OFFICE OF ENVIRONMENTAL HEALTH HAZARD ASSESSMENT

Climate Change Indicators

Recent Research on Climate Change:

A bibliography with an emphasis on California

July 2016

Air, Community, and Environmental Research Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

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RECENT RESEARCH ON CLIMATE CHANGE:

A bibliography with an emphasis on California

Compiled to support the preparation of the report, Indicators of Climate Change in California

July 2016

Air, Community and Environmental Research Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

Prepared and compiled by:
Tamara Kadir
Linda Mazur
Carmen Milanes
Karen Randles

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Introduction

The Office of Environmental Health Hazard Assessment (OEHHA) continually monitors the scientific literature, publications of research organizations, governmental entities and academia, and other sources for information relating to climate change and its impacts on California. This bibliography is a compilation of selected publications presenting observations and new or emerging scientific information on climate change with an emphasis on California impacts. This report supports OEHHA's efforts to compile indicators of climate change in California (*Indicators of Climate Change in California* (OEHHA, 2013)), and is made available as a resource for environmental and public health agencies, the research community, non-government organizations, and the public.

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. (IPCC, 2007)

This bibliography covers research published from 2011 to 2016, a period that overlaps with literature summarized in earlier bibliographies (OEHHA, 2013; 2015). No references from the earlier bibliographies are repeated in this document.

Identifying and selecting references

OEHHA identified publications describing past and current data or new or modified scientific understanding about changes in climate, the causes or drivers of climate change, and its impacts from literature searches, environmental newsletters, websites of research institutions and government entities and the popular press (see Appendix). Publications that relate to California were targeted, although references that cover other geographic areas were included if their findings are applicable or relevant to California. Specifically excluded are references that primarily present future scenarios or modelled projections, or that mainly discuss mitigation or adaptation measures.

Structure of the report

References are organized into five categories described below. Except for the first one, the categories correspond to the structure of the climate change indicators report.

Authoritative reports

Certain national and international scientific organizations are generally recognized to be authoritative, with established expertise in topics relating to climate and climate change. These organizations publish reports, assessments or periodic updates on one or more climate change-related topics.

Drivers of climate change

The climate system is influenced by its own internal dynamics and by changes in external factors, or "forcings." Natural forcings (e.g., solar radiation and volcanic

eruptions) and human-induced forcings (e.g., changes in atmospheric composition due to fossil fuel combustion and land use) alter the energy balance of the climate system and are drivers of climate change. Land use can affect climate by altering the amount of solar radiation that is reflected by such surfaces back into space.

Changes in climate
Climate, which is generally defined as "average weather," is usually described in terms of the mean and variability of temperature, precipitation, and wind over a period of time.

Impacts of climate on physical systems
Climate is a key factor affecting the characteristics of natural physical systems. These systems include snow, glaciers, ice, water vapor, streams, rivers, lakes and the ocean. Examples of impacts include erosion, sea level rise, salt water intrusion, and changes in snowmelt runoff.

Impacts of climate on biological systems
Terrestrial, marine and freshwater biological systems are strongly influenced by climatic conditions. Changes in climate can impact humans (e.g., increased mortality during heat waves), vegetation (e.g., wildfires and vegetation distribution shifts) and animals (e.g., small mammal population migration).

The citations
The categories listed above are further divided into subcategories. Within these subcategories, the references are arranged by publication date, from the earliest to most recent. For each reference, the following are provided: a full citation; a web address for accessing the publication or its abstract; the geographic location (e.g., California, northern Pacific Ocean); the type of reference (e.g., report, research paper); and the publication's abstract. References that cover information that is relevant to more than one subcategory are cross-referenced to the related subcategory (see for example papers listed under *extreme events*).

References:
IPCC (2007). *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

OEHHA (2013). *Indicators of Climate Change in California*. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Authoritative Reports

This chapter presents citations of publications by authoritative national and international scientific organizations in topics relating to climate and climate change. Examples of such organizations are the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO) and the United States Environmental Protection Agency (U.S. EPA).

Global

WMO Statement on the Status of the Global Climate in 2013. World Meteorological Organization (2014). WMO-No. 1130.
http://library.wmo.int/opac/index.php?lvl=notice_display&id=15957#.VxleuGGFN3c

Geographic Location: Global
Type of Reference: Report

Abstract: The dramatic impact of climate variability and climate change continued to be felt all over the world throughout 2013. The WMO Statement on the Status of the Global Climate in 2013 provides a snapshot of global and regional trends in weather and climate over the past year and highlights some of the year's most significant extreme events.

WMO Statement on the Status of the Global Climate in 2014. World Meteorological Organization (2015). WMO-No. 1152.
http://www.wmo.int/pages/prog/wcp/wcdmp/documents/wmo_1152_en.pdf

Geographic Location: Global
Type of Reference: Report

Abstract: The warming trend observed over the past few decades continued in 2014, which WMO has ranked as nominally the warmest year since modern instrumental measurements began in the mid-1800s. The WMO Statement for 2014 reports that global-average sea-surface temperatures for 2014 were warmer than for any previous year on record. This Statement also highlights extremes that occurred in 2014 at the national and regional levels. Another interesting phenomenon in 2014 was the behavior of the seas around Antarctica. While parts of Antarctica's land-based glaciers are melting, the sea ice expanded to a record extent for the third year in a row.

WMO Statement on the Status of the Global Climate in 2015. World Meteorological Organization (2016). WMO-No. 1167. http://library.wmo.int/pmb_ged/wmo_1167_en.pdf

Geographic Location: Global
Type of Reference: Report

Abstract: The year 2015 will stand out in the historical record of the global climate in many ways. Modern records for heat were broken: 2015 was a record warm year both globally and in many individual countries. Heatwaves were extremely intense in various parts of the world, leading to thousands of deaths in India and Pakistan. Record extreme precipitation led to flooding that affected tens of thousands of people across South America, West Africa and Europe. Dry conditions in southern Africa and Brazil exacerbated multi-year droughts. The influence of the strong El Niño that developed in the later part of 2015 can be discerned in many of the year's weather and climate events. While much work remains to be done, advances in international collaboration, the near-real-time sharing of data, and progress in attribution science are starting to make it possible to disentangle the respective roles played by El Niño, other natural climate variations and human-induced climate change.

The Global Climate 2001-2010: A Decade of Climate Extremes. World Meteorological Organization (2013). WMO- No. 1103. http://library.wmo.int/pmb_ged/wmo_1103_en.pdf

Geographic Location: Global
Type of Reference: Report

Abstract: The Global Climate 2001–2010 summarizes the state of the climate for the decade and its assessment in the historical context. It aims at providing a decadal perspective of climate variability and change and its observed impacts on different sectors. It complements the annual WMO statements on the status of the global climate and the more comprehensive annual report State of the Climate, which is published regularly in the Bulletin of the American Meteorological Society (BAMS) by the National Oceanic and Atmospheric Administration-National Climate Date Center (NOAA-NCDC). The report analyzes global and regional temperatures and precipitation, as well as extreme events such as the heat waves in Europe and Russia, Hurricane Katrina in the United States, Tropical Cyclone Nargis in Myanmar, droughts in the Amazon Basin, Australia and East Africa and floods in Pakistan.

Attribution of Extreme Weather Events in the Context of Climate Change. National Academies of Sciences, Engineering and Medicine (2016) Washington DC: The National Academies Press. http://www.nap.edu/download.php?record_id=21852

Geographic Location: Global
Type of Reference: Report

Abstract: As climate has warmed over recent years, a new pattern of more frequent and more intense weather events has unfolded across the globe. Warming increases the likelihood of extremely hot days and nights, favors increased atmospheric moisture

that may result in more frequent heavy rainfall and snowfall, and leads to evaporation that can exacerbate droughts. Even with evidence of these broad trends, scientists cautioned in the past that individual weather events could not be attributed to climate change. Now, with advances in understanding the climate science behind extreme events and the science of extreme event attribution, such blanket statements may not be accurate. The relatively young science of extreme event attribution seeks to tease out the influence of human-caused climate change from other factors, such as natural sources of variability like El Niño, as contributors to individual extreme events. As event attribution capabilities improve, they could help inform choices about assessing and managing risk, and in guiding climate adaptation strategies. This report examines the current state of science of extreme weather attribution, and identifies ways to move the science forward to improve attribution capabilities.

State of the Climate: Global Analysis for Annual (*for years 2012 to 2015*). National Oceanic and Atmospheric Administration's (NOAA), National Climatic Data Center (2015)

Annual 2012 (http://www.ncdc.noaa.gov/sotc/global/201213)
Annual 2013 (http://www.ncdc.noaa.gov/sotc/global/201313)
Annual 2014 (http://www.ncdc.noaa.gov/sotc/global/201413)
Annual 2015 (http://www.ncdc.noaa.gov/sotc/global/201513)
Geographic Location: Global
Type of Reference: Interactive web-based report

Abstract: NOAA's National Climatic Data Center publishes an annual report summarizing climate-related data on both a global and national scale. (The annual national overview is described separately, below. Monthly reports are also available from the above URL). The Global Analysis presents data for each calendar year, including global and regional temperatures, precipitation and a list of the year's top ten global weather or climate events.

State of the Climate for Annual 2013. Blunden, J, and DS Arndt, Eds., (2014): Bull. Amer. Meteor. Soc., 96(7), S1– S257.
http://journals.ametsoc.org/doi/pdf/10.1175/2014BAMSStateoftheClimate.1

Geographic Location: Global
Type of Reference: Report

Abstract: An international, peer-reviewed publication released each summer, the "State of the Climate" is the authoritative annual summary of the global climate published as a supplement to the *Bulletin of the American Meteorological Society*. This 24th edition of the series puts weather and climate events of the year into historical perspective, and provides information on the state, trends, and variability of the climate system's many variables and phenomena. In 2013, the vast majority of the monitored climate variables reported maintained trends established in recent decades. According to several independent analyses, 2013 was again among the 10 warmest years on record at the global scale, both at the Earth's surface and through the troposphere. The North Pacific

reached a historic high temperature in 2013 and on balance the globally-averaged sea surface temperature was among the 10 highest on record. Global mean sea level continued to rise, on pace with a trend of 3.2 millimeters per year over the past two decades. In the atmosphere, carbon dioxide, methane, and nitrous oxide all continued to increase in 2013. Each of these major greenhouse gases once again reached historic high concentrations. At Mauna Loa, Hawaii the daily average mixing ratio of carbon dioxide exceeded 400 parts per million on 9 May. The state of these variables, along with dozens of others, is discussed in further detail.

State of the Climate for Annual 2014. Blunden, J, and DS Arndt, Eds., (2015): Bull. Amer. Meteor. Soc., S1– S267.
https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/

Geographic Location: Global
Type of Reference: Report

Abstract: The 25th edition of the "State of the Climate" is based on contributions from 413 scientists from 58 countries around the world. It provides a detailed update on global climate indicators, notable weather events, and other data collected by environmental monitoring stations and instruments located on land, water, ice, and in space. The report's climate indicators show patterns, changes, and trends of the global climate system. Examples of the indicators include various types of greenhouse gases; temperatures throughout the atmosphere, ocean, and land; cloud cover; sea level; ocean salinity; sea ice extent; and snow cover. The indicators often reflect many thousands of measurements from multiple independent datasets.

National

State of the Climate: National Overview for Annual (*for years 2012 to 2015*).
National Oceanic and Atmospheric Administration's (NOAA), National Climatic Data Center
Annual 2012 (http://www.ncdc.noaa.gov/sotc/national/201213)
Annual 2013 (http://www.ncdc.noaa.gov/sotc/national/201313)
Annual 2014 (http://www.ncdc.noaa.gov/sotc/national/201413)
Annual 2015 (http://www.ncdc.noaa.gov/sotc/national/201513)

Geographic Location: United States
Type of Reference: Interactive web-based report

Abstract: The National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center publishes an annual report summarizing climate-related data on both a global and national scale. (The annual global analysis is described separately, below. Monthly reports are also available from the above URL). The National Overview presents data for each calendar year, including a national temperature and precipitation

analysis (both annual and seasonal), a list of the year's top ten weather or climate events in the United States and a discussion of the Climate Extremes Index.

National Climate Assessment. Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., (2014): *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. http://www.globalchange.gov/nca3-downloads-materials

Geographic Location: United States
Type of Reference: Report

Abstract: The National Climate Assessment (NCA) assesses the science of climate change and its impacts across the United States, now and throughout this century. A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced the report, which was extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences. It documents climate change related impacts and responses for various sectors and regions, with the goal of better informing decision-making at all levels. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public.

Climate Change Indicators in the United States, 2014. Third Ed., U.S. Environmental Protection Agency. (2014). EPA 430-R-14-004.
http://www.epa.gov/climatechange/pdfs/climateindicators-full-2014.pdf

Geographic Location: United States
Type of Reference: Report

Abstract: The US Environmental Protection Agency (EPA) publishes this report to communicate information about the science and impacts of climate change, assess trends in environmental quality, and inform decision-making. This report is the third edition of a report first published by the EPA in 2010 and updated in 2012. It presents 30 indicators to help understand observed long-term trends related to the causes and effects of climate change, the significance of these changes, and their possible consequences for people, the environment, and society. The indicators look at the composition of the atmosphere, fundamental measures of climate, and the extent to which several climate-sensitive aspects of the oceans, snow and ice, human health, society, and ecosystems are changing.

The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. US Global Change Research Program (USGCRP). (2016). Crimmins, A, J Balbus, JL Gamble, CB Beard, JE Bell, D Dodgen, RJ Eisen, N Fann, MD Hawkins, SC Herring, L Jantarasami, DM Mills, S Saha, MC Sarofim, J Trtanj, and L Ziska, Eds., Washington, DC, 312 pp.
https://s3.amazonaws.com/climatehealth2016/high/ClimateHealth2016_FullReport.pdf

Geographic Location: United States
Type of Reference: Report

Abstract: The purpose of this assessment is to provide a comprehensive, evidence-based, and, where possible, quantitative estimation of observed and projected climate change related health impacts in the United States. The US Global Change Research Program Climate and Health Assessment has been developed to inform public health officials, urban and disaster response planners, decision makers, and other stakeholders within and outside of government who are interested in better understanding the risks climate change presents to human health. Chapters address the following topics: *Climate Change and Human Health; Temperature-Related Death and Illness; Air Quality Impacts; Impacts of Extreme Events on Human Health; Vector-Borne Diseases; Climate Impacts on Water-Related Illness; Food Safety, Nutrition, and Distribution; Mental Health and Well-Being;* and *Populations of Concern*.

California

California Current Integrated Ecosystem Assessment (CCIEA): Phase II Report. Levin, P.S., B.K. Wells, M.B. Sheer (eds). (2013).
http://www.noaa.gov/iea/Assets/iea/california/Report/pdf/CCIEA_2012_Report.pdf
(This is a web-based report and meant to be accessed online. This PDF version does not include some transitional material included on the website: http://www.noaa.gov/iea/CCIEA-Report/pdf/index.html.)

Geographic Location: Pacific Ocean/California
Type of Reference: Report (pdf and web-based)

Abstract: Integrated ecosystem assessments (IEAs) are a critical science support element enabling ecosystem-based management (EBM) strategies. An IEA is a formal synthesis and quantitative analysis of information on relevant natural and socioeconomic factors in relation to specified ecosystem management goals. The ultimate aim of the California Current IEA is to fully understand the web of interactions that links drivers and pressures to EBM components and to forecast how changing environmental conditions and management actions affect the status of EBM components. This work focused on four EBM components: Ecosystem Integrity, Fisheries (groundfish and coastal pelagic species), Protected Species (marine mammals, seabirds, Pacific salmon) and Vibrant Coastal Communities. Status, trends and impacts of oceanographic/climatic drivers and anthropogenic pressures are addressed throughout the IEA. Status and trends of drivers and pressures are discussed in Chapters 2 and 3. In Chapter 10 a series of scenarios that link large-scale

drivers to pressures in the California Current are described, and then a variety of techniques used to estimate how the status of ecosystem components might change under different scenarios.

California Current Integrated Ecosystem Assessment (CCIEA): Phase III Report. Harvey, C.J., N. Garfield, E.L. Hazen and G.D. Williams (eds.) (2014). http://www.noaa.gov/iea/Assets/iea/california/Report/pdf/CCIEA%20Phase%20III%20Introduction.pdf

Geographic Location: Pacific Ocean/California
Type of Reference: Report

Abstract: This report describes the physical, chemical, ecological, and socioeconomic conditions in the California Current through the year 2013. It also formally introduces two major new components into the CCIEA effort: *Habitat*, the matrix within which ecological interactions occur; and *Human Dimensions,* the interface between humans and the other components (living and non-living) of the CCLME. It also further advances the effort to make this work truly integrative across components; examples of this are perhaps most clearly seen in sections on Salmon, Risk Assessment, and Management Strategy Evaluation. The Phase III Report is presented as a series of time -stamped documents in downloadable formats with accompanying web-based materials available at the CCIEA website (http://www.noaa.gov/iea/regions/california-current-region/).

California Current Integrated Ecosystem Assessment (CCIEA) State of the California Current Report. A report of the CCIEA team (National Oceanic and Atmospheric Administration (NOAA) Northwest, Southwest and Alaska Fisheries Science Centers) to the Pacific Fishery Management Council (2015). http://www.noaa.gov/iea/Assets/iea/california/Report/pdf/IEA%20State%20of%20the%20California%20Current%20Report%202015.pdf

Geographic Location: Pacific Ocean/California
Type of Reference: Report

Abstract: This report is the CCIEA third annual update on the state of the California Current Ecosystem (CCE) as derived from environmental, biological and socioeconomic indicators. Included in this report are indicators of: *climate and ocean drivers (*e.g., interannual variability of ocean currents and regional upwelling) and *focal components of ecological integrity* (e.g., interannual variation in biomass of copepod species; forage availability of prey species such as krill and rockfish; chinook salmon abundance and sea lion pup mortality). The report also describes indices related to *human wellbeing,* such as fishery catches and socioeconomic vulnerability of fishing-dependent coastal communities. The report contains seven appendices that provide supplementary information, such as conceptual models and details about regional indicators.

