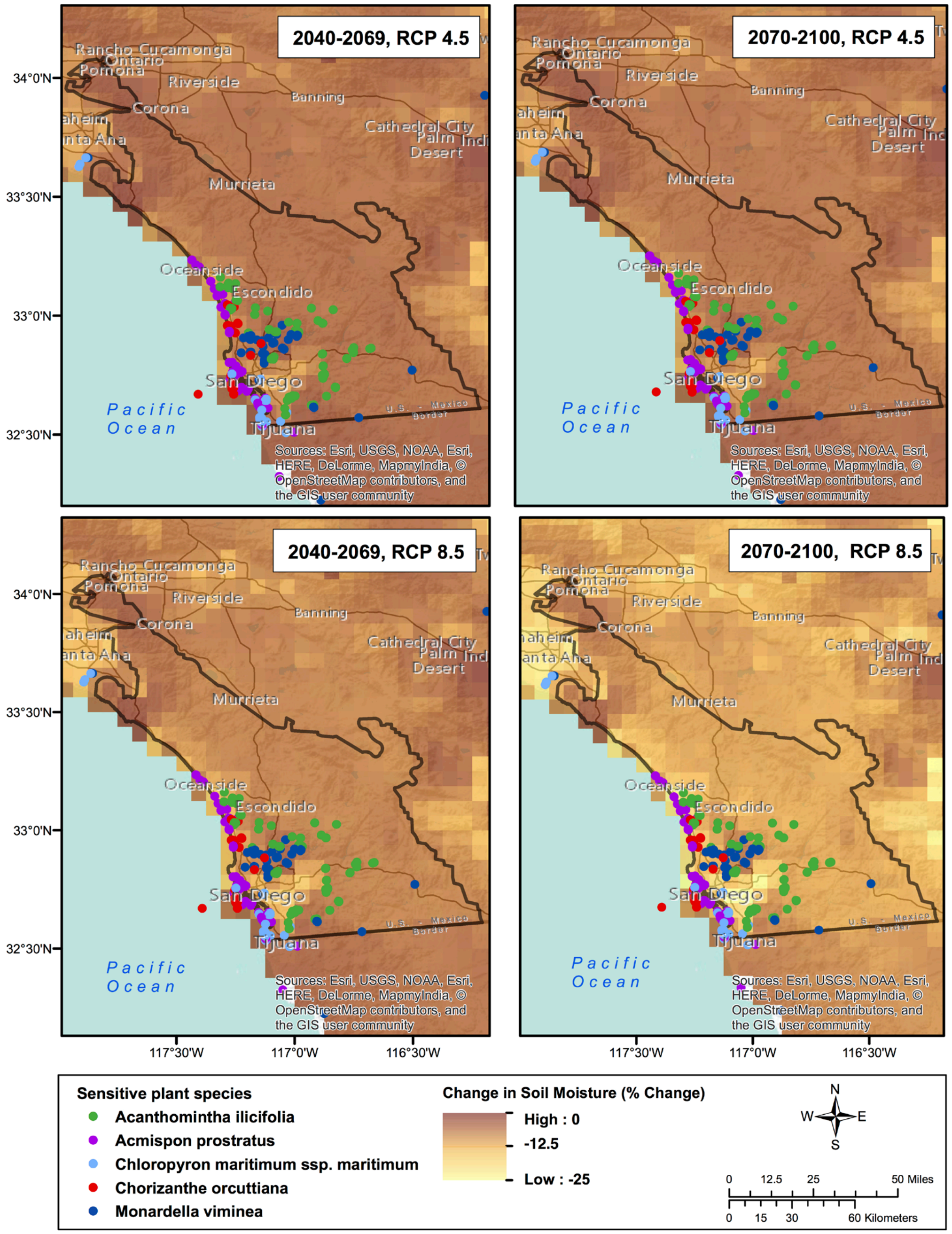


FIGURE 7: (Top) The percent of years in a 31-year sliding window that are below the 20th and 5th percentile thresholds averaged from a set of 10 RCP 4.5 (blue) and 10 RCP 8.5 (red) climate change simulations. (Bottom) Departure from average of the driest 5-years in a 31-year sliding window for RCP 8.5 (right). The anomaly is based on the average driest 5 years within the historical period.



Sources: Esri, USGS, NOAA, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

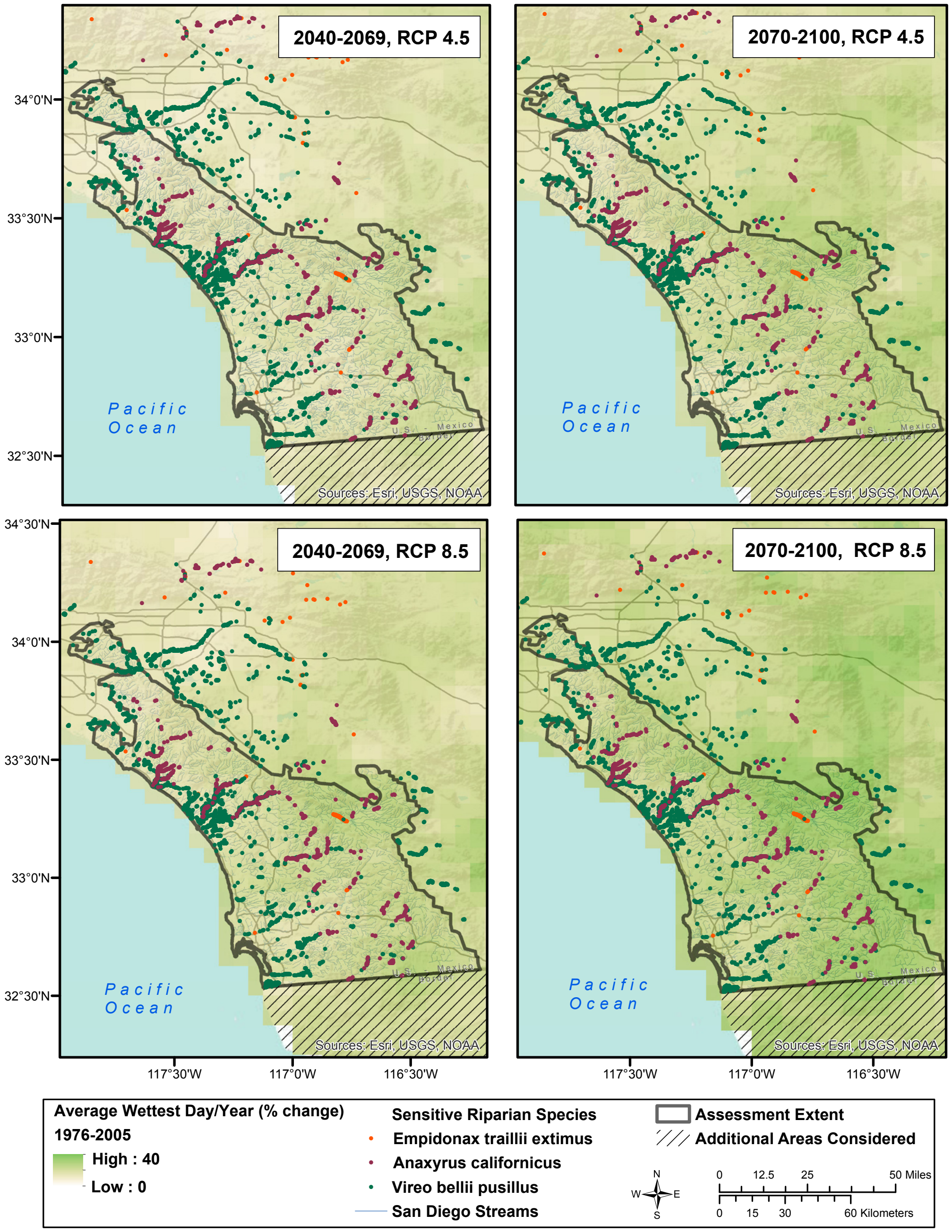
FIGURE 8: The percent change in spring (March-May) soil moisture relative to the historical global climate model runs from 1976-2005. The figures on the left are averaged during mid-century (2040-2069) and the figures on the right are averaged at the end of the century (2070-2100). Top figures are under the RCP 4.5 scenario and bottom are the RCP 8.5 scenario. Overlaid are species occurrence data of select rare, threatened, or endangered plants (*Acanthomintha ilicifolia* [San Diego thorn mint], *Acmispon prostratus* [Nuttall's acmispon], *Chloropyron maritimum* [Salt march bird's beak], *Chorizanthe orcuttiana* [San Diego spine flower], *Monardella viminea* [Willowy monardella]).

plants common to San Diego County, such as some annual grasses and vernal pool species, may be more resilient to changes in precipitation patterns because of their natural adaptation to prolonged drought and variable climatic conditions.

Effects on terrestrial animals would be mediated through changes in habitat. A study of four bird species during 2002 and 2003 indicate a strong response to drought. The wrentit (*Chamaea fasciata*), spotted towhee (*Pipilo maculatus*), California towhee (*P. crissalis*), and rufous-crowned sparrow (*Aimophila ruficeps*), are dependent on coastal sage scrub for habitat. A 2002 drought resulted in a significant decline in reproductive success with only a 1.8% success rate, attributed mainly to low arthropod food availability (Bolger et al., 2005). Although the research was specific to these species, other animals that are dependent on arthropod populations, such as many reptiles and amphibians, may also be negatively impacted by the increases in drought.