Causes and Predictability of the 2011 to 2014 California Drought. National Oceanic and Atmospheric Administration (NOAA) (2014). http://cpo.noaa.gov/sites/cpo/MAPP/Task%20Forces/DTF/californiadrought/california_drought_report.pdf

Geographic Location: California
Type of Reference: Report

Abstract: The current drought is not part of a long-term change in California precipitation, which exhibits no appreciable trend since 1895. Key oceanic features that caused precipitation inhibiting atmospheric ridging off the West Coast during 2011-14 were symptomatic of natural internal atmosphere-ocean variability. Model simulations indicate that human-induced climate change increases California precipitation in mid-winter, with a low-pressure circulation anomaly over the North Pacific, opposite to conditions of the last three winters. The same model simulations indicate a decrease in spring precipitation over California. However, precipitation deficits observed during the past three years are an order of magnitude greater than the model simulated changes related to human-induced forcing. Nonetheless, record setting high temperature that accompanied this recent drought was likely made more extreme due to human-induced global warming.

Drivers of Climate Change

The Earth's climate is influenced by its own internal dynamics and by external factors (referred to as "forcings"), both natural and human-induced. Solar radiation and volcanic eruptions are natural forcings. Greenhouse gases and aerosols from combustion, agriculture and other human activities, and changes in land use are anthropogenic forcings recognized as drivers of climate change.

Greenhouse gases and aerosols

Greenhouse gases enhance the heat-trapping capacity of the Earth's atmosphere. Globally, human emissions of these gases have been increasing since the Industrial Revolution, primarily from power plant electricity generation and from the combustion of fossil fuels for transportation. The primary greenhouse gases are carbon dioxide (CO_2), methane, halogenated hydrocarbons, nitrous oxide, and ozone-depleting gases with varying global warming potentials. Human activities also produce aerosols, which can have either a cooling effect by reflecting incoming sunlight away from the Earth (sulfate particles), or a warming effect, by absorbing incoming sunlight and trapping heat in the atmosphere (black soot).

The amount of CO_2 in the atmosphere is controlled by the flow of carbon between the atmosphere, ocean and biosphere. The burning of fossil fuels and changes in landscape have moved carbon from ocean sediments and terrestrial environments and mobilized it into the atmosphere. CO_2 and methane in the atmosphere can change fundamental chemical and physical properties of the atmosphere and oceans. Increasing amounts of CO_2 have dissolved in sea water, making the oceans more acidic. Hence, anthropogenic climate change can in part be thought of as an enormous perturbation in the global carbon cycle.

The relative contribution of waste heat from power plants to global warming. Zevenhoven R and Beyene A (2011). *Energy*, 36(6): 3754-3762. http://www.sciencedirect.com/science/article/pii/S0360544210005694

Geographic Location: Global, with California example
Type of Reference: Review Article

Abstract: Evidence on global climate change, being caused primarily by rising levels of greenhouse gases in the atmosphere, is perceived as fairly conclusive. It is generally attributed to the enhanced greenhouse effect, resulting from higher levels of trapped heat radiation by increasing atmospheric concentrations of gases such as carbon dioxide (CO_2). Much of these gases originate from power plants and fossil fuel combustion. However, the fate of vast amounts of waste heat rejected into the environment has evaded serious scholarly research. While one kilowatt-hour (kWh) electricity generation in a typical condensing coal-fired power plant emits around

1 kilogram (kg) of CO_2, it also puts about two kWh energy into the environment as low-grade heat. For nuclear (fission) electricity the waste heat release per kWh is somewhat higher despite much lower CO_2 releases. This paper evaluates the impact of waste heat rejection combined with CO_2 emissions using Finland and California as case examples. The immediate effects of waste heat release from power production and radiative forcing by CO_2 are shown to be similar. However, the long-term (hundred years) global warming by CO_2-caused radiative forcing is about twenty-five times stronger than the immediate effects, being responsible for around 92 percent of the heat-up caused by electricity production.

The mixing state of carbonaceous aerosol particles in northern and southern California measured during CARES and CalNex 2010. Cahill JF, Suski K, Seinfeld JH, Zaveri RA and Prather KA (2012). *Atmospheric Chemistry and Physics*, 12(22): 10989-11002. http://dx.doi.org/10.5194/acp-12-10989-2012

Geographic Location: California
Type of Reference: Research Paper

Abstract: Carbonaceous aerosols impact climate directly by scattering and absorbing radiation, and hence play a major, although highly uncertain, role in global radiative forcing. Commonly, ambient carbonaceous aerosols are internally mixed with secondary species such as nitrate, sulfate, and ammonium, which influences their optical properties, hygroscopicity, and atmospheric lifetime, thus impacting climate forcing. Aircraft-aerosol time-of-flight mass spectrometry (A-ATOFMS), which measures single-particle mixing state, was used to determine the fraction of organic and soot aerosols that are internally mixed and the variability of their mixing state in California during the Carbonaceous Aerosols and Radiative Effects Study (CARES) and the Research at the Nexus of Air Quality and Climate Change (CalNex) field campaigns in the late spring and early summer of 2010. Nearly 88 percent (%) of all A-ATOFMS measured particles (100-1000 nanometers in diameter) were internally mixed with secondary species, with 96% and 75% of particles internally mixed with nitrate and/or sulfate in southern and northern California, respectively. Even though atmospheric particle composition in both regions was primarily influenced by urban sources, the mixing state was found to vary greatly, with nitrate and soot being the dominant species in southern California, and sulfate and organic carbon in northern California. Furthermore, mixing state varied temporally in northern California, with soot becoming the prevalent particle type towards the end of the study as regional pollution levels increased. The results from these studies demonstrate that the majority of ambient carbonaceous particles in California are internally mixed and are heavily influenced by secondary species that are most prevalent in the particular region. Based on these findings, considerations of regionally dominant sources and secondary species, as well as temporal variations of aerosol physical and optical properties, will be required to obtain more accurate predictions of the climate impacts of aerosol in California.

On the sources of methane to the Los Angeles atmosphere. Wennberg PO, Mui W, Wunch D, Kort EA, Blake DR, Atlas EL, et al. (2012). *Environmental Science and Technology*, 46(17): 9282-9289. http://pubs.acs.org/doi/abs/10.1021/es301138y

Geographic Location: California/Southern Air Basin
Type of Reference: Research Paper

Abstract: We use historical and new atmospheric trace gas observations to refine the estimated source of methane (CH_4) emitted into California's South Coast Air Basin (the larger Los Angeles metropolitan region). Referenced to the California Air Resources Board (CARB) greenhouse gas emissions inventory, total CH_4 emissions are 0.44 ± 0.15 teragrams (Tg) each year. To investigate the possible contribution of fossil fuel emissions, we use ambient air observations of methane (CH_4), ethane (C_2H_6), and carbon monoxide (CO), together with measured C_2H_6 to CH_4 enhancement ratios in the Los Angeles natural gas supply. The observed atmospheric C_2H_6 to CH_4 ratio during the ARCTAS (2008) and CalNex (2010) aircraft campaigns is similar to the ratio of these gases in the natural gas supplied to the basin during both these campaigns. Thus, at the upper limit (assuming that the only major source of atmospheric C_2H_6 is fugitive emissions from the natural gas infrastructure) these data are consistent with the attribution of most (0.39 ± 0.15 Tg per year) of the excess CH_4 in the basin to uncombusted losses from the natural gas system (approximately 2.5-6% of natural gas delivered to basin customers). However, there are other sources of C_2H_6 in the region. In particular, emissions of C_2H_6 (and CH_4) from natural gas seeps as well as those associated with petroleum production, both of which are poorly known, will reduce the inferred contribution of the natural gas infrastructure to the total CH_4 emissions, potentially significantly. This study highlights both the value and challenges associated with the use of ethane as a tracer for fugitive emissions from the natural gas production and distribution system.

Overview of the 2010 Carbonaceous Aerosols and Radiative Effects Study (CARES). Zaveri RA, Shaw WJ, Cziczo DJ, Schmid B, Ferrare RA, Alexander ML, et al. (2012). *Atmospheric Chemistry and Physics*, 12(16): 7647-7687. http://www.atmos-chem-phys.net/12/7647/2012/

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: Substantial uncertainties still exist in the scientific understanding of the possible interactions between urban and natural (biogenic) emissions in the production and transformation of atmospheric aerosol and the resulting impact on climate change. The US Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program's Carbonaceous Aerosol and Radiative Effects Study (CARES) carried out in June 2010 in Central Valley, California, was a comprehensive effort designed to improve this understanding. The primary objective of the field study was to investigate the evolution of secondary organic and black carbon aerosols and their climate-related properties in the Sacramento urban plume as it was routinely transported into the forested Sierra Nevada foothills area. Urban aerosols and trace gases experienced significant physical and chemical transformations as they mixed with the reactive

biogenic hydrocarbons emitted from the forest. Two heavily-instrumented ground sites-one within the Sacramento urban area and another about 40 kilometers (km) to the northeast in the foothills area-were set up to characterize the evolution of meteorological variables, trace gases, aerosol precursors, aerosol size, composition, and climate-related properties in freshly polluted and "aged" urban air. On selected days, the DOE G-1 aircraft was deployed to make similar measurements upwind and across the evolving Sacramento plume in the morning and again in the afternoon. The NASA B-200 aircraft, carrying remote sensing instruments, was also deployed to characterize the vertical and horizontal distribution of aerosols and aerosol optical properties within and around the plume. This overview provides: (a) the scientific background and motivation for the study, (b) the operational and logistical information pertinent to the execution of the study, (c) an overview of key observations and initial findings from the aircraft and ground-based sampling platforms, and (d) a roadmap of planned data analyses and focused modeling efforts that will facilitate the integration of new knowledge into improved representations of key aerosol processes and properties in climate models.

Emission ratios of anthropogenic volatile organic compounds in northern mid-latitude megacities: Observations versus emission inventories in Los Angeles and Paris. Borbon A, Gilman JB, Kuster WC, Grand N, Chevaillier S, Colomb A, et al. (2013). *Journal of Geophysical Research D: Atmospheres*, 118(4): 2041-2057. http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50059/abstract

Geographic Locations: California and France
Type of Reference: Research Paper

Abstract: Ground-based and airborne volatile organic compound (VOC) measurements in Los Angeles, California, and Paris, France, during the Research at the Nexus of Air Quality and Climate Change (CalNex) and Megacities: Emissions, Urban, Regional and Global Atmospheric Pollution and Climate Effects, and Integrated Tools for Assessment and Mitigation (MEGAPOLI) campaigns, respectively, are used to examine the spatial variability of the composition of anthropogenic VOC urban emissions and to evaluate regional emission inventories. Two independent methods that take into account the effect of chemistry were used to determine the emission ratios of anthropogenic VOCs (including anthropogenic isoprene and oxygenated VOCs) over carbon monoxide (CO) and acetylene. Emission ratios from both methods agree within ±20 percent (%), showing the reliability of our approach. Emission ratios for alkenes, alkanes, and benzene are fairly similar between Los Angeles and Paris, whereas the emission ratios for C7-C9 aromatics in Paris are higher than in Los Angeles and other French and European Union urban areas by a factor of two-to-three. The results suggest that the emissions of gasoline-powered vehicles still dominate the hydrocarbon distribution in northern mid-latitude urban areas, which disagrees with emission inventories. However, regional characteristics like the gasoline composition could affect the composition of hydrocarbon emissions. The observed emission ratios show large discrepancies by a factor of two-to-four (alkanes and oxygenated VOC) with the ones derived from four reference emission databases. A bias in CO emissions was also evident for both megacities. Nevertheless, the difference between measurements and inventory in terms

of the overall hydroxide (OH) reactivity is, in general, lower than 40%, and the potential to form secondary organic aerosols (SOA) agrees within 30% when considering volatile organic emissions as the main SOA precursors.

Nitrous oxide (N_2O) emissions from California based on 2010 CalNex airborne measurements. Xiang B, Miller SM, Kort EA, Santoni GW, Daube BC, Commane R, et al. (2013). *Journal of Geophysical Research-Atmospheres*, 118(7): 2809-2820. http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50189/abstract

Geographic Location: California
Type of Reference: Research Paper

Abstract: Nitrous oxide (N_2O) is an important gas for climate and for stratospheric chemistry, with a lifetime exceeding 100 years. Global concentrations have increased steadily since the 18th century, apparently due to human-associated emissions, principally from the application of nitrogen fertilizers. However, quantitative studies of agricultural emissions at large spatial scales are lacking, inhibited by the difficulty of measuring small enhancements in atmospheric concentration. Here we derive regional emission rates for N_2O in the agricultural heartland of California based on analysis of in-situ airborne atmospheric observations collected using a new quantum cascade laser spectrometer. The data were obtained on board the NOAA WP-3 research aircraft during the CalNex (California Research at the Nexus of Air Quality and Climate Change) program in late spring 2010. We coupled the WRF (weather research and forecasting) model, a meso-scale meteorology model, with the STILT (stochastic time-inverted Lagrangian transport) model, a Lagrangian particle dispersion model, to link our in-situ airborne observations to surface emissions. We then used a variety of statistical methods to identify source areas and to optimize emission rates. Our results are consistent with the view that fertilizer application is the largest source of N_2O in the Central Valley. The spatial distribution of surface emissions, based on California land use and activity maps, was very different than indicated in the leading emission inventory (EDGAR 4.0). Our estimated total emission flux of N_2O for California in May and June was three-to- four times larger than the annual mean given for the state by EDGAR and other inventories, indicating a strong seasonal variation. We estimated the statewide total annual emissions of N_2O to be 0.042 +/- 0.011 teragrams nitrogen per year (Tg N/year), roughly equivalent to inventory values if we account for seasonal variations using observations obtained in the midwestern United States. This state total N_2O emission is 20.5 Tg carbon dioxide (CO_2) equivalent (100 year global warming potential=310 CO_2 equivalent per gram N_2O), accounting for approximately four percent of the state total greenhouse gas emissions.

Forests and carbon cycling

Forests are an important component of the global carbon cycle. They withdraw carbon from the atmosphere through photosynthesis and release it to the atmosphere through both plant and microbial respiration. Disturbance such as stand-replacing fire can release large amounts of CO_2 from forests but forest carbon stocks will usually fully recover over the life cycle of the forest. Humans affect forest carbon dynamics

indirectly by altering disturbance regimes, increasing atmospheric CO_2 and nitrogen deposition, and changing global and regional climate.

Climate change impacts and carbon in U.S. national parks. Gonzalez P (2011). *Park Science*, 28(2). http://www.nature.nps.gov/parkscience/Archive/PDF/Article_PDFs/ParkScience28(2)Summer2011_10-15_Gonzalez_2804.pdf

Geographic Location: United States, including California
Type of Reference: Review Article

Abstract: New spatial analyses of climate data and 123 peer-reviewed scientific publications document impacts of climate change and carbon stocks and emissions in the U.S. National Park System. Ninety-six percent of land administered by the National Park Service (NPS) is located in areas of observed warming in the 20th century, with an average mean annual temperature increase of 0.6 ± 0.5°Celsius (1.1 ± 0.9°Fahrenheit). Scientific evidence attributes this warming to human greenhouse gas emissions. Field measurements in national parks have detected glacial melt, decreased snowfall and snowpack, earlier spring warmth and streamflow, sea-level rise, increased conifer mortality, and shifts of vegetation biomes, small-mammal ranges, and winter bird ranges. Analyses attribute these impacts to climate change. In California, the National Park Service manages ecosystems with some of the highest forest carbon densities in the world. Carbon emissions from fossil fuel use in parks that cover 10 percent of system area are equivalent to the emissions of a U.S. city of 21,000 people. These published scientific results provide national parks with information for vulnerability analyses of key resources, adaptation of resource management, and the reduction of climate change through forest conservation and management and energy conservation and efficiency.

Woodland expansion's influence on belowground carbon and nitrogen in the Great Basin U.S. Rau BM, Johnson DW, Blank RR, Tausch RJ, Roundy BA, Miller RF, et al. (2011). *Journal of Arid Environments*, 75(9): 827-835. http://www.sciencedirect.com/science/article/pii/S0140196311001078

Geographic Location: Western United States
Type of Reference: Research Paper

Abstract: Vegetation changes associated with climate shifts and anthropogenic disturbance can have major impacts on biogeochemical cycling and soils. Much of the Great Basin, U.S. is currently dominated by sagebrush (*Artemisia tridentate (Rydb.) Boivin*) ecosystems. Sagebrush ecosystems are increasingly influenced by pinyon (*Pinus monophylla* Torr & Frém *and Pinus edulis* Engelm.) and juniper (*Juniperus osteosperma* Torr. and *Juniperus occidentalis* Hook.) expansion. Some scientists and policy makers believe that increasing woodland cover in the intermountain western U.S. offers the possibility of increased organic carbon (OC) storage on the landscape; however, little is currently known about the distribution of OC on these landscapes, or the role that nitrogen (N) plays in OC retention. We quantified the relationship between

tree cover, belowground OC, and total below ground N in expansion woodlands at 13 sites in Utah, Oregon, Idaho, California, and Nevada, USA. One hundred and twenty nine soil cores were taken using a mechanically driven diamond tipped core drill to a depth of 90 cm (centimeters). Soil, coarse fragments, and coarse roots were analyzed for OC and total N. Woodland expansion influenced the vertical distribution of root OC by increasing 15-30 cm root OC by 2.6 $Mgha^{-1}$ (megagrams per hectare) and root N by 0.04 $Mgha^{-1}$. Root OC and N increased through the entire profile by 3.8 and 0.06 $Mgha^{-1}$ respectively. Woodland expansion influenced the vertical distribution of soil OC by increasing surface soil (0-15 cm) OC by 2.2 $Mgha^{-1}$. Woodland expansion also caused a 1.3 $Mgha^{-1}$ decrease in coarse fragment associated OC from 75-90 cm. Our data suggests that woodland expansion into sagebrush ecosystems has limited potential to store additional belowground OC, and must be weighed against the risk of increased wildfire and exotic grass invasion.

Estimating California ecosystem carbon change using process model and land cover disturbance data: 1951-2000. Liu JX, Vogelmann JE, Zhu ZL, Key CH, Sleeter BM, Price DT, et al. (2011). *Ecological Modelling*, 222(14): 2333-2341. http://www.sciencedirect.com/science/article/pii/S0304380011001943

Geographic Location: California
Type of Reference: Research Paper

Abstract: Land use change, natural disturbance, and climate change directly alter ecosystem productivity and carbon (C) stock level. The estimation of ecosystem carbon dynamics depends on the quality of land cover change data and the effectiveness of the ecosystem models that represent the vegetation growth processes and disturbance effects. We used the Integrated Biosphere Simulator (IBIS) and a set of 30- to 60-meter resolution fire and land cover change data to examine the carbon changes of California's forests, shrublands, and grasslands. Simulation results indicate that during 1951-2000, the net primary productivity (NPP) increased by 7%, from 72.2 to 77.1 teragrams of carbon per year (Tg C yr^{-1}) (1 teragram = 10^{12} grams), mainly due to carbon dioxide (CO_2) fertilization, since the climate hardly changed during this period. Similarly, heterotrophic respiration increased by 5%, from 69.4 to 73.1 Tg Cyr^{-1}, mainly due to increased forest soil carbon and temperature. Net ecosystem production (NEP) was highly variable in the 50-year period but on average equaled 3.0 Tg C yr^{-1} (total of 149 Tg C). As with NEP, the net biome production (NBP) was also highly variable but averaged – 0.55 Tg C yr^{-1} (total of -27.3 Tg C) because NBP in the 1980s was very low (-5.34 Tg C yr^{-1}). During the study period, a total of 126 Tg carbon were removed by logging and land use change, and 50 Tg carbon were directly removed by wildland fires. For carbon pools, the estimated total living upper canopy (tree) biomass decreased from 928 to 834 Tg C, and the understory (including shrub and grass) biomass increased from 59 to 63 Tg C. Soil carbon and dead biomass carbon increased from 1136 to 1197 Tg C. Our analyses suggest that both natural and human processes have significant influence on the carbon change in California. During 1951-2000, climate interannual variability was the key driving force for the large interannual changes of ecosystem carbon source and sink at the state level, while logging and fire were the dominant driving forces for carbon balances in several specific ecoregions. From a long-

term perspective, CO_2 fertilization plays a key role in maintaining higher NPP. However, our study shows that the increase in C sequestration by CO_2 fertilization is largely offset by logging/land use change and wildland fires.

A life cycle greenhouse gas inventory of a tree production system. Kendall A and McPherson EG (2012). *International Journal of Life Cycle Assessment*, 17(4): 444-452. http://dx.doi.org/10.1007/s11367-011-0339-x

Geographic Location: California
Type of Reference: Research Paper

Abstract: This study provides a detailed, process-based life cycle greenhouse gas (GHG) inventory of an ornamental tree production system for urban forestry. The success of large-scale tree planting initiatives for climate protection depends on projects being net sinks for carbon dioxide (CO_2) over their entire life cycle. However, previous assessments of urban tree planting initiatives have not accounted for the inputs required for tree production in nurseries, which include greenhouse systems, irrigation, and fertilization. A GHG inventory of nursery operations for tree production is a necessary step to assess the life cycle benefits or drawbacks of large-scale tree planting activities. Using surveys, interviews, and life cycle inventory databases, we developed a process-based life cycle inventory of GHG emissions for a large nursery operation in California, USA. The inventory demonstrated that 4.6 kilograms (kg) of CO_2-equivalent is emitted per #5 (nominally a 5- gallon) tree, a common tree size produced by nurseries. Energy use contributed 44 percent (%) of all CO_2-equivalent emissions, of which electricity and propane constituted 78%. Electricity use is dominated by irrigation demands, and propane is used primarily for greenhouse heating. Material inputs constituted the next largest contributor at 36% of emissions; plastic containers contributed just over half of these emissions. Transport emissions accounted for 16% of total nursery GHG emissions. Shipping bamboo stakes from China (43%) and diesel fuel consumed by nursery delivery trucks 33% were the largest transport emission sources. GHG emissions from the tree production life stage are 20% to 50% of mean annual CO_2 storage rates based on urban tree inventories for three California cities. While considering nursery production alone is insufficient for drawing conclusions about the net climate change benefits of tree planting initiatives, the results demonstrate that nursery production emissions are modest compared with CO_2 storage rates during tree life. Identifying key sources of emissions in the nursery tree production system can help operators reduce emissions by targeting so-called hot- spots. In particular, switching to renewable energy sources, capitalizing on energy and water efficiency opportunities, container light-weighting, and sourcing bamboo stakes from producers closer to the point of use are potential avenues for reduced emissions.

Post-fire management regimes affect carbon sequestration and storage in a Sierra Nevada mixed conifer forest. Powers EM, Marshall JD, Zhang J and Wei L (2013). *Forest Ecology and Management*, 291: 268-277. http://www.sciencedirect.com/science/article/pii/S0378112712004513

See abstract in: *Wildfires*

Ocean acidification

Covering most of the Earth's surface, oceans are a vast reservoir for CO_2. Oceans absorb approximately one quarter of the CO_2 released into the atmosphere. As atmospheric levels of CO_2 increase, so do the levels in the ocean, changing the chemistry of seawater–a process called acidification. The ocean's role as a sink for CO_2 comes at a cost to marine life. Acidification presents a significant threat to marine ecosystems, particularly those that form shells and exoskeletons such as mollusks and coral.

High-frequency dynamics of ocean pH: A multi-ecosystem comparison. Hofmann GE, Smith JE, Johnson KS, Send U, Levin LA, Micheli F, et al. (2011). *PLoS ONE*, 6(12): e28983. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0028983

Geographic Location: Global oceans (with California coast -specific data)
Type of Reference: Research Paper

Abstract: The effect of Ocean Acidification (OA) on marine biota is quasi-predictable at best. While perturbation studies, in the form of incubations under elevated carbon dioxide partial pressure (pCO_2), reveal sensitivities and responses of individual species, one missing link in the OA story results from a chronic lack of pH data specific to a given species' natural habitat. Here, we present a compilation of continuous, high-resolution time series of upper ocean pH, collected using autonomous sensors, over a variety of ecosystems ranging from polar to tropical, open-ocean to coastal, kelp forest to coral reef. These observations reveal a continuum of month-long pH variability with standard deviations from 0.004 to 0.277 and ranges spanning 0.024 to 1.430 pH units. The nature of the observed variability was also highly site-dependent, with characteristic diel, semi-diurnal, and stochastic patterns of varying amplitudes. These biome-specific pH signatures disclose current levels of exposure to both high and low dissolved CO_2, often demonstrating that resident organisms are already experiencing pH regimes that are not predicted until 2100. Our data provide a first step toward crystallizing the biophysical link between environmental history of pH exposure and physiological resilience of marine organisms to fluctuations in seawater CO_2. Knowledge of this spatial and temporal variation in seawater chemistry allows us to improve the design of OA experiments: we can test organisms with a priori expectations of their tolerance guardrails, based on their natural range of exposure. Such hypothesis-testing will provide a deeper understanding of the effects of OA. Both intuitively simple to understand and powerfully informative, these and similar comparative time series can help guide management efforts to identify areas of marine habitat that can serve as

refugia to acidification as well as areas that are particularly vulnerable to future ocean change.

Decadal changes in the aragonite and calcite saturation state of the Pacific Ocean. Feely RA, Sabine CL, Byrne RH, Millero FJ, Dickson AG, Wanninkhof R, et al. (2012). *Global Biogeochemical Cycles*, 26. http://onlinelibrary.wiley.com/doi/10.1029/2011GB004157/abstract

Geographic Location: Pacific Ocean, Including California
Type of Reference: Research Paper

Abstract: Based on measurements from the WOCE/JGOFS global carbon dioxide (CO_2) survey, the CLIVAR/CO_2 Repeat Hydrography Program and the Canadian Line P survey, we have observed an average decrease of 0.34 percent (%) per year in the saturation state of surface seawater in the Pacific Ocean with respect to aragonite and calcite. The upward migrations of the aragonite and calcite saturation horizons, averaging about one-to-two meters per year, are the direct result of the uptake of anthropogenic CO_2 by the oceans and regional changes in circulation and biogeochemical processes. The shoaling of the saturation horizon is regionally variable, with more rapid shoaling in the South Pacific where there is a larger uptake of anthropogenic CO_2. In some locations, particularly in the North Pacific Subtropical Gyre and in the California Current, the decadal changes in circulation can be the dominant factor in controlling the migration of the saturation horizon. If CO_2 emissions continue as projected over the rest of this century, the resulting changes in the marine carbonate system would mean that many coral reef systems in the Pacific would no longer be able to sustain a sufficiently high rate of calcification to maintain the viability of these ecosystems as a whole, and these changes perhaps could seriously impact the thousands of marine species that depend on them for survival.

Decadal water-property trends in the California Undercurrent, with implications for ocean acidification. Meinvielle M and Johnson GC (2013). *Journal of Geophysical Research-Oceans*, 118(12): 6687-6703. http://onlinelibrary.wiley.com/doi/10.1002/2013JC009299/abstract

Geographic Location: Pacific Ocean/West Coast United States
Type of Reference: Research Paper

Abstract: This study uses data along the West Coast of North America to analyze the spatial and temporal evolution of water properties to around 500 m depth. The analysis uses potential density (sigma) as the vertical coordinate and bottom depth and latitude as the horizontal coordinates. The study uses historical data from the World Ocean Database 2009 from 25 degrees north (N) to 50 degrees N and 1950-2012 for a large-scale analysis of water-property spatial structure and temporal trends in the California Current System (CCS), finding significant trends from 1980 to 2012 along density surfaces near the core of the California Undercurrent (CUC), including decreasing dissolved oxygen (DO) concentration, increasing warmth and salinity, and decreasing potential vorticity. All these changes are consistent with an increasing influence of

Pacific equatorial waters with time. Mixing characteristics along the core of the CUC (sigma=26.5 kilograms per cubic meter) reveal that the 1980-2012 trends in the water-mass properties in the CUC are mostly consistent with a northward shift of these properties, with additional decreases in DO concentration. These modifications are associated with the shoaling and strengthening of the CUC. The changes also imply increased ocean total (natural and anthropogenic) acidification, as the trend in the DO concentration is consistent with a natural decrease in pH all along the CUC, suggesting that significantly more acidic waters are feeding upwelling onto the shelf around 2012 than around 1980.

Exploring local adaptation and the ocean acidification seascape—studies in the California Current Large Marine Ecosystem. Hofmann GE, Evans TG, Kelly MW, Padilla-Gamino JL, Blanchette CA, Washburn L, et al. (2014). *Biogeosciences*, 11(4): 1053-1064. http://www.biogeosciences.net/11/1053/2014/

Geographic Location: Pacific Ocean/California
Type of Reference: Research Paper

Abstract: The California Current Large Marine Ecosystem (CCLME), a temperate marine region dominated by episodic upwelling, is predicted to experience rapid environmental change in the future due to ocean acidification. The aragonite saturation state within the California Current System is predicted to decrease in the future with near-permanent undersaturation conditions expected by the year 2050. Thus, the CCLME is a critical region to study due to the rapid rate of environmental change that resident organisms will experience and because of the economic and societal value of this coastal region. Recent efforts by a research consortium - the Ocean Margin Ecosystems Group for Acidification Studies (OMEGAS) - has begun to characterize a portion of the CCLME; both describing the spatial mosaic of pH in coastal waters and examining the responses of key calcification-dependent benthic marine organisms to natural variation in pH and to changes in carbonate chemistry that are expected in the coming decades. In this review, we present the OMEGAS strategy of co-locating sensors and oceanographic observations with biological studies on benthic marine invertebrates, specifically measurements of functional traits such as calcification-related processes and genetic variation in populations that are locally adapted to conditions in a particular region of the coast. Highlighted in this contribution are (1) the OMEGAS sensor network that spans the west coast of the US from central Oregon to southern California, (2) initial findings of the carbonate chemistry amongst the OMEGAS study sites, and (3) an overview of the biological data that describes the acclimatization and the adaptation capacity of key benthic marine invertebrates within the CCLME.

Natural variability and anthropogenic change in equatorial Pacific surface ocean pCO_2 and pH. Sutton AJ, Feely RA, Sabine CL, McPhaden MJ, Takahashi T, Chavez FP, et al. (2014). *Global Biogeochemical Cycles*, 28(2): 2013GB004679. http://onlinelibrary.wiley.com/doi/10.1002/2013GB004679/abstract

Geographic Location: Pacific Ocean/Equatorial
Type of Reference: Research Paper

Abstract: The equatorial Pacific is a dynamic region that plays an important role in the global carbon cycle. This region is the largest oceanic source of carbon dioxide (CO_2) to the atmosphere, which varies interannually dependent on the El Niño-Southern Oscillation (ENSO) and other climatic and oceanic drivers. We present high-resolution observations of surface ocean CO_2 partial pressure (pCO_2) at four fixed locations in the Niño 3.4 area with data sets encompassing 10 ENSO warm and cold events from 1997 to 2011. The mooring observations confirm that ENSO controls much of the interannual variability in surface seawater pCO_2 with values ranging from 315 to 578 microatmospheres (µatm). The mooring time series also capture the temporal variability necessary to make the first estimates of long-term pH trends in the equatorial Pacific, which suggests that the combination of ocean acidification and decadal variability creates conditions for high rates of pH change since the beginning of the mooring record. Anthropogenic CO_2 increases play a dominant role in significant observed seawater pCO_2 trends of +2.3 to +3.3 µatm per year and pH trends of −0.0018 to −0.0026 per year across the full time series in this region. However, increased upwelling driven by increased trade winds, a shallower thermocline, and increased frequency of La Niña events also contribute an average of 40 percent of the observed trends since 1998. These trends are higher than previous estimates based on underway observations and suggest that the equatorial Pacific is contributing a greater amount of CO_2 to the atmospheric CO_2 inventory over the last decade.

Ocean acidification in the coastal zone from an organism's perspective: Multiple system parameters, frequency domains, and habitats. Waldbusser GG and Salisbury JE (2014). *Annual Review of Marine Science,* 6: 221-247. http://www.annualreviews.org/doi/abs/10.1146/annurev-marine-121211-172238

Geographic Location: Global Oceans, Including California
Type of Reference: Review Article

Abstract: Multiple natural and anthropogenic processes alter the carbonate chemistry of the coastal zone in ways that either exacerbate or mitigate ocean acidification effects. Freshwater inputs and multiple acid-base reactions change carbonate chemistry conditions, sometimes synergistically. The shallow nature of these systems results in strong benthic-pelagic coupling, and marine invertebrates at different life history stages rely on both benthic and pelagic habitats. Carbonate chemistry in coastal systems can be highly variable, responding to processes with temporal modes ranging from seconds to centuries. Identifying scales of variability relevant to levels of biological organization requires a fuller characterization of both the frequency and magnitude domains of processes contributing to or reducing acidification in pelagic and benthic habitats. We

review the processes that contribute to coastal acidification with attention to timescales of variability and habitats relevant to marine bivalves.

Climatic modulation of recent trends in ocean acidification in the California Current System. Turi G, Lachkar Z, Gruber N, and Münnich M (2016). *Environmental Research Letters*, 11(1): 014007.
http://iopscience.iop.org/article/10.1088/1748-9326/11/1/014007/meta

Geographic Location: California Current
Type of Reference: Research Paper

Abstract: We reconstruct the evolution of ocean acidification in the California Current System (CalCS) from 1979 through 2012 using hindcast simulations with an eddy-resolving ocean biogeochemical model forced with observation-based variations of wind and fluxes of heat and freshwater. We find that domain-wide pH and aragonite saturation state (Ω_{arag}) in the top 60 meters (m) of the water column decreased significantly over these three decades by about −0.02 per decade (decade^{-1}) and −0.12 decade^{-1}, respectively. In the nearshore areas of northern California and Oregon, ocean acidification is reconstructed to have progressed much more rapidly, with rates up to 30 percent (%) higher than the domain-wide trends. Furthermore, ocean acidification penetrated substantially into the thermocline, causing a significant domain-wide shoaling of the aragonite saturation depth of on average −33 m decade^{-1} and up to −50 m decade^{-1} in the nearshore area of northern California. This resulted in a coast-wide increase in nearly undersaturated waters and the appearance of waters with Ω_{arag} <1, leading to a substantial reduction of habitat suitability.

Averaged over the whole domain, the main driver of these trends is the oceanic uptake of anthropogenic CO_2 from the atmosphere. However, recent changes in the climatic forcing have substantially modulated these trends regionally. This is particularly evident in the nearshore regions, where the total trends in pH are up to 50% larger and trends in aragonite saturation state and in the aragonite saturation depth are even twice to three times larger than the purely atmospheric CO_2-driven trends. This modulation in the nearshore regions is a result of the recent marked increase in alongshore wind stress, which brought elevated levels of dissolved inorganic carbon to the surface via upwelling. Our results demonstrate that changes in the climatic forcing need to be taken into consideration in future projections of the progression of ocean acidification in coastal upwelling regions.