Another aspect of projected intensification of droughts is that global climate models (GCMs) indicate seasonal summer drought in Southern California may become more prolonged due to earlier drying in spring, warmer summers and increased dryness in fall. From the GCMs, spring precipitation decreases considerably, by approximately 20% during the mid-century and approximately 25% by the end of the century under RCP 8.5. Fall precipitation decreases by approximately 15% during mid-century and approximately 20% by the end of the century. Under RCP 8.5 the spring precipitation decline, combined with effects of warming, result in progressive declines in spring soil moisture, amounting to 10-15% decreases by late 21st century (Figure 8). The impacts of the change in hydroperiod will have immense effects on intermittent and ephemeral streams in terms of reduced richness and disruption of breeding and dispersal patterns of invertebrates, fish, and amphibians whose life histories are tuned to cues associated with seasonal flow and inundation patterns. Survival, growth, reproduction, and dispersal of aquatic species, such as stream invertebrates, fish, and amphibians would likely be affected by changes in flow patterns, earlier stream drying, and less frequent, but more extreme scouring high flow events. Secondary effects may occur due to proliferation of macroalgae (due to warmer, slower moving water) which can displace habitat and reduce oxygen due to eutrophication.

FIGURE 9: Change in the average wettest day per year at the end of the century, 2070-2100. The top figures are shown as increase, and the bottom figures are shown as percent. The middle panel is under RCP 4.5 and right is under RCP 8.5. Overlay with select sensitive riparian species (*Empidonax traillili extimus* [SW willow flycatcher], *Anaxyrus califoricus* [arroyo toad], and *Vireo bellii pusillus* [least Bell's vireo]).



The drying that is projected with increased drought intensity and longer seasonal dry periods is offset with a projected increase in the wettest days, representing an increase in precipitation variability. At the end of the 21st century the wettest day of the year is projected to increase by 15-25% percent under RCP 4.5 and 20-30% under RCP 8.5 (Figure 9). Less frequent and occasionally stronger storms might result in more precipitation flushed out to the Pacific and less retained by the soil and biosphere. The future bioavailability of water as a result of this precipitation regime change is a knowledge gap. More research and improved modeling is needed to understand how changes in precipitation regimes will affect the bio-availability of water. Improved observations of soil moisture and stream gauges are needed to track changes and to evaluate and verify hydrological models.

The impacts of specific extreme events are most likely to affect intermittent, ephemeral and headwater streams, such as those common to the San Diego region (Dhungel et al. 2016). Habitat shifts may result in less stabilizing streamside vegetation and increased erosion changing the nature of allochthonous input potentially affecting net primary productivity (Archer and Predick 2008, Heino et al. 2009).

Future changes in the amount of annual precipitation are uncertain, however climate models generally agree the precipitation variability will increase in the future leading to more droughts and more extreme storms. The effects of a changing precipitation regime are highly uncertain because the difficulty in predicting future rainfall is compounded by uncertainty in how far the inherent resiliency of plants and animals adapted for dry, variable climates can accommodate changing conditions. A benefit of the naturally highly variable climate in the region is that it provides a laboratory to better understand how ecosystems will respond to the more variable climate projected in the future. Therefore, once long-term and continuous monitoring begins, it could provide a wealth of knowledge to understand how an even more variable climate would impact ecosystems in the region. Increased monitoring of sentinel sites and indicator species under programs such as the existing Multiple Species Conservation Plan and the Surface Water Ambient Monitoring Program will be critical for gaining the knowledge necessary to inform future management decisions.

SAN DIEGO WILDFIRES: DRIVERS OF CHANGE AND FUTURE OUTLOOK

by Alexandra D. Syphard, Alexander Gershunov, Dawn M. Lawson, Hiram Rivera-Huerta, Janin Guzman-Morales, and Megan K. Jennings

Wildfire is one of the most important yet complex drivers of ecological function and biodiversity in San Diego County. As in other Mediterranean-type ecosystems, fire is a natural ecosystem process that shapes the structure and distribution of the region's diverse plant communities, and in turn, the habitat for the region's animal species. Nevertheless, its occurrence, distribution, and ecological and social impact have evolved substantially over time in response to both climatic and anthropogenic factors.

Until recently, large, high-intensity fires occurred regularly but infrequently, largely due to the low frequency of natural ignition sources (Keeley 1982, Keeley and Syphard in press). In the 20th century, human population growth skyrocketed, and with it came massive expansion in urban development. As a result, human-caused ignitions have increased dramatically, both in number and in spatial extent, such that much of the landscape is burning at return intervals that are uncharacteristically short relative to pre-Euro-American settlement conditions (Figure 10; Safford and Van de Water 2014). Although the frequency and spatial pattern of fires have changed in response to population growth and urban expansion, the overall seasonality and severity, as well as the mean area burned, have remained relatively consistent (Keeley and Syphard 2016).

Repeated wildfires, at intervals too short to allow recovery of native vegetation, facilitate the conversion of native shrublands to weedy annual grasses (Figure 11), forming a positive feedback cycle that could irreversibly eliminate some of the region's rich biodiversity; evidence suggests

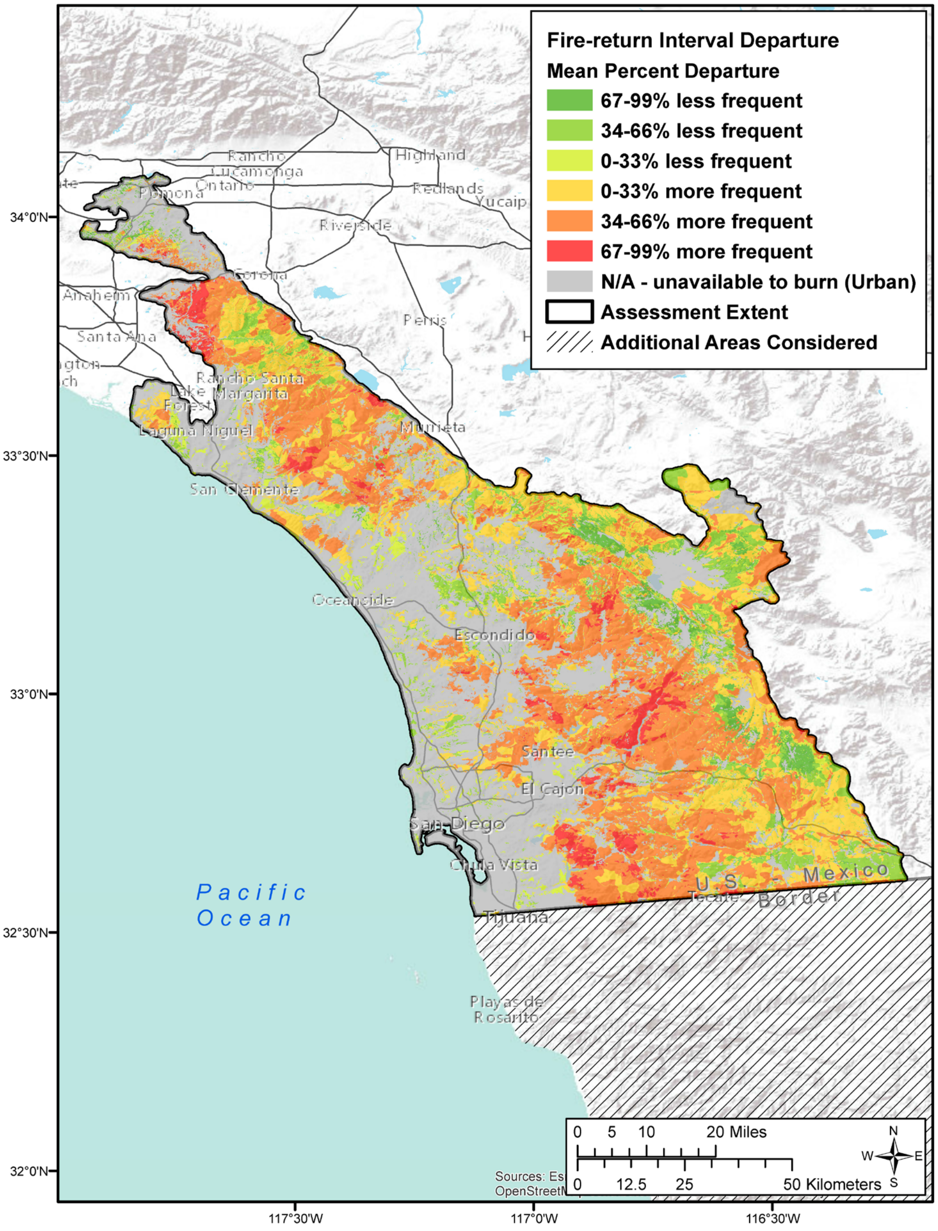


FIGURE 10: Map of study area with mean percent fire-return interval departure (Safford and Van de Water 2014). Values range from 67-99% less frequent fire than historic return intervals for a given vegetation type in dark green to 67-99% more frequent than historic intervals in red where repeated fires have burned in short succession.