Land use

Human activities can affect regional climate through land use changes, such as deforestation, irrigation, and urbanization. Modifications to land surfaces affect the amount of solar radiation that is reflected by such surfaces back into space. For example, there is strong evidence that deforestation increases the reflection of sunlight and impacts local air temperature. Urbanization and the use of certain building materials (such as white roofs or dark pavements) reduce or increase the warming

associated with "urban heat islands." In addition to affecting the reflection or absorption of radiative energy, land use changes can impact surface temperatures as a result of altered surface roughness, latent heat flux (the transfer of heat from surface waters to the atmosphere), river runoff and irrigation.

Influence of irrigated agriculture on diurnal surface energy and water fluxes, surface climate, and atmospheric circulation in California. Kueppers LM and Snyder MA (2012). *Climate Dynamics*, 38(5-6): 1017-1029. http://link.springer.com/article/10.1007%2Fs00382-011-1123-0

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: The impact of land use change on regional climate can be substantial but also is variable in space and time. Past observational and modeling work suggests that in a 'Mediterranean' climate such as in California's Central Valley, the impact of irrigated agriculture can be large in the dry season but negligible in the wet season due to seasonal variation in surface energy partitioning. Here we report further analysis of regional climate model simulations showing that diurnal variation in the impact of irrigated agriculture on climate similarly reflects variation in surface energy partitioning, as well as smaller changes in net radiation. With conversion of natural vegetation to irrigated agriculture, statistically significant decreases of 4-8 Kelvin (K) at 2 meters (m) occurred at midday June-September, and small decreases of similar to 1 K occurred in winter months only in relatively dry years. This corresponded to reduced sensible heat flux of 100-350 watts per square meter (W m^{-2}) and increased latent heat fluxes of 200-450 W m^{-2} at the same times and in the same months. We also observed decreases of up to 1,500 meters in boundary layer height at midday in summer months, and marginally significant reductions in surface zonal wind speed in July and August at 19:00 PST. The large decrease in daytime temperature due to shifts in energy partitioning overwhelmed any temperature increase related to the reduced zonal sea breeze. Such changes in climate and atmospheric dynamics from conversion to (or away from) irrigated agriculture could have important implications for regional air quality in California's Central Valley.

How will land use affect air temperature in the surface boundary layer? Lessons learned from a comparative study on the energy balance of an oak savanna and annual grassland in California, USA. Baldocchi D and Ma SY (2013). *Tellus Series B-Chemical and Physical Meteorology*, 65. http://www.tellusb.net/index.php/tellusb/article/view/19994

Geographic Location: California
Type of Reference: Research Paper

Abstract: We investigated the effect of land use on differences in air temperature. We based our analysis on a decade of weather and energy flux measurements, collected over two contrasting landscapes, an oak savanna and an annual grassland, growing under the same climate conditions. Over the decade, the daily-averaged, potential air

temperature above the aerodynamically rougher and optically darker oak savanna was 0.5 degrees Celsius (C) warmer than that above the aerodynamically smoother and optically brighter annual grassland. However, air temperature differences were seasonal. Smallest differences in potential air temperature occurred towards the end of spring, when much of the soil moisture reservoir was depleted. Largest differences in potential air temperature occurred during the winter rain season when the grass was green and transpiring and when the trees were senescent or deciduous. To understand the effect of land use on the local climate, we examined the concomitant changes in net radiation, sensible and latent heat exchange, the aerodynamic roughness (R-a), the surface resistance to water transfer (R-s), aerodynamic surface temperature and the growth of the planetary boundary layer, with measurements and model computations. Overall, these biophysical variables provide us with mechanistic information to diagnose and predict how changes in air temperature will follow changes in land use or management. In conclusion, land use change is responsible for having a marked impact on the local climate of a region. At the local level, the change in the surface energy balance, towards a darker and rougher surface, will produce an additive increment to climate warming induced by a greater greenhouse gas burden in the atmosphere.

Changes in Climate

The atmosphere, land surface, glaciers, ice and other frozen surfaces, oceans and other bodies of water and living things make up the complex, interactive climate system. Climate, often defined as "average weather," is commonly measured in terms of temperature, precipitation, atmospheric pressure, and wind over a period of time (generally 30 years).

Temperature

Warming of the Earth's surface temperatures is the most widely reported direct observation of changes in climate. The global average temperature has increased by more than 1.4 degrees Fahrenheit (^{o}F) over the last century. In California, annual average air temperatures have increased by about 1.5 ^{o}F since 1895; minimum temperatures have increased at a rate almost twice as fast as the increase in maximum temperatures. Among the lines of evidence for a changing climate is the increased frequency of extreme climate events including record high temperatures. Extreme heat events are increasing in frequency in large cities and are responsible for a greater number of climate-related illnesses and deaths.

The relative contribution of waste heat from power plants to global warming. Zevenhoven R and Beyene A (2011). *Energy*, 36(6): 3754-3762. http://www.sciencedirect.com/science/article/pii/S0360544210005694

See abstract in: *Drivers of climate change: greenhouse gases and aerosols*

Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought. AghaKouchak A, Cheng L, Mazdiyasni O and Farahmand A (2014). *Geophysical Research Letters*: 41: 8847-8852. http://onlinelibrary.wiley.com/doi/10.1002/2014GL062308/abstract

Geographic Location: California
Type of Reference: Research Paper

Abstract: Global warming and the associated rise in extreme temperatures substantially increase the chance of concurrent droughts and heat waves. The 2014 California drought is an archetype of an event characterized by not only low precipitation but also extreme high temperatures. From the raging wildfires, to record low storage levels and snowpack conditions, the impacts of this event can be felt throughout California. Wintertime water shortages worry decision-makers the most because it is the season to build up water supplies for the rest of the year. Here we show that the traditional univariate risk assessment methods based on precipitation condition may substantially underestimate the risk of extreme events such as the 2014 California drought because of ignoring the effects of temperature. We argue that a multivariate viewpoint is necessary for assessing risk of extreme events, especially in a

warming climate. This study discusses a methodology for assessing the risk of concurrent extremes such as droughts and extreme temperatures.

Winter fog is decreasing in the fruit growing region of the Central Valley of California. Baldocchi D and Waller E (2014). *Geophysical Research Letters*, 41(9):3251-3256. http://onlinelibrary.wiley.com/doi/10.1002/2014GL060018/abstract

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: The Central Valley of California is home to a variety of fruit and nut trees. These trees account for 95 percent (%) of the U.S. production, but they need a sufficient amount of winter chill to achieve rest and quiescence for the next season's buds and flowers. In prior work, we reported that the accumulation of winter chill is declining in the Central Valley. We hypothesize that a reduction in winter fog is co-occurring and is contributing to the reduction in winter chill. We examined a 33 year record of satellite remote sensing to develop a fog climatology for the Central Valley. We find that the number of winter fog events, integrated spatially, decreased 46%, on average, over 32 winters, with much year to year variability. Less fog means warmer air and an increase in the energy balance on buds, which amplifies their warming, reducing their chill accumulation more.

Precipitation

A changing climate can directly influence the amount, intensity and frequency of snowfall, rainfall and other forms of precipitation. Large natural variability and strong geographic variations in these parameters are evident, and substantially affected by atmospheric circulation patterns such as the El Niño Southern Oscillation. Increased warming accelerates evaporation and increases the amount of water vapor in the atmosphere, resulting in certain areas getting wetter and others getting drier. Widespread increases in heavy precipitation events have occurred even in places where total amounts have decreased.

In California, statewide and regional trends in total precipitation have shown little change over the past century. Recent studies have examined changes in heavy precipitation patterns, including the nature of "atmospheric rivers," powerful winter systems that draw warm, wet air from the tropics near Hawaii and deliver unusually warm and unusually wet storms on the west coast of North America.

Inferring precipitation-anomaly gradients from tree rings. Meko DM, Stahle DW, Griffin D and Knight TA (2011). *Quaternary International*, 235: 89-100. http://www.sciencedirect.com/science/article/pii/S1040618210003654

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: Long-term information on gradients in precipitation-anomaly over tens to hundreds of kilometers is important to hydroclimatology for improved understanding of the spatiotemporal variability of moisture-delivery systems and runoff. Site-centered reconstructions of cool-season (November-April) precipitation at 36 *Quercus douglasii* tree-ring sites in the Central Valley of California, USA, are generated, regionalized, and evaluated for ability to track north south gradients in precipitation-anomaly. Event series are constructed for overall-wet (W), overall-dry (D), wetter-to-north (W/D) and wetter-to-south (D/W) conditions, from 1557-2001. Interesting features of the event series are clustering of W events in the 1780-1790s and a three-year run of D/W events in 1816-1818 (coincidentally following the eruption of Tambora in 1815). The most recent 25 years of the event series stand out for a high frequency of W and D events and low frequency of events associated with strong gradients in precipitation-anomaly. The five strongest W events in this period and seven of the nine W events since 1934 match El Niño years. Recent changes in the event series may be a Central-Valley footprint of a well-documented post-1976 change in the atmosphere-ocean climate system over the North Pacific. Similar studies may prove useful in other geographical areas where networks of tree-ring data sufficiently sensitive to precipitation are available.

Effects of atmospheric river landfalls on the cold season precipitation in California. Kim J, Waliser DE, Neiman PJ, Guan B, Ryoo JM and Wick GA (2013). *Climate Dynamics*, 40(1-2): 465-474. http://link.springer.com/article/10.1007%2Fs00382-012-1322-3

Geographic Location: California
Type of Reference: Research Paper

Abstract: Effects of atmospheric river (AR) landfalls in the California coast on the *cold-season* precipitation in California are examined for the cold seasons of 10 water years (WYs) 2001-2010 using observed data and regional modeling in conjunction with AR-landfall inventory based on visual inspections of precipitable water vapor (PWV) from remote sensing and reanalysis. The PWV in the SSM/I and SSMIS model retrievals and the ERA-Interim reanalysis shows 95 AR-landfall days in the California coast that are almost evenly split between the northern and southern coasts across 37.5 north (N). The CPC/NCEP gridded daily precipitation analysis shows that 10-30 percent of the cold-season precipitation totals in California have occurred during these AR landfalls. The analysis also reveals that the percentage of precipitation and the precipitation intensity during AR landfalls in California are characterized by strong north-to-south gradient. This north- south contrast in the AR precipitation is reversed for the non-AR precipitation in the coastal range. The frequency of AR landfalls and the cold-season precipitation totals in the Sierra Nevada region are only marginally correlated. Instead, AR landfalls are closely related with the occurrence of heavy precipitation events. The

freezing-level altitudes are systematically higher for AR wet days than non-AR wet days indicating warmer low-troposphere during AR storms. Cold season simulations for the 10 WYs 2001-2010 show that the Weather Research and Forecast (WRF) model can reasonably simulate important features in both the seasonal and AR precipitation totals. The daily pattern correlation coefficients between the simulated and ERA-Interim upper-air fields exceed 0.9 for most of the period. This suggests that the simulated temporal variations in the atmospheric circulation agree reasonably with the reanalysis over seasonal time scales, characteristics critical for reliable simulations of regional scale hydrologic cycle. The simulated seasonal and AR precipitation totals also agree reasonably with the CPC/NCEP precipitation analysis. The most notable model errors include the overestimation (underestimation) of the season-total and AR precipitation in the northern (southern) California region. The differences in the freezing- level altitudes during the AR- and non-AR wet days in the simulation agree with those from the ERA-Interim reanalysis. The freezing level altitudes are systematically overestimated in the simulations, suggesting warm biases in the low troposphere. Overall, WRF appears to perform reasonably in simulating the key features in the cold season precipitation related with AR landfalls, an important capability for assessing the impact of global climate variations and change on future hydrology in California.

Regional and local increases in storm intensity in the San Francisco Bay Area, USA, between 1890 and 2010. Russo TA, Fisher AT and Winslow DM (2013). *Journal of Geophysical Research D: Atmospheres*, 118(8): 3392-3401. http://onlinelibrary.wiley.com/doi/10.1002/2015GL066727/abstract

Geographic Location: California/San Francisco Bay Area
Type of Reference: Research Paper

Abstract: Studies of extreme precipitation have documented changes at the continental scale during the twentieth century, but few studies have quantified changes at small to regional spatial scales during the same time. We analyze historic data from over 600 precipitation stations in the San Francisco Bay Area (SFBA), California, to assess whether there have been statistically significant changes in extreme precipitation between 1890 and 2010. An annual exceedance probability analysis of extreme precipitation events in the SFBA, coupled with a Markov chain Monte Carlo algorithm, reveals an increase in the occurrence of large events. The depth-duration-frequency characteristics of maximum annual precipitation events having durations of 1 hour to 60 days indicate on average an increase in storm intensity in the last 120 years, with the intensity of the largest (least frequent) events increasing the most. Mean annual precipitation (MAP) also increased during the study period, but the relative increase in extreme event intensity exceeds that of MAP, indicating that a greater fraction of precipitation fell during large events. Analysis of data from subareas within the SFBA region indicates considerable heterogeneity in the observed nonstationarity; for example, the 5-day, 25-year event exceedance depth changed by +26 percent (%), +16%, and minus 1% in San Francisco, Santa Rosa, and San Jose, respectively. These results emphasize the importance of analyzing local data for accurate risk assessment, emergency planning, resource management, and climate model calibration.

Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought. AghaKouchak A, Cheng L, Mazdiyasni O and Farahmand A (2014). *Geophysical Research Letters*: 41: 8847-8852. http://onlinelibrary.wiley.com/doi/10.1002/2014GL062308/abstract

See abstract in *Changes in Climate: Temperature*

Running dry: The U.S. Southwest's drift into a drier climate state. Prein AF, Holland GJ, Rasmussen RM, Clark MP, and Tye MR (2016). *Geophysical Research Letters*. http://dx.doi.org/10.1002/2015GL066727

Geographic Location: U.S. Southwest
Type of Reference: Research Paper

Abstract: Changes in precipitation have far-reaching consequences on human society and ecosystems as has been demonstrated by recent severe droughts in California and the Oklahoma region. Droughts are beside tropical cyclones the most costly weather and climate related extreme events in the U.S. We apply a weather type (WT) analysis to reanalysis data from 1979–2014 that characterize typical weather conditions over the contiguous United States. This enables us to assign precipitation trends within 1980–2010 to changes in WT frequencies and changes in precipitation intensities. We show that in the North Atlantic and Midwest region precipitation intensity changes are the major driver of increasing precipitation trends. In the U.S. Southwest, however, WT frequency changes lead to a significant precipitation decrease of up to −25% related to an increase in anticyclonic conditions in the North East Pacific. This trend is partly counteracted by increasing precipitation intensities.

Drought

Drought is characterized by a period of abnormally dry weather long enough to cause a serious hydrological imbalance. Droughts can have significant impacts on the environment, agriculture, public health, the economy, and societies as a whole. Shortage of precipitation during the growing season impinges on crop production or ecosystem function in general (due to soil moisture drought). During the runoff and percolation season, precipitation deficits affect water supplies. In addition to reductions in precipitation, changes in soil moisture and groundwater are also affected by increases in evaporation and evapotranspiration.

Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought. AghaKouchak A, Cheng L, Mazdiyasni O and Farahmand A (2014). *Geophysical Research Letters*: 41: 8847-8852. http://onlinelibrary.wiley.com/doi/10.1002/2014GL062308/abstract

See abstract in *Changes in Climate: Temperature*

How unusual is the California drought? Griffin D and Anchukaitis K (2014).*Geophysical Research Letters,* 41, 9017-9023. http://onlinelibrary.wiley.com/doi/10.1002/2014GL062433/epdf

Geographic Location: California
Type of Reference: Research Paper

Abstract: For the past three years (2012–2014), California has experienced the most severe drought conditions in its last century. But how unusual is this event? Here we use two paleoclimate reconstructions of drought and precipitation for Central and Southern California to place this current event in the context of the last millennium. We demonstrate that while three-year periods of persistent below-average soil moisture are not uncommon, the current event is the most severe drought in the last 1200 years, with single year (2014) and accumulated moisture deficits worse than any previous continuous span of dry years. Tree ring chronologies extended through the 2014 growing season reveal that precipitation during the drought has been anomalously low but not outside the range of natural variability. The current California drought is exceptionally severe in the context of at least the last millennium and is driven by reduced though not unprecedented precipitation and record high temperatures.

The extraordinary California drought of 2013–2014: Character, context, and the role of climate change. Swain DL, Tsiang M, Haugen M, Singh D, Charland A, Rajaratnam B, and Diffenbaugh NS. (2014). *Bulletin American Meteorol Soc* 95(9):S3–S7. https://www2.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-of-2013-from-a-climate-perspective/

Geographic Location: California
Type of Reference: Research Paper

Abstract: California's driest 12-month period on record occurred during 2013-14, and although global warming has very likely increased the probability of certain large-scale atmospheric conditions, implications for extremely low precipitation in California remain uncertain.

Anthropogenic warming has increased drought risk in California. Diffenbaugh NS, Swain DL, and Touma D (2015). *PNAS,* 112(13): 3931-3936. http://www.pnas.org/content/112/13/3931.full.pdf

Geographic Location: California
Type of Reference: Research Paper

Abstract: California is currently in the midst of a record-setting drought. The drought began in 2012 and now includes the lowest calendar-year and 12-month precipitation, the highest annual temperature, and the most extreme drought indicators on record. The extremely warm and dry conditions have led to acute water shortages, groundwater overdraft, critically low streamflow, and enhanced wildfire risk. Analyzing historical climate observations from California, we find that precipitation deficits in California were

more than twice as likely to yield drought years if they occurred when conditions were warm. We find that although there has not been a substantial change in the probability of either negative or moderately negative precipitation anomalies in recent decades, the occurrence of drought years has been greater in the past two decades than in the preceding century. In addition, the probability that precipitation deficits co-occur with warm conditions and the probability that precipitation deficits produce drought have both increased. Climate model experiments with and without anthropogenic forcings reveal that human activities have increased the probability that dry precipitation years are also warm. Further, a large ensemble of climate model realizations reveals that additional global warming over the next few decades is very likely to create ∼100 percent probability that any annual-scale dry period is also extremely warm. We therefore conclude that anthropogenic warming is increasing the probability of co-occurring warm–dry conditions like those that have created the acute human and ecosystem impacts associated with the "exceptional" 2012–2014 drought in California.