FIGURE 11: Examples of shrubland systems that are intact (left), degraded (center), and completely converted to non-native annual grassland vegetation type (right).

that widespread vegetation change has been occurring in recent decades (Syphard et al. in press). Characteristic bird, mammal, and insect communities mostly align with shrub cover, and thus the loss of shrub cover also represents a loss of those associated species (Diffendorfer et al. 2007). Wildfire also threatens human lives and property due to the growing interface between residential communities and wildland vegetation; thousands of structures have been destroyed in recent decades (Keeley et al. 2009, Syphard et al. 2012).

Given the unique combination of factors that shape the modern-day fire regime in the region, the potential effect of climate change on fire is nuanced, and different than in other parts of the state. Despite strong relationships between seasonal fluctuations in temperature and precipitation with area burned in higher-elevation forested areas, in lower-elevation coastal and foothill-dominated regions, there has been little or no increase in fire activity associated with hotter and drier conditions, likely because seasonal conditions are already prime for extreme fire behavior every year (Keeley and Syphard 2015, 2016, 2017, Syphard et al. 2017). One climatic variable that has become important in recent years is high prior-year precipitation, likely due to its role in promoting higher abundance of annual grasses that, once dry, become extremely ignition-prone in the subsequent year (Littell et al. 2009, Pilliod et al. 2017, Syphard et al. 2017).

The climatic causes of Southern California's unique wildfire regime are the Mediterranean climate with its warm dry summers and the dry, hot and gusty Santa Ana winds, whose season starts in the fall, typically before the first rainstorms of winter. Given that fire activity is predominantly a weather-driven phenomenon, fuel age is not a limiting factor in area burned, as evidenced by the sometimes extraordinarily short intervals that occur between fires (Moritz 2003, Keeley et al. 2004, Moritz et al. 2004, Keeley and Zedler 2009, Price et al. 2012). As such, mechanical fuel treatments and prescription burning in non-forested parts of the landscape play a limited role in reducing area burned, and come at a substantial ecological cost (Syphard et al. 2011, 2012, Penman et al. 2014).

As our climate continues to warm, rainstorms will become less frequent in Southern California, particularly so in the fall and spring, while rare extreme rainfall events will produce more precipitation. Moreover, with less frequent but more extreme rainfall, year-to-year precipitation becomes more volatile. The recent years of historic drought (2012-2016) followed by extremely wet winter 2017 and a bone-dry (record-dry, in fact) fall and early winter, is an example of such volatility, which we expect to see more of in the future. In addition, more frequent, longer, or more intense multi-year droughts could also increase the number of large fires in the region by increasing the proportion of dead fuels in a stand (Figure 12; Keeley and Zedler 2009).

Starting in October, but peaking in December and January, Santa Ana winds fan Southern California's most catastrophic wildfires. Santa Ana winds will likely become warmer with climate change, increasing their desiccating potential (Hughes et al. 2011). Also, due to the changing precipitation regime, vegetation will more often remain dry into the traditional wet season when Santa Ana winds peak, lengthening the fire season of Southern California from fall into winter and even spring. The most recent hot and fiery December (2017) {and extreme precipitation from the first significant storm in winter (January 2018) causing mudslides on fire-scarred slopes,} is a perfect example of conditions we expect to occur more frequently in the future.

In San Diego County, fire activity is significantly limited by ignitions. That is, despite the fact that Santa Ana winds and extreme fire-weather create ideal fire conditions every year, a resulting large fire will only occur if an ignition coincides in space and time with a wind-driven weather event. More than 95% of the ignitions are caused by humans (Syphard et al. 2007); and because highly flammable shrublands and grasslands are closely juxtaposed with human habitations, fire regimes are and will continue to be most strongly controlled by anthropogenic impacts. Studies show that ignition patterns are non-random in San Diego County; thus, prevention strategies could be customized to target the locations, causes, and timing of the most catastrophic events (Syphard and Keeley 2015).

Housing development patterns and proximity to human infrastructure like roads are also significant correlates of fire frequency and area burned, with the highest levels

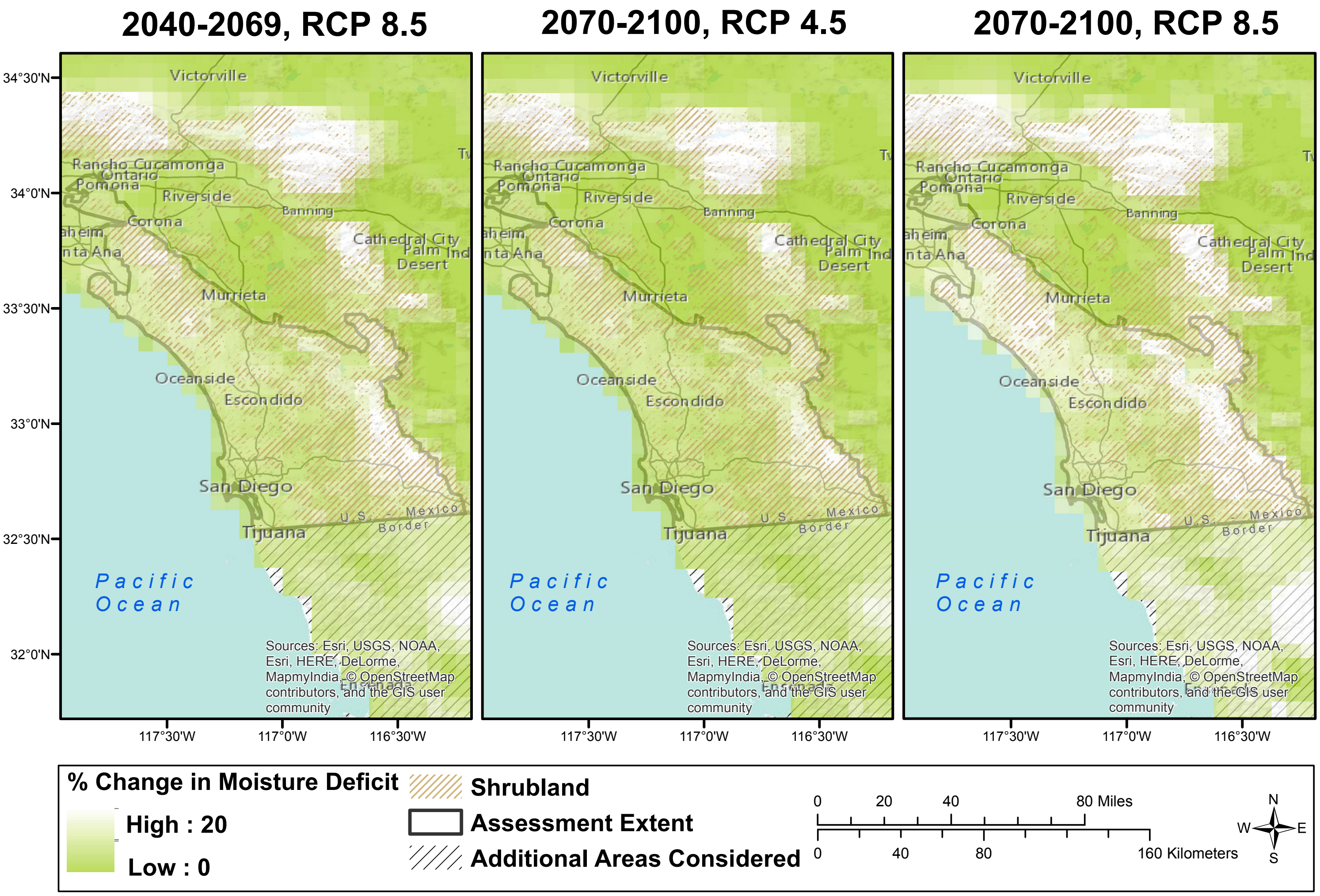


FIGURE 12: Map of climatic water deficit (CWD) in the San Diego region and shrubland vegetation types, where a lack of available moisture during extended droughts is most likely to result in vegetation dieback that will greatly increase fire risk.

of fire activity occurring at low-to-intermediate levels of development which is also where most houses are destroyed by wildfire (Keeley 2005, Syphard et al. 2007, 2009, 2012, Archibald et al. 2010, Mann et al. 2016). The reason for this nonlinear relationship between fire activity and housing density is that, especially in places where most fires are human-caused, there are few people in remote landscapes to start fires, and there is little available fuel to burn in intensely developed areas. At low- to intermediate-housing density, houses are generally more exposed to wildfire, and dispersed housing is more challenging for firefighters to defend (Gude et al. 2013). Research has shown that land use decision-making, either via zoning for housing growth, or through the prioritization of where to purchase private land for conservation, could significantly reduce not only fire risk to humans, but also result in better ecological outcomes (Syphard et al. 2013, 2016, Butsic et al. 2017).

The northern portion of the state of Baja California contains similar species and ecosystems as those in San Diego County and thus can be used to contrast the impact of land use on fire regimes (Ojeda-Revah and Espejel-Carbajal 2008). Significant vegetation changes have occurred over the last 150 years, in part due to population increases in urban areas, the migration of people to the border zone, and industrial and tourist activities that consume large quantities of water and energy. The state of Baja California has one of the highest incidences of forest fires in Mexico (Sepúlveda-Betancourt et al. 1999). While the causes of these fires are diverse, human activity has been the primary ignition source in recent years, with most incidences of forest fires documented close to urban areas and along roads (Minnich et al. 1993, Delgadillo-Rodriguez 1998, Rodríguez-Trejo et al. 2011, CONAFOR 2015). In the montane regions of Baja California, in the Sierra de Juárez and the Sierra San Pedro Mártir, natural lightning ignition is common during summer.

As we move into the future, extended drought that happens to coincide with Santa Ana winds may lead to increased potential for out-of-season large-fire events. If combined with increasing human-caused ignitions associated with continued urban development, or further type conversion from woody shrubs to flammable herbaceous vegetation, some challenging management decisions will need to be made to allow people and fire to coexist while maintaining the county's natural heritage.

IMPACTS AND INFLUENCES OF COASTAL LOW CLOUDS AND FOG ON BIODIVERSITY IN SAN DIEGO

by Dawn M. Lawson, Rachel E.S. Clemesha, Sula E. Vanderplank, Alexander Gershunov, and Dan Cayan

San Diego's Mediterranean climate is characterized by a regular summer drought which, along the coast, can be offset by moisture and shading from coastal low clouds and fog (CLCF) (Figure 13). The commonly used local terms "May Gray" and "June Gloom" attest to the seasonally persistent nature and horizontally uniform appearance of these stratiform ("layer") clouds. The blanket-like clouds reduce daytime maximum temperatures and when fog occurs (i.e., the cloud base meets Earth's surface), provide an incremental moisture source. CLCF occurrence responds to a combination of global and regional climate features.

Additionally, at the local scale, the inland penetration of these low level marine clouds is limited by distance from the coast and topography. Figure 14 shows the long-term summer average of daily CLCF derived from a satellite record. Within 10 miles (16.5 km) of the coast in San Diego County, low clouds occur more than 30% of each summer day on average. For example, in La Jolla on the coast, CLCF is present about 45% of the time on average for May – September, while less than 30 miles inland of La Jolla this value drops to about 15%. Through reducing solar input, CLCF lowers daytime maximum temperatures. Thus, if CLCF were to change under climate change, its shading effects upon the modulation of daytime temperatures may be altered. The low cloud cover also modulates heat waves at the coast (Clemesha et al. 2017). A striking recent example occurred on June 20, 2017; during all-time record breaking heat in the San Diego County deserts (reaching 124°F), coastal Del Mar was almost 60 °F cooler.

The inland extent of CLCF varies seasonally with a wider swath of San Diego consistently impacted by low clouds in May (Figure 15) and June (the zone covered 30% of the time reaches over 20 miles inland) and, as the summer proceeds, the low cloud cover contracts to the coast. The farthest inland extent of CLCF occurs in the early morning and the cloud deck typically recedes towards the coast later in the day due to daytime warming, drying and mixing processes.

Observational records exhibit declines in California CLCF. Johnstone et al. (2010) inferred a 33% reduction in fog for northern California over the last century, but this reduction was not necessarily driven by anthropogenic climate change and may be attributed to natural atmospheric variability (Johnstone and

Figure 13: Fog adapted life forms, *Agave sebastiana* (lower left) and *Pinus radiata var. cedrosensis* (upper left).
Photo credit: Sula Vanderplank

Mantua 2014). Although observations of declines in southern California fog have been linked to urban warming (Williams et al. 2015), the decreasing trends have not been linked to anthropogenic greenhouse gas induced climate change with certainty.

How will CLCF along the San Diego County coast respond to climate change? Definitive answers await more research and continued observations, but it is possible to speculate how some of the major atmospheric and ocean drivers of CLCF (e.g., Schwartz 2015) may change. Thus far, coastal California observations and climate model simulations of marine low cloud cover provide more evidence for future decreases than increases in CLCF. Conversely, theory suggests that the widening subtropical subsidence zone could cause the CLCF season to lengthen. Although the uncertainty in projected changes in CLCF is high, there is much more certainty in projected warming and through their effects on shading and cooling, CLCF, if not substantially reduced, could buffer these warming effects (Williams et al. 2015b, Fischer et al. 2016).

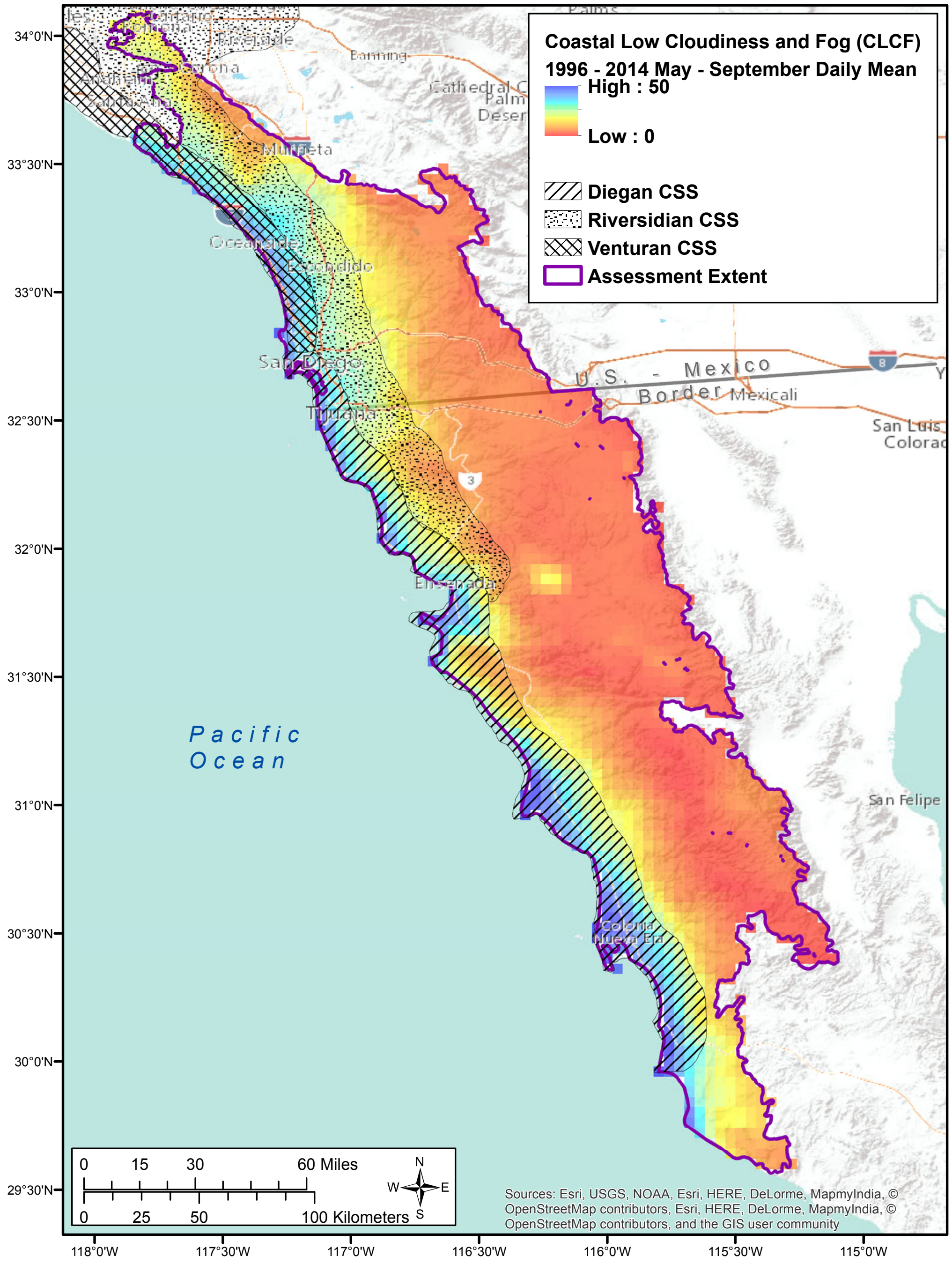


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FIGURE 14: Average summer (May-September) coastal low clouds and fog. Coastal sage scrub (CSS) data from Axelrod 1978.

Through effects on water balance, low clouds and fog are important drivers of species dynamics and ecosystem function (Dawson 1998, D'Antonio et al. 2002, Vasey et al. 2012, Fischer et al. 2016). In arid systems, low clouds and fog during the regular dry season or prolonged drought can be particularly influential to ecological communities due to their contribution to the hydrological regime and effects on ambient temperature when moisture is most limiting (Breshears et al. 2008, Fischer et al. 2009). CLCF influences the water budget by water addition through uptake of fog drip by shallow roots, foliar uptake of fog water and reduction in water loss by shading.

Fog drip supports a diverse range of taxa including plants, animals and microbes (Manzoni et al. 2012) and ecosystem processes including nutrient mineralization and carbon cycling (Carbone et al. 2013). In addition to fog drip, direct foliar uptake of fog water is important even where fog water is insufficient to change soil moisture (Breshears et al. 2008). Shading reduces solar input and thus thermal loading and ultimately evapotranspirative stress on plants (Fischer et al. 2009) and heat stress on animals (Henschel and Seely 2008).