Contribution of anthropogenic warming to California drought during 2012-2014. Williams AP, Seager R, Abatzoglou JT, Cook BI, Smerdon JE, and Cook ER (2015). *Geophysical Research Letters*, 42: 6819-6828. http://dx.doi.org/10.1002/2015GL064924

Geographic Location: California
Type of Reference: Research Article

Abstract: A suite of climate data sets and multiple representations of atmospheric moisture demand are used to calculate many estimates of the self-calibrated Palmer Drought Severity Index, a proxy for near-surface soil moisture, across California from 1901 to 2014 at high spatial resolution. Based on the ensemble of calculations, California drought conditions were record breaking in 2014, but probably not record breaking in 2012–2014, contrary to prior findings. Regionally, the 2012–2014 drought was record breaking in the agriculturally important southern Central Valley and highly populated coastal areas. Contributions of individual climate variables to recent drought are also examined, including the temperature component associated with anthropogenic warming. Precipitation is the primary driver of drought variability but anthropogenic warming is estimated to have accounted for 8–27 percent (%) of the observed drought anomaly in 2012–2014 and 5–18% in 2014. Although natural variability dominates, anthropogenic warming has substantially increased the overall likelihood of extreme California droughts.

Is climate change implicated in the 2013-2014 California drought? A hydrologic perspective. Mao Y, Nijssen B, and Lettenmaier DP (2015). *Geophysical Research Letters*, 42: 2805-2813.
http://onlinelibrary.wiley.com/doi/10.1002/2015GL063456/abstract

Geographic Location: California
Type of Reference: Research Paper

Abstract: California has experienced severe drought in 2012–2014 (which appears to be continuing into 2015), with especially low winter precipitation and mountain

snowpack in winter 2013–2014. However, the extent to which climate change is implicated in the drought, if at all, is not clear. By applying modeling and statistical approaches, we construct a historical record of California snowpack, runoff, and other hydrological variables of almost 100 years in length and use the reconstructed records to analyze climate trends in the Sierra Nevada and their impact on extreme drought events in the historic record. We confirm a general warming trend and associated decreasing trends in spring snowpack and runoff. We find that the warming may have slightly exacerbated some extreme events (including the 2013–2014 drought and the 1976–1977 drought of record), but the effect is modest; instead, these drought events are mainly the result of variability in precipitation.

How has human-induced climate change affected California drought risk? Cheng L, Hoerling M, AghaKouchak A, Livneh B, Quan XW, and Eischeid J (2016). *American Meteorological Society.* http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-15-0260.1

Geographic Location: California
Type of Reference: Research Paper

Abstract: The current California drought has cast a heavy burden on statewide agriculture and water resources, further exacerbated by concurrent extreme high temperatures. Furthermore, industrial-era global radiative forcing brings into question the role of long-term climate change with regard to California drought. How has human-induced climate change affected California drought risk? Here, observations and model experimentation are applied to characterize this drought employing metrics that synthesize drought duration, cumulative precipitation deficit, and soil moisture depletion. The model simulations show that increases in radiative forcing since the late nineteenth century induce both increased annual precipitation and increased surface temperature over California, consistent with prior model studies and with observed long-term change. As a result, there is no material difference in the frequency of droughts defined using bivariate indicators of precipitation and near-surface (10 centimeters) soil moisture, because shallow soil moisture responds most sensitively to increased evaporation driven by warming, which compensates the increase in the precipitation. However, when using soil moisture within a deep root zone layer (1 meter) as covariate, droughts become less frequent because deep soil moisture responds most sensitively to increased precipitation. The results illustrate the different land surface responses to anthropogenic forcing that are relevant for near-surface moisture exchange and for root zone moisture availability. The latter is especially relevant for agricultural impacts as the deep layer dictates moisture availability for plants, trees, and many crops. The results thus indicate that the net effect of climate change has made agricultural drought less likely and that the current severe impacts of drought on California's agriculture have not been substantially caused by long-term climate changes.

Extreme events

An extreme climate event is one which appears only rarely in the historical record, such as a 1-in-100 year flood or a three-day heat wave that is hotter than 95 percent of all previous 3-day heat waves. Changes in the frequency, intensity, spatial extent, duration and timing of extreme events can occur in a changing climate. Global evidence since 1950 indicates a change in some extremes (such as a decrease in the number of cold days and nights and an overall increase in the number of warm days and nights). Further, there is evidence of human influence on some extremes. However, determining whether a specific single extreme event is due to human influence is difficult. Extreme events usually result from a combination of factors, some strongly affected by human activities, some not. Nevertheless, climate models can be used to determine whether human influences have changed the likelihood of certain types of extreme events.

Has the magnitude of floods across the USA changed with global CO_2 levels?
Hirsch RM and Ryberg KR (2012). *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 57(1): 1-9.
http://www.tandfonline.com/doi/full/10.1080/02626667.2011.621895#.VyKVsHpvkvk

Geographic Location: United States
Type of Reference: Research Paper

Abstract: Statistical relationships between annual floods at 200 long-term (85-127 years of record) stream gauges in the coterminous United States and the global mean carbon dioxide concentration ($GMCO_2$) record are explored. The stream gauge locations are limited to those with little or no regulation or urban development. The coterminous US is divided into four large regions and stationary bootstrapping is used to evaluate if the patterns of these statistical associations are significantly different from what would be expected under the null hypothesis that flood magnitudes are independent of $GMCO_2$. In none of the four regions defined in this study is there strong statistical evidence for flood magnitudes increasing with increasing $GMCO_2$. One region, the southwest, showed a statistically significant negative relationship between $GMCO_2$ and flood magnitudes. The statistical methods applied compensate both for the inter-site correlation of flood magnitudes and the shorter-term (up to a few decades) serial correlation of floods.

Regional and local increases in storm intensity in the San Francisco Bay Area, USA, between 1890 and 2010. Russo TA, Fisher AT and Winslow DM (2013). *Journal of Geophysical Research D: Atmospheres*, 118(8): 3392-3401.
http://onlinelibrary.wiley.com/doi/10.1002/2015GL066727/abstract

See abstract in *Changes in Climate: Precipitation*

Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought. AghaKouchak A, Cheng L, Mazdiyasni O and Farahmand A (2014). *Geophysical Research Letters*: 41: 8847-8852. http://onlinelibrary.wiley.com/doi/10.1002/2014GL062308/abstract

See abstract in *Changes in Climate: Temperature*

Impacts of Climate Change on Physical Systems

Physical systems include the ocean, coastal and freshwater systems and the cryosphere (snow, ice and frozen ground). These systems are intricately linked to climate and to each other. Observed changes in these systems may reflect a response to long-term climate change or to patterns of natural climate variability, such as the El Niño/La Niña Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation or all of them. Examples of impacts include erosion, sea level rise, salt water intrusion, and changes in snowmelt runoff. Many of these observed changes are the direct result of rising temperatures. This chapter lists publications on: changes in ocean temperature and circulation; upwelling; sea level rise; and snowmelt and other freshwater impacts.

Changes in ocean temperature and circulation

The ocean plays an important role in climate variability and change. Ocean circulation transfers heat from the oceans to the atmosphere, and distributes heat between the equatorial and polar region. Ocean processes vary over a broad range of time scales. The main modes of climate variability most relevant to California are the ENSO and the PDO. ENSO is an ocean-atmosphere system in the tropical Pacific marked by El Niño events, which occur about every three to seven years and bring warm rainy weather, alternating with periods of below-average temperatures (La Niña). The more northerly PDO, an atmospheric circulation pattern, is often described as a long-lived El Niño-like pattern, extending from 20 to 40 years. Its extreme phases are classified as being either warm or cool, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean.

Global ocean temperatures have been increasing. The oceans have absorbed an estimated 84 percent of the heat added to the atmosphere between 1955 and 2008, increasing the average temperature of the upper 700 meters of water by 0.2^{o}Celsius (0.36^{o}F). Observed temperature increases around the globe have been uneven, as they are governed by atmospheric factors (such as wind speed and air temperature) and oceanic processes (such as currents and vertical mixing).[1]

Evidence for Changes to the Northeast Pacific Wave Climate. Seymour RJ (2011). *Journal of Coastal Research*, 27(1): 194-201.
http://www.bioone.org/doi/abs/10.2112/JCOASTRES-D-09-00149.1

Geographic Location: Pacific Ocean/West Coast United States
Type of Reference: Research Paper

[1] U.S. Global Change Research Program (2012). *Oceans and Marine Resources in a Changing Climate: Technical Input to the 2013 National Climate Assessment.*

Abstract: A large database of deep water wave buoy measurements over a 24-year period is created for four regions comprising the West Coast of the United States. The regional monthly mean significant wave height (MMSWH) is selected as the defining wave climate parameter and averaging multiple data sources within a region is found to significantly reduce data gaps. Two 12-year periods are compared, showing significant temporal variability but high correlation between regions, allowing the further collapse of the data to a northern and a southern region. Correlations between MMSWH records with three global-scale climate indices are investigated and only the North Pacific Index (NPI), a measure of atmospheric pressure in the Gulf of Alaska, shows strong correlation. The Multivariate ENSO Index (MET) is less correlated and the Pacific Decadal Index (PDO), which is a measure of ocean surface temperature, provides no significant correlation.

A method for displaying multiple correlations is developed that shows the mean of all MMSWH records that occur at unique temporal combinations of two climate indices. The graphics depicting the mean wave height as a function of NPI and MET for the two 12-year periods are shown to be very instructive in establishing why the two periods are so different. On the contrary, the same procedure with PDO substituted for MEI produces uniform distributions with little interpretive value.

Century-scale variation in the climate indices is investigated, and significant linear trends are found for NPI and MET, both consistent with causing increases in mean wave energy in these regions. Causal relationships for the observed correlations are discussed, and conclusions are reached indicating that global warming is a likely contributor to observed increases in wave intensity in the North Pacific.

Ecoregional analysis of nearshore sea-surface temperature in the North Pacific. Payne MC, Brown CA, Reusser DA and Lee Ii H (2012). *PLoS ONE*, 7(1). http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0030105

Geographic Location: Pacific Ocean/North Pacific Coastline
Type of Reference: Research Paper

Abstract: The quantification and description of sea surface temperature (SST) is critically important because it can influence the distribution, migration, and invasion of marine species; furthermore, SSTs are expected to be affected by climate change. To better understand present temperature regimes, we assembled a 29-year nearshore time series of mean monthly SSTs along the North Pacific coastline using remotely-sensed satellite data collected with the Advanced Very High Resolution Radiometer (AVHRR) instrument. We then used the dataset to describe nearshore (<20 kilometers offshore) SST patterns of 16 North Pacific ecoregions delineated by the Marine Ecoregions of the World (MEOW) hierarchical schema. Annual mean temperature varied from 3.8°Celsius (C) along the Kamchatka ecoregion to 24.8°C in the Cortezian ecoregion. There are smaller annual ranges and less variability in SST in the Northeast Pacific relative to the Northwest Pacific. Within the 16 ecoregions, 31-94 percent (%) of the variance in SST is explained by the annual cycle, with the annual cycle explaining the least variation in the Northern California ecoregion and the most variation in the

Yellow Sea ecoregion. Clustering on mean monthly SSTs of each ecoregion showed a clear break between the ecoregions within the Warm and Cold Temperate provinces of the MEOW schema, though several of the ecoregions contained within the provinces did not show a significant difference in mean seasonal temperature patterns. Comparison of these temperature patterns shared some similarities and differences with previous biogeographic classifications and the Large Marine Ecosystems (LMEs). Finally, we provide a web link to the processed data for use by other researchers.

Synthesis of Pacific Ocean Climate & Ecosystem Dynamics. Di Lorenzo E, Combes V, Keister J, Strub T, Franks TA, et al. (2013). *Oceanograpy,* 26(4):68-81. http://tos.org/oceanography/article/synthesis-of-pacific-ocean-climate-and-ecosystem-dynamics

Geographic Location: Northeast Pacific Ocean, including California
Type of Reference: Report

Abstract: The goal of the Pacific Ocean Boundary Ecosystem Climate Study (POBEX) was to diagnose the large-scale climate controls on regional transport dynamics and lower-trophic marine ecosystem variability in Pacific Ocean boundary systems. An international team of collaborators shared observational and eddy-resolving modeling datasets in the Northeast Pacific (NEP) including the Gulf of Alaska (GOA) and California Current System (CCS), the Humboldt or Peru-Chile Current System (PCCS), and the Kuroshio-Oyashio Extension (KOE) region. POBEX found that a dominant fraction of decadal variability in basin and regional-scale salinity, nutrients, chlorophyll, and zooplankton taxa is explained by a newly discovered pattern of ocean-climate variability dubbed the North Pacific Gyre Oscillation (NPGO), and the Pacific Decadal Oscillation (PDO).

NPGO dynamics originate in the tropics and resect the decadal expression of central Pacific El Niños (CP-Niño), much as the PDO captures the low-frequency expression of eastern Pacific El Niños (EP-Niño). By combining hindcasts of eddy-resolving ocean models over the period 1950-2008 with model passive tracers and long-term observations (e.g., CalCOFI, Line-P,Newport and Odate Collection), POBEX showed that the PDO and NPGO combine to control low-frequency upwelling and alongshore transport dynamics in the North Pacific section, while the EP-Niño dominates in the South Pacific. Although different climate modes have different regional expressions, changes in vertical transport (e.g. upwelling) were found to explain the dominant nutrient and phytoplankton variability in the CCS, GOA and PCCS, while changes in alongshore transport forced much of the observed long-term changes in zooplankton species composition in the KOE, the northern and southern CCS. In contrast, cross-shelf transport dynamics were linked to mesoscale eddy activity and driven by regional-scale dynamics that are largely decoupled from variations associated with the large-scale climate modes. Indeed, preliminary findings suggested that mesoscale circulation plays a key role in offshore transport of zooplankton and the life cycle of higher trophic levels (e.g., fish) in the CCS, PCCS and GOA. Looking forward, POBEX results may guide the development of new modelling and observational strategies to establish the

mechanistic links between climate forcing, mesoscale circulation, and marine population dynamics.

Modeling Physical-Biological Responses to Climate Change in the California Current System. Franks PJS, Di Lorenzo E, Goebel NL, Chenillat F, Riviere P, Edward CA, et al. (2013). *Oceanography*, 26(3): 26-33. http://tos.org/oceanography/article/modeling-physical-biological-responses-to-climate-change-in-the-californiac

Geographic Location: Pacific Ocean/Southern California
Type of Reference: Review Article

Abstract: Understanding the effects of climate change on planktonic ecosystems requires the synthesis of large, diverse data sets of variables that often interact in nonlinear ways. One fruitful approach to this synthesis is the use of numerical models. Here, we describe how models have been used to gain understanding of the physical-biological couplings leading to decadal changes in the southern California Current ecosystem. Moving from basin scales to local scales, we show how atmospheric, physical oceanographic, and biological dynamics interact to create long-term fluctuations in the dynamics of the California Current ecosystem.

State of the California Current 2012-13: No Such Thing as an "Average" Year. Wells BK, Schroeder ID, Santora JA, Hazen EL, Bograd SJ, Bjorkstedt EP, et al. (2013). California Cooperative Oceanic Fisheries Investigations Reports, 54: 37-71. http://www.calcofi.org/publications/calcofireports/v54/Vol_54_StateOfCurrent_37-71.pdf

Geographic Location: Pacific Ocean/West Coast United States
Type of Reference: Report

Abstract: This report reviews the state of the California Current System (CCS) between winter 2012 and spring 2013, and includes observations from Washington State to Baja California. During 2012, large-scale climate modes indicated the CCS remained in a cool, productive phase present since 2007. The upwelling season was delayed north of 42 degrees north (N), but regions to the south, especially 33 degrees to 36 degrees N, experienced average to above average upwelling that persisted throughout the summer. Contrary to the indication of high production suggested by the climate indices, chlorophyll observed from surveys and remote sensing was below average along much of the coast. As well, some members of the forage assemblages along the coast experienced low abundances in 2012 surveys. Specifically, the concentrations of all life-stages observed directly or from egg densities of Pacific sardine, *Sardinops sagax*, and northern anchovy, *Engraulis mordax*, were less than previous years' survey estimates. However, 2013 surveys and observations indicate an increase in abundance of northern anchovy. During winter 2011/2012, the increased presence of northern copepod species off northern California was consistent with stronger southward transport. Krill and small-fraction zooplankton abundances, where examined, were generally above average. North of 42 degrees N, salps returned to typical abundances in 2012 after greater observed concentrations in 2010 and 2011. In contrast, salp abundance off

central and southern California increased after a period of southward transport during winter 2011/2012. Reproductive success of piscivorous Brandt's cormorant, *Phalacrocorax penicillatus*, was reduced while planktivorous Cassin's auklet, *Ptychoramphus aleuticus* was elevated. Differences between the productivity of these two seabirds may be related to the available forage assemblage observed in the surveys. California sea lion pups from San Miguel Island were undernourished resulting in a pup mortality event perhaps in response to changes in forage availability. Limited biological data were available for spring 2013, but strong winter upwelling coastwide indicated an early spring transition, with the strong upwelling persisting into early summer.