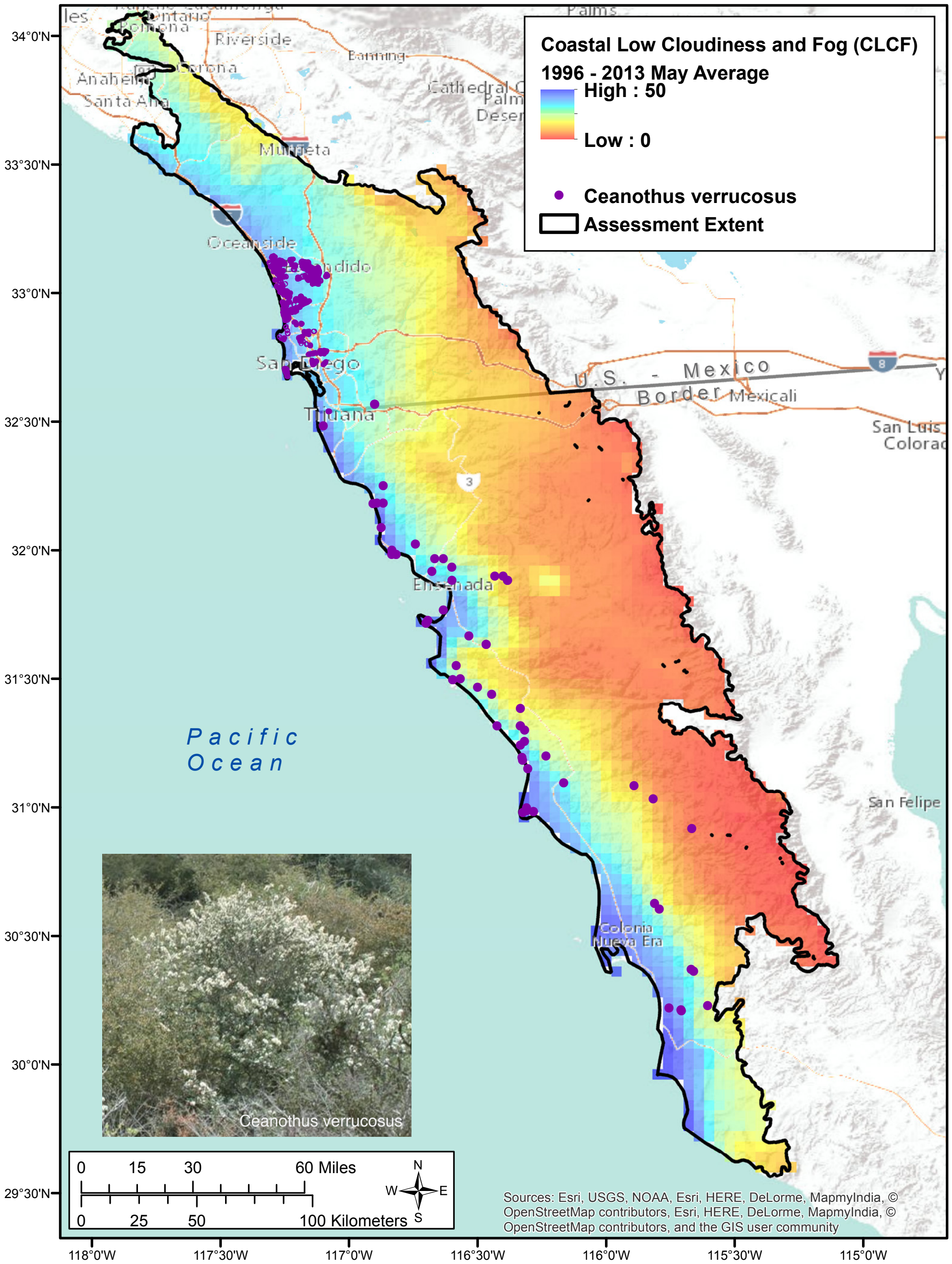
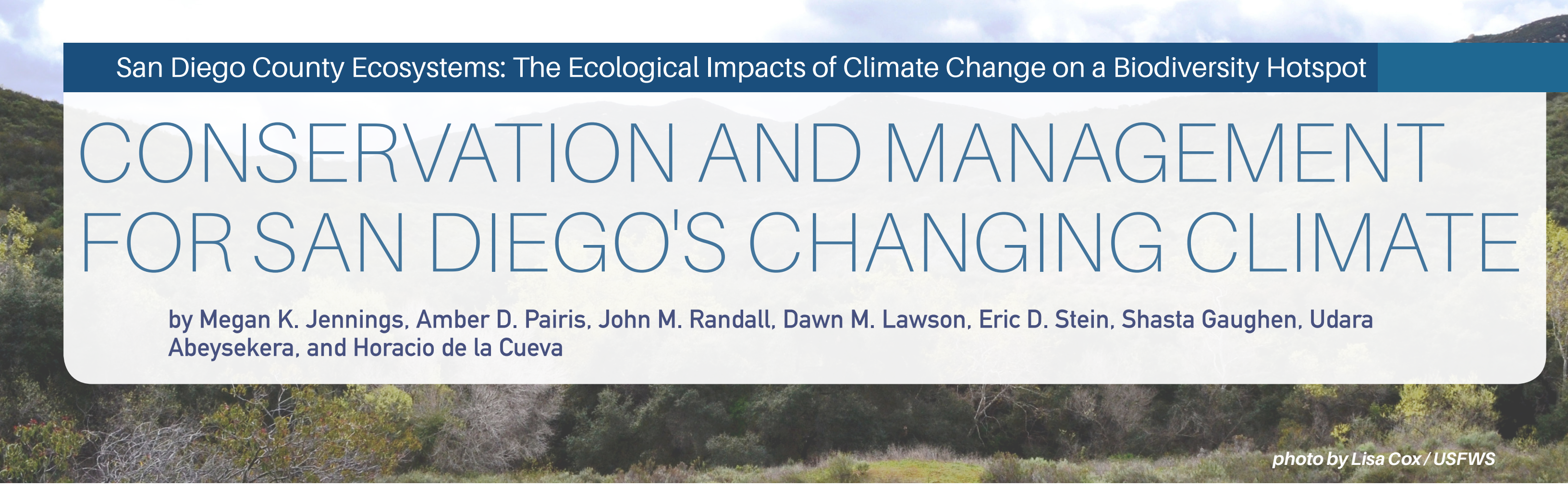


FIGURE 15: Distribution of wart-stemmed ceanothus (*Ceanothus verrucosus*) and May long-term mean CLCF. Wart-stemmed ceanothus is a highly visible component of chaparral when flowering around February of each year (inset picture). Distrubution data from San Diego Natural History Museum (2017), California Department of Fish and Wildlife (2017), Lawson (2009).

The effects of CLCF on plants are varied and include phenology, productivity, and demographics. Vanderplank and Ezcurra (2015) showed that coastal sites in the California Floristic Province (CFP) of Baja California with a stronger influence of CLCF showed lower variances in timing of flowering than sites further inland. While there are trade-offs in light that supports photosynthesis and shade that reduces evapotranspirative stress, a number of studies have found higher growth rates in woody species that experience CLCF during the dry season (Burgess and Dawson 2004, Fischer et al. 2016, Oladi et al. 2017). Further, CLCF can have significant effects on plant demographics including survival, growth and consequent recruitment to larger size classes, reproduction, and overall population size (Baguskas et al. 2014, Baguskas et al. 2016, Allen et al. 2010, Corbin and D'Antonio 2004). A number of species are limited to areas with CLCF including the narrow range endemic wart-stemmed ceanothus (*Ceanothus verrucosus*) (Figure 15). Based on physiological and biogeographical evidence this restricted range may be due to the effect of CLCF on winter low temperatures (Lawson et al. 2010). High floristic diversity in both coastal sage scrub and maritime chaparral has been linked to CLCF (Axelrod 1978, Vasey et al. 2014). In coastal sage scrub this is reflected in the diversity of the three coastal sage subtypes within the study region where the coastal sub-types Diegan and Venturan have higher diversity than the inland Riversidian Scrub type (Figure 14).

Less is known about the effects of CLCF on fauna, but a review of the literature reveals collection of aerosolized water by a number of different mechanisms and reduction of heat stress, and shows a wide range of effects from flight behavior in birds, to timing of nesting, nesting success, and behavior in different taxa.

Individual species' ability and effectiveness at utilizing fog water is highly variable (Emery and Lesage 2015) with many trade-offs. This combined with high spatial and temporal variation in the presence and intensity of CLCF results in a complex web of effects across the landscape. This variation influences interspecific interactions and species distributions, species assemblages, and ultimately biodiversity (Fischer et al. 2009).



CONSERVATION AND MANAGEMENT FOR SAN DIEGO'S CHANGING CLIMATE

by Megan K. Jennings, Amber D. Pairis, John M. Randall, Dawn M. Lawson, Eric D. Stein, Shasta Gaughen, Udara Abeysekera, and Horacio de la Cueva

photo by Lisa Cox / USFWS

Southern California is a biodiversity hotspot situated in a highly urbanized landscape with a growing population. The most immediate threats to the region's ecosystems and rich biodiversity are urbanization, land use change, and changing water management practices. However, climate change will act synergistically to exacerbate existing stressors and bring new impacts to a landscape already compromised by habitat loss and fragmentation. San Diego County has a long history of landscape-scale conservation and management, yet current management paradigms are not necessarily conducive to addressing and minimizing climate impacts. In addition, management goals and approaches that are required to address near-term, regulatory requirements for single-species management may hamper the ability to build resilience to climate change and increased climate variability into the future.