State of the California Current 2013-2014: El Niño Looming. (2014). *CalCOFI Reports*, 55.
http://www.calcofi.org/publications/calcofireports/v55/Vol_55_SOTCC_51-87.pdf

Geographic Location: Pacific Ocean/US West Coast
Type of Reference: Report

Abstract: In 2013, the California current was dominated by strong coastal upwelling and high productivity. Indices of total cumulative upwelling for particular coastal locations reached some of the highest values on record. Chlorophyll a levels were high throughout spring and summer. Catches of upwelling-related fish species were also high. After a moderate drop in upwelling during fall 2013, the California current system underwent a major change in phase. Three major basin-scale indicators, the Pacific Decadal Oscillation (PDO), the North Pacific Gyre Oscillation (NPGO), and the Multivariate ENSO Index (ENSO-MEI), all changed phase at some point during the winter of 2013/14. The PDO changed to positive values, indicative of warmer waters in the North Pacific; the NPGO to negative values, indicative of lower productivity along the coast; and the MEI to positive values, indicative of an oncoming El Niño. Whereas the majority of the California Current system appears to have transitioned to an El Niño state by August 2014, based on decreases in upwelling and chlorophyll a concentration, and increases in SST, there still remained pockets of moderate upwelling, cold water, and high chlorophyll a biomass at various central coast locations, unlike patterns seen during the more major El Niños (e.g., the 97–98 event). Catches of rockfish, market squid, euphausiids, and juvenile sanddab remained high along the central coast, whereas catches of sardine and anchovy were low throughout the CCS. 2014 appears to be heading towards a moderate El Niño state, with some remaining patchy regions of upwelling-driven productivity along the coast. Superimposed on this pattern, three major regions have experienced possibly non-El Niño-related warming since winter: the Bering Sea, the Gulf of Alaska, and offshore of southern California. It is unclear how this warming may interact with the predicted El Niño, but the result will likely be reduced growth or reproduction for many key fisheries species.

Atmospheric controls on northeast pacific temperature variability and change, 1900-2012. Johnstone JA and Mantua NJ (2014). *Proceedings of the National Academy of Sciences of the United States of America*, 111(40): 14360-14365. http://www.pnas.org/content/111/40/14360.abstract

Geographic Location: Pacific Ocean/Northeast pacific Coast
Type of Reference: Research Paper

Abstract: Over the last century, northeast Pacific coastal sea surface temperatures (SSTs) and land-based surface air temperatures (SATs) display multi-decadal variations associated with the Pacific Decadal Oscillation, in addition to a warming trend of about 0.5-1 degree Celsius. Using independent records of sea-level pressure (SLP), SST, and SAT, this study investigates northeast (NE) Pacific coupled atmosphere-ocean variability from 1900 to 2012, with emphasis on the coastal areas around North America. We use a linear stochastic time series model to show that the SST evolution around the NE Pacific coast can be explained by a combination of regional atmospheric forcing and ocean persistence, accounting for 63 percent (%) of nonseasonal monthly SST variance (r = 0.79) and 73% of variance in annual means (r = 0.86). We show that SLP reductions and related atmospheric forcing led to century-long warming around the NE Pacific margins, with the strongest trends observed from 1910-1920 to 1940. NE Pacific circulation changes are estimated to account for more than 80% of the 1900-2012 linear warming in coastal NE Pacific SST and US Pacific northwest (Washington, Oregon, and northern California) SAT. An ensemble of climate model simulations run under the same historical radiative forcings fails to reproduce the observed regional circulation trends. These results suggest that natural internally generated changes in atmospheric circulation were the primary cause of coastal NE Pacific warming from 1900 to 2012 and demonstrate more generally that regional mechanisms of interannual and multi-decadal temperature variability can also extend to century time scales.

North American west coast summer low cloudiness: Broadscale variability associated with sea surface temperature. Schwartz RE, Gershunov A, Iacobellis SF and Cayan DR (2014). *Geophysical Research Letters*, 41(9): 3307-3314. http://onlinelibrary.wiley.com/doi/10.1002/2014GL059825/abstract;jsessionid=95E81924DF553E1ED6666CC1C21DE0F0.f01t02

Geographic Location: Pacific Ocean/Alaska to So. California
Type of Reference: Research Paper

Abstract: Six decades of observations at 20 coastal airports, from Alaska to southern California, reveal coherent interannual to interdecadal variation of coastal low cloudiness (CLC) from summer to summer over this broad region. The leading mode of CLC variability represents coherent variation, accounting for nearly 40 percent of the total CLC variance spanning 1950–2012. This leading mode and the majority of individual airports exhibit decreased low cloudiness from the earlier to the later part of the record. Exploring climatic controls on CLC, we identify North Pacific Sea Surface Temperature anomalies, largely in the form of the Pacific Decadal Oscillation (PDO) as well correlated with, and evidently helping to organize, the coherent patterns of summer coastal cloud variability. Links from the PDO to summer CLC appear a few months in

advance of the summer. These associations hold up consistently in interannual and interdecadal frequencies.

Industrial-era global ocean heat uptake doubles in recent decades. Glecker PJ, Durack PJ, Stouffer RJ, Johnson GC, and Forest CE (2016). *Nature Climate Change*, advanced online publication.
http://www.nature.com/nclimate/journal/v6/n4/full/nclimate2915.html

Geographic Location: Global Ocean
Type of Reference: Research Paper

Abstract: Formal detection and attribution studies have used observations and climate models to identify an anthropogenic warming signature in the upper (0–700 meters (m)) ocean. Recently, as a result of the so-called surface warming hiatus, there has been considerable interest in global ocean heat content (OHC) changes in the deeper ocean, including natural and anthropogenically forced changes identified in observational, modelling and data re-analysis studies. Here, we examine OHC changes in the context of the Earth's global energy budget since early in the industrial era (circa 1865–2015) for a range of depths. We rely on OHC change estimates from a diverse collection of measurement systems including data from the nineteenth-century Challenger expedition, a multi-decadal record of ship-based in situ mostly upper-ocean measurements, the more recent near-global Argo floats profiling to intermediate (2,000 m) depths, and full-depth repeated transoceanic sections. We show that the multi-model mean constructed from the current generation of historically forced climate models is consistent with the OHC changes from this diverse collection of observational systems. Our model-based analysis suggests that nearly half of the industrial-era increases in global OHC have occurred in recent decades, with over a third of the accumulated heat occurring below 700 m and steadily rising.

Upwelling

The California Current is a seasonal southward-flowing ocean current that transports cool, low salinity- and nutrient-rich water from sub-Arctic regions to the California coast. A regional wind-driven process known as "upwelling" carries the deep, cooler waters transported by the current upward, closer to the surface where photosynthesis stimulates the growth and reproduction of phytoplankton. Climate change impacts on winds may be changing the upwelling patterns and impacting marine ecosystems.

Winter and summer upwelling modes and their biological importance in the California Current Ecosystem. Black BA, Schroeder ID, Sydeman WJ, Bograd SJ, Wells BK and Schwing FB (2011). *Global Change Biology*, 17(8): 2536-2545.
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2011.02422.x/abstract

Geographic Location: Pacific Ocean/California
Type of Reference: Research Paper

Abstract: Analysis of monthly coastal upwelling intensities revealed two seasonal and *biologically* relevant upwelling 'modes' in the California Current Ecosystem (CCE). The first mode reflected upwelling during the summer months and was characterized by low-frequency (multi-decadal) processes, including significant (P<0.01) linear trends at some latitudes. In contrast, the second mode reflected wintertime upwelling and was defined by higher-frequency variability associated with the North Pacific High and El Niño Southern Oscillation events. These modes were compared with multi-decadal time series of splitnose rockfish (*Sebastes diploproa*) otolith growth, yelloweye rockfish (*S. ruberrimus*) otolith growth, Chinook salmon (*Oncorhynchus tshawytscha*) scale growth, and indices of Cassin's auklet (*Ptychoramphus aleuticus*) and common murre (*Uria aalge*) reproduction in the central-northern CCE. In redundancy and correlation analyses, salmon growth and Cassin's auklet fledgling success associated with the summer upwelling mode while all other time series associated with the winter upwelling mode, indicating that CCE biology was differentially sensitive to these seasonal upwelling patterns. Thus, upwelling occurred in unrelated seasonal modes with contrasting trends, atmospheric forcing mechanisms, and impacts on the biology of the CCE, underscoring the importance of seasonality when evaluating ecosystem response to climate variability and change.

Climatic Control of Upwelling Variability along the Western North-American Coast. Macias D, Landry MR, Gershunov A, Miller AJ and Franks PJS (2012). *PLoS ONE*, 7(1): e30436.
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0030436

Geographic Location: Pacific Ocean/California
Type of Reference: Research Paper

Abstract: The high biological production of the California Current System (CCS) results from the seasonal development of equatorward alongshore winds that drive coastal upwelling. While several climatic fluctuation patterns influence the dynamics and biological productivity of the CCS, including the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation index (PDO) and the North Pacific Gyre Oscillation (NPGO), the mechanisms of interaction between climatic oscillations and the CCS upwelling dynamics have remained obscure. Here, we use Singular Spectral Analysis (SSA) to reveal, for the first time, low-frequency concordance between the time series of climatic indices and upwelling intensity along the coast of western North America. Based on energy distributions in annual, semiannual and low-frequency signals, we can divide the coast into three distinct regions. While the annual upwelling signal dominates the energy spectrum elsewhere, low-frequency variability is maximal in the regions south of 33°north (N). Non-structured variability associated with storms and turbulent mixing is enhanced at northerly locations. We found that the low-frequency signal is significantly correlated with different climatic indices such as PDO, NPGO and ENSO with the correlation patterns being latitude-dependent. We also analyzed the correlations between this upwelling variability and sea surface temperature (SST) and sea level pressure (SLP) throughout the North Pacific to visualize and interpret the large- scale teleconnection dynamics in the atmosphere that drive the low-frequency coastal winds. These results provide new insights into the underlying mechanisms

connecting climatic patterns with upwelling dynamics, which could enhance our prediction and forecast capabilities of the effects of future oceanographic and climatic variability in the CCS.

What determines the spatial pattern in summer upwelling trends on the US West Coast? Seo H, Brink KH, Dorman CE, Koracin D and Edwards CA (2012). *Journal of Geophysical Research-Oceans*, 117. CO812. http://onlinelibrary.wiley.com/doi/10.1029/2012JC008016/abstract

Geographic Location: Pacific Ocean/US West Coast
Type of Reference: Research Paper

Abstract: Analysis of sea surface temperature (SST) from coastal buoys suggests that the summertime over-shelf water temperature off the U. S. West Coast has been declining during the past 30 years at an average rate of -0.19 degrees Celsius per decade. This cooling trend manifests itself more strongly off south-central California than off Oregon and northern California. The variability and trend in the upwelling north of off San Francisco are positively correlated with those of the equatorward wind, indicating a role of offshore Ekman transport in the north. In contrast, Ekman pumping associated with wind stress curls better explains the stronger and statistically more significant cooling trend in the south. While the coast-wide variability and trend in SST are strongly correlated with those of large-scale modes of climate variability, they in general fail to explain the southward intensification of the trend in SST and wind stress curl. This result suggests that the local wind stress curl, often topographically forced, may have played a role in the upwelling trend pattern.

Changes in the onset and intensity of wind-driven upwelling and downwelling along the North American Pacific coast. Bylhouwer B, Ianson D and Kohfeld K (2013). *Journal of Geophysical Research C: Oceans*, 118(5): 2565-2580. http://onlinelibrary.wiley.com/doi/10.1002/jgrc.20194/full

Geographic Location: Pacific Ocean/North American Pacific Coast
Type of Reference: Research Paper

Abstract: The timing, duration, and intensity of wind-driven upwelling and downwelling along the North American Pacific coast play an integral role in coastal circulation and basinwide ecosystem composition. It has been suggested that global warming will cause changes in these winds. Here we develop a new set of objective criteria to unambiguously determine the onset, duration, and intensity of upwelling and downwelling seasons due to local wind forcing. We use these criteria to examine and better characterize temporal trends in wind-driven coastal currents over the previous 60 years and relate them to global warming and large-scale climate oscillations in the coastal ocean between northern California and Vancouver Island (37°north (N) and 51°N). We find an exceptionally variable onset of upwelling at all locations. Some significant temporal trends are found in summer onset and upwelling intensity time series near the Juan de Fuca Strait and off the coast of Oregon. Positive phases of the Pacific Decadal Oscillation are correlated to later and shorter upwelling seasons with

weaker upwelling. Warm phases of the El Niño Southern Oscillation are associated with a later onset of summer upwelling south of Oregon and with more intense downwelling throughout the study area. Our analysis identifies strong interannual to interdecadal variability, and emphasizes the importance of time series length when isolating physical temporal trends influenced by large-scale oscillatory behavior of the climate.

Relative influence of oceanic and terrestrial pressure systems in driving upwelling-favorable winds. Garcia-Reyes M, Sydeman WJ, Black BA, Rykaczewski RR, Schoeman DS, Thompson SA, et al. (2013). *Geophysical Research Letters*, 40(19): 5311-5315.
http://onlinelibrary.wiley.com/doi/10.1002/2013GL057729/abstract;jsessionid=53E830D4B2270FA0202695CC64FCF7F8.f01t01

Geographic Location: Global Oceans
Type of Reference: Research Paper

Abstract: We use the 20th Century Reanalysis database to assess the influence of oceanic and terrestrial atmospheric pressure systems on winter and summer upwelling-favorable winds in Eastern Boundary Upwelling Systems. The analysis provides baseline information regarding the roles of continental thermal low (CTL) and oceanic high (OH) pressure systems in driving seasonal upwelling modes, which have high biological relevance. We show that variability in upwelling-favorable winds is dominated by OH, particularly in winter, and only weakly influenced by CTL, except at annual time scales. This is most pronounced in the California system given that the North Pacific High dominates wind variability. In contrast, CTL and OH equally influence Benguela upwelling-favorable winds during summer. This work underscores the need to understand how OH systems are likely to respond to climate change and how this might impact coastal winds that drive upwelling and productivity in these ecosystems.

Synoptic-scale upwelling indices and predictions of phyto- and zooplankton populations. García-Reyes M, Largier JL and Sydeman WJ (2014). *Progress in Oceanography*, 120: 177-188.
http://www.sciencedirect.com/science/article/pii/S007966111300164X

Geographic Location: Pacific Ocean/California
Type of Reference: Research Paper

Abstract: Seasonal upwelling is responsible for the biologically rich and productive ecosystems of coastal eastern boundary currents. In most studies of physical – biological interactions in these systems, upwelling statistics are computed on monthly, seasonal, and annual time scales, whereas upwelling naturally occurs at high frequencies (days to weeks). This simplification of the upwelling process may misrepresent relationships between upwelling and biological populations. Based on 31 years (1982–2012) of hourly-measured winds and sea surface temperature (SST) at buoys off the central-northern California coast, we characterized upwelling and relaxation events at synoptic time scales, and used event-scale statistics to relate to local lower trophic level populations. We defined three metrics to quantify synoptic-scale

upwelling: (i) Intensity, a measure of cumulative wind stress forcing during each upwelling event, (ii) SSTevent, a measure of the oceanic response to wind forcing, and (iii) Nutrient Upwelling Index (NUI), a measure of the nitrate availability at the surface during upwelling events. We compared cumulative values of Intensity and NUI, and average values of SSTevent during the peak of the upwelling season (April–June in central-northern California) to proxies of phytoplankton biomass (chlorophyll-a concentrations) and krill abundance to assess the abilities of high frequency upwelling indices to predict biology. Wind forcing alone (Intensity) did not explain population variability, but SSTevent and NUI showed excellent relationships to chlorophyll concentrations (44% and 54% of variance explained, respectively) and krill abundance (68% of variance explained). All relationships appeared to be dome-shaped, supporting the hypothesis that moderate upwelling and ocean temperature are optimal for these populations. SSTevent and NUI performed better than the traditional Bakun upwelling index in predicting populations. We conclude that investigating upwelling characteristics on event scales can improve understanding of lower trophic level dynamics in eastern boundary current systems.

Climate change and wind intensification in coastal upwelling ecosystems. Sydeman WJ, García-Reyes M, Schoeman DS, Rykaczewski RR, Thompson SA, Black BA, et al. (2014). *Science*, 345(6192): 77-80. https://www.sciencemag.org/content/345/6192/77.full.pdf

Geographic Location: Pacific and Atlantic Oceans
Type of Reference: Research Paper

Abstract: In 1990, Andrew Bakun proposed that increasing greenhouse gas concentrations would force intensification of upwelling-favorable winds in eastern boundary current systems that contribute substantial services to society. Because there is considerable disagreement about whether contemporary wind trends support Bakun's hypothesis, we performed a meta-analysis of the literature on upwelling-favorable wind intensification. The preponderance of published analyses suggests that winds have intensified in the California, Benguela, and Humboldt upwelling systems and weakened in the Iberian system over time scales ranging up to 60 years; wind change is equivocal in the Canary system. Stronger intensification signals are observed at higher latitudes, consistent with the warming pattern associated with climate change. Overall, reported changes in coastal winds, although subtle and spatially variable, support Bakun's hypothesis of upwelling intensification in eastern boundary current systems.

Sea level rise

Sea level rise provides a physical measure of the ocean's response to climate change. The rise in global sea level is attributed to thermal expansion of ocean water and the melting of mountain glaciers and ice sheets. Coupled atmosphere-ocean perturbations, like El Niño–Southern Oscillation (ENSO), affect sea level in a complex manner. Sea level rise could lead to flooding of low-lying areas, loss of coastal wetlands such as portions of the San Francisco Bay Delta system, and wave-driven erosion and accretion of cliffs and beaches.

The 154-year record of sea level at San Francisco: Extracting the long-term trend, recent changes, and other tidbits. Breaker LC and Ruzmaikin A (2011). *Climate Dynamics*, 36(3): 545-559
http://link.springer.com/article/10.1007%2Fs00382-010-0865-4

Geographic Location: Pacific Ocean/San Francisco
Type of Reference: Research Paper

Abstract: A data adaptive method called ensemble empirical mode decomposition (EEMD) is used to examine the 154-year record of monthly sea level at San Francisco. The mode that is lowest in frequency corresponds to the long-term trend. The next highest mode corresponds to an oscillation with a period of ~100 years and may be related to solar variability. When this mode is combined with the long-term trend, the rate of increase in sea level starts to decrease by ~1980. The next lower mode corresponds to interdecadal time scales and thus includes the Pacific Decadal Oscillation. When combined with the two lower modes, sea level itself starts to decrease by the mid-1990s. These results are consistent with the most recent results from the Intergovernmental Panel on Climate Change (IPCC), and may be the first obtained from a tidal record. Prior to conducting EEMD, corrections for glacial isostatic adjustment (GIA) and the inverse barometer (IB) effect were applied. The effect of applying the GIA correction was relatively small, but the IB correction reduced the slope of the long-term trend in sea level by almost 15 percent (%). This reduction is due to a long-term increase in the variance of sea level pressure. To determine if the 10-15 year ENSO modulation cycle could be detected from the decomposition we first compared the envelope from the mode associated with ENSO, with the two adjacent modes that were lower in frequency. Spectral analysis revealed no significant maxima in the ENSO mode envelope, but a major peak in the spectrum for the two adjacent modes, with a period of 12.8 years. This is consistent with a local response to El Niño warming for the ENSO mode, but a non-local response for the two adjacent modes. A similar analysis was performed for the Southern Oscillation Index and a spectral maximum was found between 12 and 16 years, consistent with our non-local interpretation of the previous two modes.

Sea level variations along the U.S. Pacific Northwest coast: Tectonic and climate controls. Komar PD, Allan JC and Ruggiero P (2011). *Journal of Coastal Research*, 27(5): 808-823. http://www.bioone.org/doi/abs/10.2112/JCOASTRES-D-10-00116.1

Geographic Location: Pacific Ocean/US Northwest Coast
Type of Reference: Research Paper

Abstract: Analyses of the progressive multi-decadal trends and climate-controlled annual variations in mean sea levels are presented for nine tide-gauge stations along the coast of the U.S. Pacific Northwest: Washington, Oregon, and Northern California. The trends in relative sea levels are strongly affected by the tectonics of this region, characterized by significant alongcoast variations in changing land elevations measured by benchmarks and global positioning system data. These combined data sets

document the existence of both submergent and emergent stretches of shore. The Pacific Northwest sea levels are also affected by variations in the monthly mean seasonal cycles, with its extreme water levels occurring in the winter during strong El Niños. To quantify this climate control and to derive improved multi-decadal sea-level trends, separate evaluations of the winter and summer-averaged measured water levels have been undertaken. The resulting pair of linear regressions for each tide gauge shows a consistent difference in the mean water levels over the years, at their highest during the winters, reflecting the total magnitude in the seasonal cycle of water levels. Of importance, the degree of scatter in the summer averages is reduced compared with the annual averages, yielding sea-level trends that generally have the highest statistical significance. In contrast, the winter records emphasize the extreme water levels associated with strong El Niños, yielding a predictive correlation with the Multivariate El Niño/Southern Oscillation Index. Both trends in relative sea levels and extremes in the winter monthly elevations produced by El Niños are important to the Pacific Northwest coastal hazard assessments, combining with the multi-decade increase in wave heights measured by buoys. With these multiple processes and their climate controls, the erosion hazards are projected to significantly increase in future decades.

Physical and ecological responses of sandy beaches to the 1997-98 El Niño. Revell DL, Dugan JE and Hubbard DM (2011). *Journal of Coastal Research*, 27(4): 718-730. http://www.bioone.org/doi/abs/10.2112/JCOASTRES-D-09-00179.1

Geographic Location: Pacific Ocean/Isla Vista, California
Type of Reference: Research Paper

Abstract: El Niño events elevate water levels, change wave direction and storm frequency, and provide an analogy to the likely impacts of climate change. Elevated sea levels intensify coastal erosion impacts affecting not only oceanfront property and recreational users, but also habitats and species that depend on the coast. This study examines physical and ecological responses to and recovery from the extreme 1997-98 El Niño along beaches of Isla Vista, California, a stretch of coastline dominated by unidirectional alongshore sediment transport. Using topographic light detection and ranging (LIDAR), physical measurements, and biological surveys we quantify physical changes and assess ecological responses. We quantify short-term reductions in beach widths (>60 percent) and sand volumes (~80 percent). Although dune-backed beaches lost greater sand volumes, bluff-backed shorelines lost greater percentages of beach width. Four erosion hot spots were identified consistent with a pattern of beach reorientations. Macrophyte wrack abundance, a primary food for sandy beach ecosystems, was significantly correlated with dry sand beach width. Macroinvertebrate biomass was reduced and a decline in mean size of individuals persisted for several species. Abundance and species richness of shorebirds were lower during the El Niño. Beach segments and reorientations recovered at different times, on the basis of littoral drift direction, shoreline orientation, and wave exposure. The reorientation at the updrift beach impounded sand for >3 years after the El Niño, catalysing an erosion wave that propagated downdrift affecting downcoast beaches. Recovery of the updrift beach led to the widest beach widths shown in the historic record, whereas the downdrift beach underwent continued erosion >6 years after the El Niño. Recovery of wrack abundance

and shorebirds to pre-El Niño levels took >3 years. Reductions in biomass and mean size of invertebrates were detected two years after the event. Recovery time lines provide information for coastal managers evaluating impacts and timing of erosion mitigation alternatives.

Snowmelt and other freshwater impacts

Annual mountain snowpack provides natural storage for water supplies. The water supply from spring and summer snowmelt runoff supports agriculture and industry, growing urban areas, and the ecological health of coastal ocean and riverine environments. Surface water supplies throughout western North America rely on a highly seasonal and variable mountain runoff pattern that is sensitive to climatic variability and change.

The accumulation of snow at high elevations can be affected by warming temperatures. During the winter months, more precipitation will fall as rain instead of snow when temperatures are warmer. Warmer temperatures will also shift the timing of snowmelt to occur earlier in the spring. As warming and precipitation shifts continue, runoff and streamflow amounts and patterns could be affected, impacting water supplies.

Fens as whole-ecosystem gauges of groundwater recharge under climate change. Drexler JZ, Knifong D, Tuil J, Flint LE and Flint AL (2013). *Journal of Hydrology*, 481: 22-34.
http://www.sciencedirect.com/science/article/pii/S0022169412010359

Geographic Location: California/Sierra Nevada and Cascade Range
Type of Reference: Research Paper

Abstract: Currently, little is known about the impact of climate change on groundwater recharge in the Sierra Nevada and southern Cascade Range of California or other mountainous regions of the world. The purpose of this study was to determine whether small alpine peatlands called fens can be used as whole-ecosystem gauges of groundwater recharge through time. Fens are sustained by groundwater discharge and are highly sensitive to changes in groundwater flow due to hydrologic disturbance including climate change. Seven fens in the Sierra Nevada and southern Cascade Range were studied over a 50-80 year period using historic aerial photography. In each aerial photograph, fen areas were identified as open lawn and partially treed areas that exhibited (1) dark brownish-green coloring or various shades of gray and black in black and white imagery and (2) mottling of colors and clustering of vegetation, which signified a distinct moss canopy with overlying clumped sedge vegetation. In addition to the aerial photography study, a climate analysis for the study sites was carried out using both measured data (U.S. Department of Agriculture Natural Resources Conservation Service SNOwpack TELemetry system) and modeled data (a downscaled version of the Parameter-elevation Regressions on Independent Slopes Model) for the period from 1951 to 2010. Over the study period, the five fens in the Sierra Nevada were found to be decreasing between 10 percent (%) and 16% in delineated area. The climate analysis revealed significant increases through time in annual mean minimum

temperature (T_{min}) between 1951-1980 and 1981-2010. In addition, April 1 snow water equivalent and snowpack longevity also decreased between 1951-1980 and 1981-2010. For the fens in the Cascade Range, there were no discernible changes in delineated area. At these sites, increases in T_{min} occurred only within the past 20-25 years and decreases in snowpack longevity were more subtle. A conceptual model is presented, which illustrates that basic differences in hydrogeology of the Sierra Nevada vs. the Cascade Range may control the threshold at which changes in delineated fen areas are discernible. Overall, the results from this study show that fens in the Sierra Nevada have strong potential as whole-ecosystem gauges for determining long-term changes in groundwater recharge under climate change. Due to either more moderate climate change and/or hydrogeological differences, fens in the southern Cascade Range currently do not appear to have the same utility. A greater sample size of fens in the Sierra Nevada is needed to confirm the general applicability of this method. In addition, future work needs to focus on integrating fen monitoring with geochemical and/or isotopic process-level studies in order to quantify changes in groundwater recharge identified using this new approach.

Climate change: Impacts in the third dimension. Dettinger M (2014). *Nature Geosci*, 7(3): 166-167. http://www.nature.com/ngeo/journal/v7/n3/full/ngeo2096.html

Geographic Location: Northwest United States
Type of Reference: Review Article

Abstract: Despite reports of no trends in snow- and rainfall, rivers in the northwest USA have run lower and lower in recent decades. A closer look at high- and low-altitude precipitation suggests that observational networks have missed a decline in mountain rain and snow that can explain the discrepancy.

Response surfaces of vulnerability to climate change: The Colorado River Basin, the High Plains, and California. Foti R, Ramirez JA and Brown TC (2014). *Climatic Change*, 125(3-4): 429-444. http://link.springer.com/article/10.1007%2Fs10584-014-1178-0

Geographic Location: Colorado River Basin, High Plains, California
Type of Reference: Research Paper

Abstract: We quantify the vulnerability of water supply to shortage for the Colorado River Basin and basins of the High Plains and California and assess the sensitivity of their water supply system to future changes in the statistical variability of supply and demand. We do so for current conditions and future socio-economic scenarios within a probabilistic framework that incorporates the inherent uncertainties in the drivers of vulnerability. Our analysis indicates that the most sensitive basins to both current and future variability of demand and supply are the Central California and the San Joaquin-Tulare basins. Large sensitivity is also found for the Kansas basin of the High Plains. Within the Colorado River Basin, the Lower Colorado and Gila were found to be the most vulnerable and sensitive sub-basins. By accounting for future uncertainty within the above probabilistic framework, this study unveils and isolates the individual

responses of a given basin to changes in the statistical properties of demand and supply and offers a valuable tool for the identification of policy strategies and adaptation measures.

Effects of changes in winter snowpacks on summer low flows: Case studies in the Sierra Nevada, California, USA. Godsey SE, Kirchner JW and Tague CL (2014). *Hydrological Processes*, 28(19): 5048-5064. http://onlinelibrary.wiley.com/doi/10.1002/hyp.9943/abstract

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Seasonal low flows are important for sustaining ecosystems and for supplying human needs during the dry season. In California's Sierra Nevada mountains, low flows are primarily sustained by groundwater that is recharged during snowmelt. As the climate warms over the next century, the volume of the annual Sierra Nevada snowpack is expected to decrease by ~40-90 percent (%). In eight snow-dominated catchments in the Sierra Nevada, we analyzed records of snow water equivalent (SWE) and unimpaired streamflow records spanning 10-33 years. Linear extrapolations of historical SWE/streamflow relationships suggest that annual minimum flows in some catchments could decrease to zero if peak SWE is reduced to roughly half of its historical average. For every 10% decrease in peak SWE, annual minimum flows decrease 9-22% and occur 3-7days earlier in the year. In two of the study catchments, Sagehen and Pitman Creeks, seasonal low flows are significantly correlated with the previous year's snowpack as well as the current year's snowpack. We explore how future warming could affect the relationship between winter snowpacks and summer low flows, using a distributed hydrologic model Regional Hydro-ecologic Ecosystem Simulation System (RHESSys) to simulate the response of two study catchments. Model results suggest that a 10% decrease in peak SWE will lead to a 1-8% decrease in low flows. The modelled streams do not dry up completely, because the effects of reduced SWE are partly offset by increased fall or winter net gains in storage, and by shifts in the timing of peak evapotranspiration. We consider how groundwater storage, snowmelt and evapotranspiration rates, and precipitation phase (snow vs rain) influence catchment response to warming.

Thermal Regimes and Snowpack Relations of Periglacial Talus Slopes, Sierra Nevada, California, U.S.A. Millar CI, D. Westfall R and Delany DL (2014). *Arctic, Antarctic, and Alpine Research*, 46(2): 483-504. http://www.bioone.org/doi/abs/10.1657/1938-4246-46.2.483

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Thermal regimes of eight periglacial talus slopes, at contrasting elevations, aspects, and substrates, in the Sierra Nevada, California, had complex microclimatic patterns partially decoupled from external conditions. Over three years, warm seasons showed mean talus matrix temperatures and daily variances lower than surfaces and

cooler than free-air; talus surface and matrix positions low in the taluses were colder than higher positions, yielding highly positive altitudinal temperature differentials; ground surface temperatures had greater daily extremes than talus positions; and talus matrix temperatures lagged in response to surface temperature changes. Regulating processes in summer include evaporative cooling, cold-air drainage and Balch effect, and shading effects. In the cold season, talus matrices were warmer than surfaces; low talus positions were warmer than high; isothermal zero-curtain periods occurred before snow disappearance; and snow covered talus low positions more often and longer than higher in the taluses, which were often snow-free. Winter thermal processes likely include insulation from snow cover at talus bases, free exchange between talus matrix and external air in the upper talus, and latent heat from thaw-refreezing in late winter. Permanent ice may occur within high elevation talus slopes. Partially decoupled talus thermal regimes provide buffered habitats for mammals such as American pikas and are likely to be important refugia under future warming.

Impacts on Biological Systems

Climate has wide-ranging impacts on biological systems. Plants and animals reproduce and survive within specific ranges often defined by climatic and environmental conditions. Hence, changes in climate—particularly temperature and moisture—can have broad effects on organisms at all levels.

There is a growing body of evidence of the effects of climate change on biological systems around the globe, including changes in the timing of life cycle events (phenology), shifts in the elevation or latitude of plant and animal habitat ranges, and changes in the population abundance of certain species. Changes in climate add to the ecosystem stresses exerted by non-climate factors (such as habitat fragmentation and pollution). Individual species responses can impact other species and the ecosystem, as they may for example disrupt predator-prey and other ecological relationships, alter community composition, and interfere with ecosystem functioning. This chapter lists publications on impacts on humans, animals and plants. Impacts on humans are first listed under impacts on biological systems. Impacts on animals are categorized as follows: range shifts; body size changes; migration time; and population abundance and ecological interactions. Impacts on plants are categorized as follows: agricultural crops; vegetation; and wildfires.

Impacts on humans

Reports on climate-related impacts on humans tend to be focused on extreme events, notably heat waves and severe storms. Over the coming decades, average temperatures are predicted to rise and the number of days of summertime heat is projected to increase. Increases in the frequency and duration of heat waves are expected to result in a greater public health burden. Heat-related illness is a broad spectrum of disease, from mild heat cramps to severe, life-threatening heat stroke, to death. Heat waves have long been known to cause illnesses and deaths—outcomes which are largely preventable.

Recent California studies suggest increased health risk not only with extreme heat, but also with increasing ambient temperatures. Recent literature has also reported heat-related health outcomes not previously recognized to be affected by heat, such as infant mortality; increases in vector-borne disease transmission; increased death, disease and injury from storms, floods and fires; reduced water quality and availability; and increased morbidity and mortality associated with air pollution.

Researchers are beginning to focus on factors affecting vulnerability to the health impacts of climate change and indicators to represent these factors for use in vulnerability assessments. For example, future climate scenarios are expected to

disproportionately affect those who are socially and economically disadvantaged[2]. These groups include the urban poor, children and the elderly, traditional societies, agricultural workers and rural populations. Some populations in California may already be experiencing greater impacts on their health or well-being as a result of climate change. This is addressed in a 2010 Cal/EPA report: "Indicators of Climate Change in California: Environmental Justice Impacts (see http://www.oehha.ca.gov/multimedia/epic/pdf/ClimateChangeEJ123110.pdf).

Environmental Factors and Risk Areas of West Nile Virus in Southern California, 2007-2009. Liu H and Weng QH (2012). *Environmental Modeling & Assessment*, 17(4): 441-452. http://link.springer.com/article/10.1007%2Fs10666-011-9304-0

Geographic Location: Southern California
Type of Reference: Research Study

Abstract: The West Nile virus (WNV) may post a significant health risk for mammals, including humans and insects. This study examines the spatial-temporal effects of environmental factors on WNV dissemination with a case study of ten counties in the southern California, where the epidemic was recently most prevalent within the USA. WNV surveillance data were obtained from the California Vectorborne Disease Surveillance System and Centers for Disease Control and Prevention. Remote sensing and Geographic Information Systems (GIS) techniques were combined to derive environmental variables. Principal component analysis was performed to select the most relevant environmental variables. Two ecological zones were identified based on the selected variables. Identification of risk areas for WNV was limited to a zone with 95% mosquitoes surveillance records. Three time windows, the epidemiological weeks 18-26, 27-35, and 36-44 in each year of 2007-2009, were examined in details with risk area mapping. It is found that the southern part of San Joaquin Valley in Kern County and Los Angeles County (especially its southern part) were the most vulnerable locations for WNV outbreak. Main factors contributing to the WNV propagation included summer mean temperature, annual mean deviation from the mean temperature, land surface temperature, elevation, landscape complexity, landscape diversity, and vegetation water content. The result of this study improves understanding of WNV ecology and provides tools for detecting, tracking, and predicting the epidemic. The holistic approach developed for this study, which integrated remotely sensed, GIS-based, and in situ-measured environmental data with landscape metrics, may be applied to studies of other vector-borne diseases.