Since the mid-1990s, most new land preservation efforts in San Diego County have resulted from efforts to develop regional conservation networks through federal Habitat Conservation Plans (HCPs) and state Natural Community Conservation Program (NCCP) Plans (Figure 16). The unifying theme in these conservation planning efforts in San Diego County, and across much of the West, has been protection of the large number of state and federally protected species in these ecosystems. This approach has conserved lands with habitat for listed species which has also served to benefit populations of many other species. These protected lands form the foundation from which a regional network or series of networks can be built. Such a network, rather than isolated preserves, will be necessary to strengthen the region's ecosystems' ability to resist the impacts of climate change in the short-term (decades), and to ensure the region's ecosystems can accommodate and transform in the face of continuing climate change over the long-term (multiple decades and centuries). Climate change projections make it clear, however, that more will need to be done to improve resilience and adaptive capacity to the threats and stressors while also

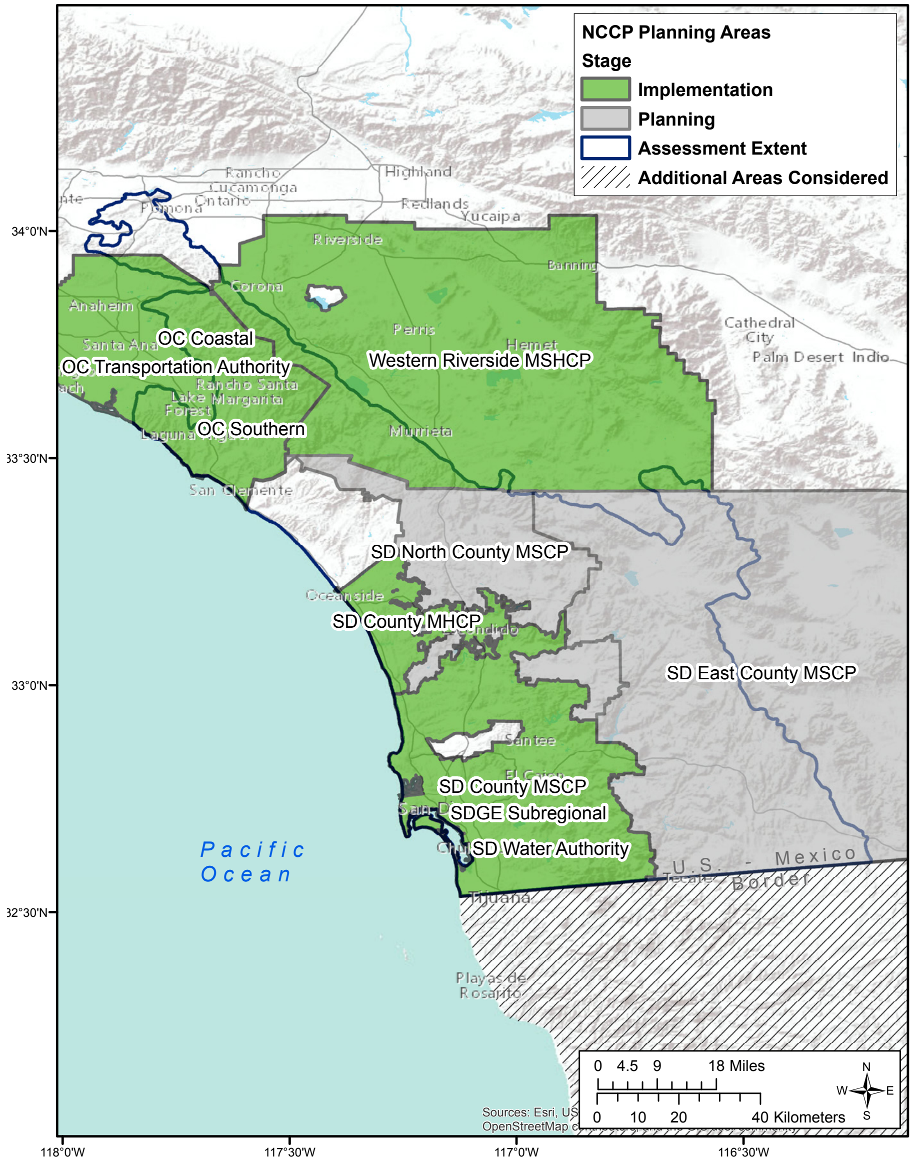


FIGURE 16: Map of NCCP and HCP planning areas. Completed plans that are in the implementation phase are shaded green. Plans that are in progress are identified with gray shading.

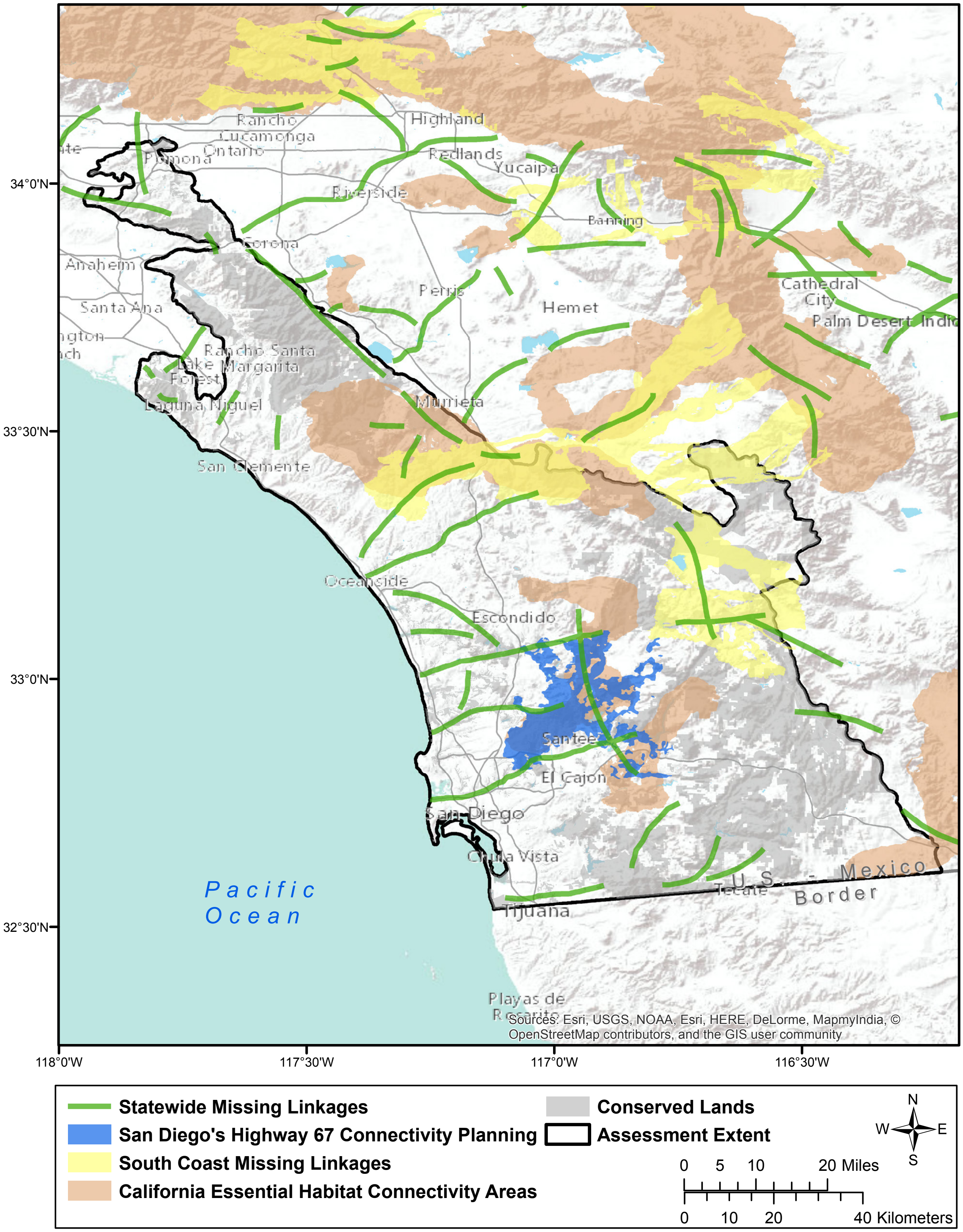


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FIGURE 17: Map of existing connectivity plans for the San Diego region. Conserved lands are depicted in gray. Green sticks represent proposed linkage zones from the Statewide Missing Linkages Project (Penrod et al. 2001). Spatially-explicit corridors mapped in yellow are the South Coast Missing Linkages Project (South Coast Wildlands 2008), brown are California Essential Habitat Connectivity Plan linkages (Spencer et al. 2010), and blue for San Diego's Highway 67 Connectivity Plan (Jennings and Zeller 2017).

mitigating those impacts. Increasing the attention given to maintaining functional diversity at the community or ecosystem level will also be necessary. Integrating climate smart conservation strategies into planning and management activities will help facilitate adaptation, or transformation, of those communities to the greater changes in climate expected over the long term.

Management approaches that allow flexibility and target the three categories of adaptation — resistance, accommodation, and transformation (Fisichelli et al. 2016) — are key to facilitating climate adaptation in natural systems. To promote resistance, we may choose to intensively manage to retain certain species or systems although the climate conditions are no longer suitable habitat for the species or system such as high profile species with isolated populations, like Cuyamaca cypress (*Hesperocyparis stephensonii*) or Tecate cypress (*Hesperocyparis forbesii*). To both resist and accommodate change in natural ecosystems management efforts may focus on ameliorating compounding stressors that may reduce resilience of populations and communities. For example, habitat connectivity (**Figure 17**) is essential to climate-smart landscape strategies (Heller and Zavaleta 2009) and strengthens ecosystem resilience to additional stressors such as habitat fragmentation (Beier and Gregory 2012), and other disturbances (Noss 1991, Hilty et al. 2006). Finally, at either preserve or regional management levels, we may choose to guide systems in their transformation to novel states that can be maintained and persist on their own. This management approach requires careful consideration of potential future states and a thoughtful process for setting goals and management targets. Adaptive management and an active monitoring program to inform it will be critical to the success of managing for altered states.

For any of the above strategies, adaptation and scenario planning are the primary approaches to facilitate the preservation of natural systems under uncertain and likely increasing climate variability. Adaptation planning is the process of assessing the risks and opportunities in a changing climate and taking actions to address climate change impacts by targeting those risks and leveraging the opportunities (Füssel 2007). Given that the general trajectories of climate change projected for the region are known (i.e., hotter, drier, more fires, less water), these adaptation planning efforts should begin without delay. This would involve identifying regions, habitats, and species that are conducive to supporting resistance, accommodation, and transformation and focusing planning strategies on these targets accordingly. Scenario planning is a type of adaptation planning focused on the process of identifying several plausible futures and exploring the consequences of a management or conservation decision in each of those scenarios. Scenario planning offers a framework for deciding on when, how, and where to act in an uncertain future (Peterson et al. 2003) and is particularly useful in informing adaptation strategies because individual climate event timelines are difficult to predict.

The spatial and temporal scales at which climate impacts must be considered to build resilience into our natural systems require landscape-scale planning that is best addressed in a cooperative, cross-jurisdictional approach. Long-term monitoring and adaptive management will be critical to managing species and ecosystems into the future, and adaptation and scenario planning will also play a role. In light of projected growing impacts of climate change, it is likely that management goals may warrant re-evaluation, recognizing that managing for the near-term, particularly single-species management, may hamper abilities to build resilience into vulnerable ecosystems (Boitani et al. 2007).

TABLE 3: The key knowledge and information gaps in San Diego's preserve system that need to be filled and targeted with adaptation and scenario planning

A cohesive strategy to understanding how species and watersheds will respond to the new projected precipitation regime.
Spatially explicit landscape linkages designed at the regional level that provide functional connectivity under shifting climate regimes and increased urbanization.
A connectivity plan and linkage design that focuses on cross-border connectivity and addresses the challenge of facilitating movement and migration for species across fenced sections of the international border.
Defined thresholds or triggers for changes in management action and monitoring programs designed to deliver the necessary data to respond accordingly.
Identification of the elements of San Diego's ecosystems that make them more or less accomodating to change. Management actions can then preserve and promote those elements that support resilience.

CONCLUSIONS AND FUTURE DIRECTIONS

by Amber D. Pairis, Udara Abeysekera, Julie Kalansky, Dan Cayan, and Megan K. Jennings

San Diego County is part of a biologically diverse and unique landscape that will be impacted in multifold ways due to current and future climatic variability (Table 2). This assessment serves as an important first step in understanding the state of the science which is critical to evaluating the vulnerability of systems, communities, and populations. Conducting the assessment has provided a summary of a wealth of known information, and a better appreciation of the large number of unknowns that will impact the region under a changing climate. In addition, we have highlighted the information needed to move forward with management and decision-making. While there is still uncertainty about exactly how some of these changes will play out across the landscape, the findings from this assessment indicate enough knowledge exists to offer insights into managing natural resources throughout the ecoregion and across jurisdictional boundaries in the face of a changing climate.

The characteristics that make San Diego unique with respect to climate and ecosystems include its remarkable variability of precipitation, coastal low clouds and fog, the region's human population and associated development,

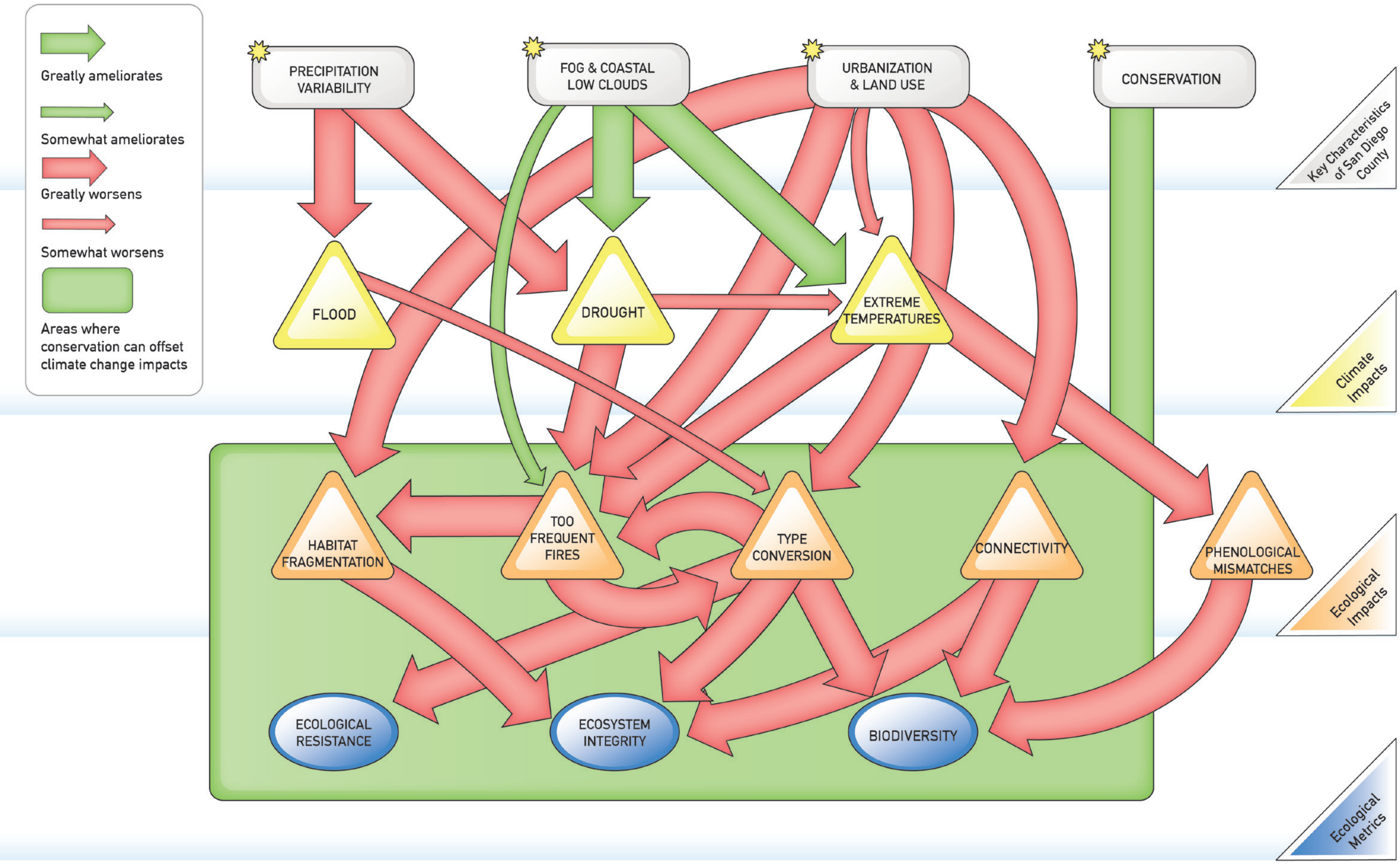

FIGURE18: Cross-cutting issues and impacts on ecosystems and biodiversity

TABLE 4

Summary of knowledge gaps that are identified throughout the report. The category that the gap best fits under is highlighted.

Climate Monitoring	*Ecological Monitoring*	*Analyses using existing data*	*Collaborations*	**TARGETED ACTIONS TO FILL KNOWLEDGE GAPS**
		●		Enhance our understanding of the interaction between climate, habitat elements, populations, and interspecific interactions through modeling of biotic interactions for a broader range of the region's species.
●			●	Build enhanced spatial resolution of temperature observations to inform ecological modeling and to determine key elements of local refugia (e.g., extent, location).
	●			Study the impacts of temperature shifts, particularly temperature extremes, on demographic parameters and population dynamics by tracking populations and species with range limits within or adjacent to the region.
	●			Utilize phenology and population trend monitoring to identify when asynchrony is likely to lead to cascading ecological impacts (e.g., timing of resource availability, loss of pollination services).
●				Evaluate how changes in precipitation regime will affect bioavailability of water. Improved observational soil moisture and hydrologic data in the region can be used to refine and validate regional hydrological modeling, which can then be used to examine future impacts.
	●			Identify drought thresholds that can lead to structural changes in regional ecosystems as specific functional groups are more severely impacted. This includes field studies of the potential for drought to impede recovery of native shrublands after disturbance, particularly fire.
	●			Gather data to evaluate the effects of an extended and more extreme dry season over several years on individual species as well as ecosystem structure and function.
		●		Generate a cost-benefit analysis and prioritization of where and when to conduct fire management strategies to optimize fire-risk reduction and biodiversity conservation.
	●			Assess the role of extended drought in vegetation die-back, and how that may lead to increased area burned under Santa Ana wind conditions.
	●	●		Investigate the interaction between drought and vegetation-type conversion through quantification of the extent and rate of conversion across the region, and the primary drivers of this vegetation change.
		●	●	Improve tracking and availability of data on ignition sources of wildland fires to evaluate unknown sources and better design prevention programs. One area of needed research is the weather conditions under which powerline-caused fires are most likely to occur and how effective vegetation clearing is for mitigating that risk.
	●			Gather data on species' responses to low clouds and fog. Studies of individual species or groups of organisms will greatly inform our understanding of local ecosystem dynamics.
		●	●	Encourage land managers to incorporate CLCF into management planning and adaptive management (e.g., restoration efforts, out-plantings and projecting natural disturbance and project effects on conservation targets) by using spatial data sets derived from remote sensing.
			●	Establish a cohesive strategy to monitor how species and watersheds will respond to the new projected climatic conditions.
		●	●	Delineate and conserve spatially-explicit landscape linkages at the regional level, including across the U.S-Mexico border. Linkages should provide for functional connectivity under shifting climate regimes and increased urbanization. These linkages should then be integrated into reserve design and regional planning and management.
			●	Define thresholds or triggers for changes in management action and refine or design monitoring programs to deliver the necessary data to respond accordingly.
		●		Identify the elements of San Diego's ecosystems that make them more or less resilient to change. Target management actions that preserve and promote those elements that support resilience (e.g., restoration using palettes of plant species resistant to increased temperatures and variable precipitation).
	●		●	Make monitoring data and the interpretation of those data readily available to decision makers and the public to encourage engagement and ongoing dialogue on adaptive management.

This review, combining the knowledge of climatologists and ecologists with regional expertise and embedded in regional conservation and planning efforts, is a demonstration of what boundary spanning organizations and projects can do to inform actions that advance realistic climate adaptation planning."

and a history of conservation planning and action to protect the region's rich biodiversity. How these key features interact to either exacerbate or dampen impacts of climatic shifts and non-climate stressors has been woven throughout the report. Here, we highlight the interactions among these key characteristics, projected climate shifts, associated ecological impacts, and the ecological variables that are likely to be affected (Figure 18).

We have also broadly summarized the knowledge and monitoring gaps that have been identified throughout the report (Table 4). In general, these questions and research gaps cannot be fully addressed by conducting experiments or mobilizing to collect data during indivdual climate events. Instead, ongoing monitoring to gather baseline and trend data for comparison can allow for analyses when environmental conditions create the opportunity to learn from natural experiments as they arise. The distinction between new monitoring and new research can become blurred as monitoring supports and informs research. As such, we do not try to separate these two gaps in the table. Instead, we identify the category (or categories) that the research falls under: more ecological monitoring, more climate monitoring, research using existing data, and need to improve collaborations. All of the gaps would benefit from enhancements in all categories, but by identifying the most critical, we hope to provide a path forward.

Numerous scientists and natural resource entities are working to address different forms of climate impacts on natural resources in the San Diego region. However, this science does not always reach the communities that are the most affected by these impacts. This means there may be missed opportunities for the public to understand the need for climate action and/or to build trust in science coming from local researchers. The continued involvement of researchers, managers, and community members in organizations like the Climate Science Alliance is vital in developing the co-produced knowledge that is transferable and actionable to decision makers and managers. This review, combining the knowledge of climatologists and ecologists with regional expertise and embedded in regional conservation and planning efforts, is a demonstration of what boundary spanning organizations and projects can do to inform actions that advance realistic climate adaptation planning. In this assessment, researchers have not limited themselves to the role of producing knowledge but instead are intent on working hand-in-hand with other disciplines and professions, and within communities where citizens will have a real stake in the welfare of the ecosystems that contribute richly to our society, economy, and values.

Recognizing that people are at the center of our climate adaptation decisions requires that research needs to be actionable and delivered in a timely manner. Actionable science, or science that is intentionally created to serve society (Palmer 2012), includes activities that take into account the existing regulatory, economic, legal, and social context that decision makers work within. Most decision makers do not have the luxury to wait for data to be published and instead need findings communicated in real-time to the greatest extent possible. This kind of dialogue can help encourage proactive and adaptive management and help to leverage and coordinate regionally specific adaptation projects.

KEY POINTS

- San Diego County *is part of a biologically diverse and unique landscape that will be impacted in multifold ways due to current and future climatic variability.*
- *This assessment of the* state of the science*, is critical to understanding the vulnerability of systems, and allowing partners to take stock of the state of knowledge about potential climate impacts at the regional level.*
- *Climate warming superimposed upon the pronounced spatially-varying temperature in the San Diego region will likely be associated with* range shifts *for many species resulting in novel community assemblages and biotic interactions.*
- *More frequent and more intense* heat waves *may disproportionately affect younger age classes and reduce reproductive and survival rates of species sensitive to temperature extremes. Warming temperatures may also create phenological mismatches.*
- *The region's* precipitation *regime is projected to become more variable with more dry days and more dry years. However, the few extremely heavy precipitation events, increased over historical levels could result in increased flooding and occasional wet years.*
- Drought *may occur more frequently due to increased occurrence of dry days and could intensify because of warmer temperatures. Since drought disproportionately affects some species, these projected changes may cause structural changes to ecosystems.*
- *Annually, the occurrence of Santa Ana winds during increasingly dry fall months would create ideal* fire *conditions. Longer dry spells and decreased precipitation in fall may extend fire season into the winter, increasing the risk of Santa Ana wind-driven fires. Regardless of climatic shifts, people will remain the major driver of fires in San Diego.*
- Coastal low clouds and fog *buffer warming and drying along the coast through shading and cooling. Although these marine stratus clouds will remain a presence, future changes in this phenomenon are uncertain, so the degree to which this will ameliorate the impacts of warming and drying is unknown.*

Photo of San Miguel Mountain by Joanna Gilkeson/USFWS

- *San Diego is a biologically diverse region that has been the focus of more than 20 years of conservation planning, investment, and innovation. However, much remains to be done to complete a* network of protected habitats *that is necessary to ensure the survival of the region's biodiversity, and through allowing for adaptability to future climate change.*
- *The spatial and temporal scales at which climate impacts must be considered to build resilience into natural systems require the integration of complementary approaches at multiple scales.* Landscape-scale planning *can build on single-species approaches that have historically driven conservation action in the region.*
- *Building resilience into San Diego's ecosystems is a challenge to be addressed in a* cross-jurisdictional, multidisciplinary *fashion by scientists, policy-makers, planners, land managers, and the broader conservation community.*
- *Conservation management goals and approaches need to be updated to balance addressing near-term, regulatory requirements for single-species management with landscape-level actions necessary to* build resilience and adaptability for the future *under climate change.*
- Long-term monitoring and adaptive management *will be critical to managing species and ecosystems into the future. This includes adaptation and scenario planning.*
- *Future research and planning to build resilience to climate impacts will need to focus on identifying and protecting* climate refugia*, understanding weather, climate, and hydrologic characteristics along protected corridors, and stronger and sustained collaborations of science, planning, policy, and implementation communities.*
- Boundary spanning organizations *like the Climate Science Alliance-South Coast can advance climate adaptation planning by providing opportunities to translate science into actions, forge new and expanded partnerships, and catalyze innovative, large-scale actions needed to build long-term resilience to climate change.*

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WHY WE DID IT

Sustained, long-term collaboration is needed to conserve biodiversity and allow species and habitats to adapt to climate change and shift over time. However, the small-to-large spatial and temporal scales at which climate impacts must be considered to build resilience into natural systems require landscape-scale planning rather than the single-species approaches which have historically driven conservation action in the region. Increasing the resilience of San Diego's ecosystems in the face of climate change is a challenge that will require multidisciplinary assessments, scenario evaluations, and other comprehensive science-based strategies to inform management and conservation actions.

The Climate Science Alliance – South Coast created a space for these ecologists and climatologists to interact and gather regionally specific climate information and assess the impacts on local species and habitats caused by climate variability as well as other stressors. This collaboration is unusual in that the project was conducted without a mandate or funding, but solely out of a desire to articulate risks that had not previously been made available to conservation planners and land managers.

Researchers taking part in this assessment are committed to the creation of actionable science that is applicable to the myriad challenges that land managers and conservation practitioners face. From the onset of this effort, all participants made an intentional effort to consider how the results of this assessment will play out across different jurisdictional boundaries within the study region and how to present the science in ways that would be most accessible to inform natural resource planning, decision-making, and management.

This review, combining the knowledge of climatologists and ecologists with regional expertise and embedded in regional conservation and planning efforts, is a demonstration of what boundary spanning organizations and projects can do to inform actions that advance realistic climate adaptation planning. In this assessment, researchers have stepped outside of their more familiar roles as knowledge producers to work hand-in-hand with other disciplines and professions. We think this is an example of how diverse experts can participate within communities where citizens will have a real stake in the welfare of the ecosystems that contribute richly to our societies, economies, and values.

For more information and links, visit www.climatesciencealliance.org/sdc-ecosystem-assessment

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