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[2] Confalonieri, UB et al., *Human health. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Posted at: http://www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html

Morello-Frosch, R., M. Pastor, J. Sadd and S.B. Shonkoff (May 2009). The Climate Gap: Inequalities in How Climate Change Hurts Americans and How to Close the Gap. -36-
Posted at: http://college.usc.edu/pere/documents/ClimateGapExecSumm_10ah_small.pdf

Coccidioidomycosis: Epidemiology. Brown J, Benedict K, Park BJ and Thompson III GR (2013). *Clinical Epidemiology*, 5(1): 185-197.
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3702223/

Geographic Location: Western United States, Including California
Type of Reference: Review Article

Abstract: Coccidioidomycosis consists of a spectrum of disease, ranging from a mild, self-limited, febrile illness to severe, life-threatening infection. It is caused by the soil-dwelling fungi, *Coccidioides immitis* and *C. posadasii*, which are present in diverse endemic areas. Climate changes and environmental factors affect the Coccidioides lifecycle and influence infection rates. The incidence of coccidioidomycosis has risen substantially over the past two decades. The vast majority of Coccidioides infections occur in the endemic zones, such as California, Arizona, Mexico, and Central America. Infections occurring outside those zones appear to be increasingly common, and pose unique clinical and public health challenges. It has long been known that elderly persons, pregnant women, and members of certain ethnic groups are at risk for severe or disseminated coccidioidomycosis. In recent years, it has become evident that persons with immunodeficiency diseases, diabetics, transplant recipients, and prisoners are also particularly vulnerable.

Heat-related illness knowledge and practices among California hired farm workers in the MICASA study. Stoecklin-Marois M, Hennessy-Burt T, Mitchell D and Schenker M (2013). *Industrial Health*, 51(1): 47-55.
https://www.jstage.jst.go.jp/article/indhealth/51/1/51_2012-0128/_article

Geographic Location: California
Type of Reference: Research Study

Abstract: Global climate change has great potential for escalating the number and duration of extreme heat events in California. California accounts for 16 percent (%) of U.S. crop production, and over 450,000 people are employed in agriculture, with more than two-thirds being of Latino ethnicity. Despite Cal/OSHA regulations which specify that potable water, toilets, shade and rest be provided to agricultural workers, heat related illnesses and deaths still occur. The Mexican Immigration to California: Agricultural Safety and Acculturation (MICASA) Study is a population-based sample of 467 hired farm worker households from Mendota, in California's Central Valley. 474 study participants completing follow-up interview and working in agriculture in the year prior are included in this analysis. Men reported an average of 222 days (standard deviation (SD)=69.7) of work compared to 148 days (SD=67.3) for women ($p<0.0001$). Over 91% of participants reported receiving training on heat-related illness, but level of heat illness knowledge was moderate with 70% responding correctly to four-five questions. Knowledge about acclimatization was low, with 44% severely underestimating the time required, and water consumption was low at an average of 10.7 drinks per day. Results suggest important areas to target for heat illness prevention in farm worker populations and that gender specific approaches may be needed for effective heat illness prevention.

The Impact of Recent Heat Waves on Human Health in California. Guirguis K, Gershunov A, Tardy A and Basu R (2014). *Journal of Applied Meteorology & Climatology*, 53(1): 3-19. http://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-13-0130.1

Geographic Location: California
Type of Reference: Research Study

Abstract: This study examines the health impacts of recent heat waves statewide and for six subregions of California: the north and south coasts, the Central Valley, the Mojave Desert, southern deserts, and northern forests. By using canonical correlation analysis applied to daily maximum temperatures and morbidity data in the form of unscheduled hospitalizations from 1999 to 2009, 19 heat waves spanning 3-15 days in duration that had a significant impact on health were identified. On average, hospital admissions were found to increase by seven seven percent (%) on the peak heat-wave day, with a significant impact seen for several disease categories, including cardiovascular disease, respiratory disease, dehydration, acute renal failure, heat illness, and mental health. Statewide, there were 11,000 excess hospitalizations that were due to extreme heat over the period, yet the majority of impactful events were not accompanied by a heat advisory or warning from the National Weather Service. On a regional basis, the strongest health impacts are seen in the Central Valley and the north and south coasts. The north coast contributes disproportionately to the statewide health impact during heat waves, with a 10.5% increase in daily morbidity at heat-wave peak as compared with 8.1% for the Central Valley and 5.6% for the south coast. The temperature threshold at which an impact is seen varies by subregion and timing within the season. These results suggest that heat-warning criteria should consider local percentile thresholds to account for acclimation to local climatological conditions as well as the seasonal timing of a forecast heat wave.

A Case-Crossover Study of Temperature and Infant Mortality in California. Basu R, Pearson D, Sie L and Broadwin R (2015). *Paediatric and Perinatal Epidemiology,* 29(5): 407-415. http://onlinelibrary.wiley.com/doi/10.1111/ppe.12204/abstract

Geographic Location: California
Type of Reference: Research Study

Abstract: While most research on temperature and mortality has focused on the elderly, little has concentrated on infants, who may also lack thermoregulatory responses to heat exposure. We examined mean daily apparent temperature, a combination of temperature and humidity, and infant deaths in California during the warm season of May through October 1999 to 2011. Deaths from all causes and specifically from congenital malformations, sudden infant death syndrome, abnormal gestation duration, respiratory causes, and circulatory causes were considered in a time-stratified case-crossover analysis of 12,356 infant deaths. For all-cause mortality, excess risk was 4.4 percent (%) (95% confidence interval (CI) −0.3, 9.2) per 5.6°Celsius increase for average of same day and previous three days apparent temperature

(lag 03). The associations for apparent temperature and both all-cause mortality and deaths caused by gestation duration were highest for Black infants (13.3%, 95% CI 0.6, 27.6 and 23.7%, 95% CI −3.3, 58.2, respectively), while White infants had elevated risk for deaths from respiratory causes (44.6%; −0.7, 110.5). We further observed differential effects for neonates (infants aged 28 days and under) and post-neonates (infants above 28 days and under 1 year), and coastal and non-coastal regions. These associations remained even after considering criteria air pollutants. This study suggests that infants are a vulnerable subgroup to heat exposure. Further studies should be conducted with a sufficient number of cases of infant deaths in other locales.

Impacts on animals

Animals reproduce and survive within specific habitat ranges defined by climatic and environmental conditions. Scientific evidence suggests that terrestrial, marine and freshwater organisms worldwide are impacted by recent warming, and have exhibited certain responses, including: shifting range boundaries; changes in the timing of growth stages (such as migration or egg-laying; known as "phenology"); changes in body size and other morphological features; and changes in population abundance. While some species will adapt to new climate conditions, not all will have the ability to respond to changes in climate. Extinctions will occur, current communities of species may disassemble as they respond differently to climate change and new species' assemblages will emerge.

The papers addressing impacts on animals are grouped below under headings that correspond to the following responses listed above: livestock; range shifts; migration time; and population abundance and ecological interactions for terrestrial and aquatic populations.

Livestock

Livestock will be impacted in a changing climate due to effects on feed-grain production and availability; forage crop production and quality; animal health, growth, and reproduction; and disease-causing pest distributions. Changes in temperature, amount of atmospheric carbon dioxide and the frequency and intensity of extreme weather could have significant impacts on forage crop yields. As seasonal temperatures rise with a changing climate, livestock will be more vulnerable to heat stress during the warmest months. Animals tend to eat less, resulting in reduced weight gain, which affects their efficiency in meat, milk, or egg production. Elevated temperatures can increase the persistence and dispersal of certain animal pathogens. Stressed animals have a weaker immune system, making them more susceptible to diseases carried by insects and other pests.

Impacts of climate change on milk production in the United States. Mauger G, Bauman Y, Nennich T, and Salathe E (2015). *The Professional Geographer, 67(1): 121-131.*
http://www.tandfonline.com/doi/abs/10.1080/00330124.2014.921017#.VyKqYHpvkvk

Geographic Location: United States, includes California
Type of Reference: Research Paper

Abstract: Climate change is likely to affect milk production because of the sensitivity of dairy cows to excessive temperature and humidity. We use downscaled climate data and county-level dairy industry data to estimate milk production losses for Holstein dairy cows in the conterminous United States. On a national level, we estimate present-day production losses of 1.9 percent relative to baseline production and project that climate impacts could increase these losses to 6.3 percent by the end of the twenty-first century. Using present-day prices, this corresponds to annual losses of $670 million per year today, rising to $2.2 billion per year by the end of the century. We also find that there is significant geographic variation in production losses and regions currently experiencing the greatest heat-related impacts are also projected to experience the greatest additional losses with climate change. Specifically, statewide average estimates of end-of-century losses range from 0.4 percent in Washington to a 25 percent loss in annual milk production in Florida. Given that the majority of these losses occur in the summer months, this has the potential to significantly impact operations in hotter climates.

Range shifts

Climate conditions typically constrain a species' geographic range. Some animals respond to changing conditions by systematically moving to geographic areas where the conditions are closer to their physiologic temperature and moisture tolerances. These species are said to be tracking their climatic niche. The area occupied by a species might increase, decrease or remain constant, depending upon gains or losses in areas with suitable climate conditions. Certain topographical or geological features, as well as habitat alteration by humans, may prevent movement to new areas.

Changes in the geographical distribution of species have been observed across a wide range of taxonomic groups and geographical locations, including marine animals. Movement towards the poles or higher latitudes, or to higher elevations, are most commonly observed.

Bryde's whale seasonal range expansion and increasing presence in the Southern California Bight from 2000 to 2010. Kerosky SM, Širović A, Roche LK, Baumann-Pickering S, Wiggins SM and Hildebrand JA (2012). *Deep Sea Research Part I: Oceanographic Research Papers*, 65: 125-132.
http://www.sciencedirect.com/science/article/pii/S0967063712000805

Geographic Location: Pacific Ocean/Southern California
Type of Reference: Research Paper

Abstract: Bryde's whales (*Balaenoptera edeni*) are commonly found in tropical and subtropical regions of the Pacific Ocean, but few studies have explored the presence of Bryde's whales at the boundary of their distribution range. Such studies are increasingly relevant as climate impact models predict the range expansion of warm water species towards the poles in response to ocean warming. Like other baleen whales, Bryde's whales produce distinct low frequency (<60 hertz) calls, which can be used for long-term acoustic monitoring of whale presence in an area. Autonomous passive acoustic recorders deployed at five sites in the Southern California Bight (SCB) were used to investigate the presence of Bryde's whales in temperate waters from 2000 to 2010. Calling Bryde's whales were observed in the SCB from summer to early winter, indicating a seasonal poleward range expansion. There was a significant increase in the presence of calling Bryde's whales in the SCB between 2000 and 2010, but no significant correlation was found between Bryde's whale presence and local sea surface temperature. Bryde's whale occurrence is likely driven by prey availability within the California Current ecosystem, which is affected by seasonal and inter-annual changes in climate and oceanographic conditions. Continued monitoring of Bryde's whales and their prey in the eastern North Pacific is needed to provide a longer time series and determine the full effect of climate variability and ocean warming on the distribution of this species.

Faunal shift in southern California's coastal fishes: A new assemblage and trophic structure takes hold. Miller EF and McGowan JA (2013). *Estuarine, Coastal and Shelf Science*, 127: 29-36
http://www.sciencedirect.com/science/article/pii/S027277141300200X

Geographic Location: Pacific Ocean/Southern California
Type of Reference: Research Paper

Abstract: Trends in coastal fish abundance indices were examined using a novel 39 year (1972-2010) time series recorded at southern California coastal power plants. Since 1972, the annual mean abundance index significantly declined (r^2=0.45, p<0.001). The mean annual biomass index likewise declined but with a large interruption in 2005-2006 when an influx of large bodied, southern species increased the annual means. Ensemble mean abundance indices for fished and unfished species declined at similar rates. Two faunal shifts were identified, 1983-1984 and 1989-1990. The ensemble mean, annual entrapment rate abundance index during the current period (1990-2010) represents only 22 percent (%) of that recorded during the first and most abundant period, 1972-1983. The mean biogeographic distribution of the assemblage was non-linear over time including a shift south during the 1980s through the 1990s before shifting north in recent years. The northern shift in recent years accompanied higher variability than previously recorded and was likely related to the overall low abundance. Since the early 1980s, the mean trophic level derived from abundance declined. The observed patterns were not correlated with commonly employed composite indices such as the Pacific Decadal Oscillation, but did show some sensitivity to changes in coastal seawater temperature and density over time. Timing of the observed faunal shifts in the fish assemblage was consistent with reported oceanographic shifts. These data suggested factors beyond fishing, such as

oceanographic change, have substantially impacted the coastal fishes of southern California.

Beyond a warming fingerprint: Individualistic biogeographic responses to heterogeneous climate change in California. Rapacciuolo G, Maher SP, Schneider AC, Hammond TT, Jabis MD, Walsh RE, et al. (2014). *Global Change Biology*, 20(9): 2841-2855. http://onlinelibrary.wiley.com/doi/10.1111/gcb.12638/full

Geographic Location: California
Type of Reference: Review Article

Abstract: Understanding recent biogeographic responses to climate change is fundamental for improving our predictions of likely future responses and guiding conservation planning at both local and global scales. Studies of observed biogeographic responses to 20th century climate change have principally examined effects related to ubiquitous increases in temperature – collectively termed a warming fingerprint. Although the importance of changes in other aspects of climate – particularly precipitation and water availability – is widely acknowledged from a theoretical standpoint and supported by paleontological evidence, we lack a practical understanding of how these changes interact with temperature to drive biogeographic responses. Further complicating matters, differences in life history and ecological attributes may lead species to respond differently to the same changes in climate. Here, we examine whether recent biogeographic patterns across California are consistent with a warming fingerprint. We describe how various components of climate have changed regionally in California during the 20th century and review empirical evidence of biogeographic responses to these changes, particularly elevational range shifts. Many responses to climate change do not appear to be consistent with a warming fingerprint, with downslope shifts in elevation being as common as upslope shifts across a number of taxa and many demographic and community responses being inconsistent with upslope shifts. We identify a number of potential direct and indirect mechanisms for these responses, including the influence of aspects of climate change other than temperature (e.g., the shifting seasonal balance of energy and water availability), differences in each taxon's sensitivity to climate change, trophic interactions, and land-use change. Finally, we highlight the need to move beyond a warming fingerprint in studies of biogeographic responses by considering a more multifaceted view of climate, emphasizing local-scale effects, and including *a priori* knowledge of relevant natural history for the taxa and regions under study.

Synchronicity in elevation range shifts among small mammal and vegetation over the last century is stronger for omnivores. Santos MJ, Thorne JH and Moritz C (2014). *Ecography*. 38(6): 556-568.
http://onlinelibrary.wiley.com/doi/10.1111/ecog.00931/abstract

Geographic Location: California/Sierra Nevada
Type of Reference: Review Article

Abstract: In mountain ecosystems, species can be said to respond synchronously to environmental change when the elevation ranges of vegetation types and their associated vertebrates expand or contract in the same direction. Conversely, the response is asynchronous when the elevation ranges of vegetation types and associated vertebrates change in different directions. The capacity of vertebrate species to respond synchronously with change in the elevation ranges of the vegetation that comprises their habitat is likely a function of their ecological traits. Here we combine measures of elevation range shifts in 23 vertebrate species with those of their associated vegetation types across 80 years, on a large elevation transect in California's Sierra Nevada mountains that encompasses Yosemite National Park. Half the species' shifts were synchronous with vegetation shifts, 25 percent of the species were asynchronous, and the others showed no relationship. Most species that responded synchronously to changes in vegetation elevation ranges expanded their elevation range, and are inhabitants of low and intermediate elevations. In contrast, those species whose range shifts were asynchronous to associated vegetation shifts inhabit high elevations. These species experienced contraction in elevation range even while their associated vegetation types expanded. However, these species were responding synchronously to a subset of their associated vegetation types. Considering trait-based predictors, omnivores were more synchronous than herbivores. Our results on synchronous and asynchronous elevation shifts with vegetation may permit more accurate modeling of future ranges for vertebrates in California's Sierra Nevada. The approach also offers a new method for use in assessment of vertebrate vulnerability in other mountain regions, and can be an important component of assessing their vulnerability to climate change.

Spatially heterogeneous impact of climate change on small mammals of montane California. Rowe KC, Rowe KMC, Tingley MW, Koo MS, Patton JL, Conroy CJ, et al. (2015). *Proceedings of the Royal Society B: Biological Sciences*, 282(1799). http://rspb.royalsocietypublishing.org/content/royprsb/282/1799/20141857.full.pdf

Geographic Location: California
Type of Reference: Research Paper

Abstract: Resurveys of historical collecting localities have revealed range shifts, primarily leading edge expansions, which have been attributed to global warming. However, there have been few spatially replicated community-scale resurveys testing whether species' responses are spatially consistent. Here we repeated early twentieth century surveys of small mammals along elevational gradients in northern, central and southern regions of montane California. Of the 34 species we analysed, 25 shifted their ranges upslope or downslope in at least one region. However, two-thirds of ranges in the three regions remained stable at one or both elevational limits and none of the 22 species found in all three regions shifted both their upper and lower limits in the same direction in all regions. When shifts occurred, high-elevation species typically contracted their lower limits upslope, whereas low-elevation species had heterogeneous responses. For high-elevation species, site-specific change in temperature better predicted the direction of shifts than change in precipitation, whereas the direction of shifts by low-elevation species was unpredictable by temperature or precipitation. While

our results support previous findings of primarily upslope shifts in montane species, they also highlight the degree to which the responses of individual species vary across geographically replicated landscapes.

Morphological and dietary responses of chipmunks to a century of climate change. Walsh RE, Assis APA, Patton JL, Marroig G, Dawson TE, and Lacey EA (2016). *Global Change Biology*.
http://onlinelibrary.wiley.com/doi/10.1111/gcb.13216/abstract

Geographic Location: California/Yosemite
Type of Reference: Research Paper

Abstract: Predicting how individual taxa will respond to climatic change is challenging, in part because the impacts of environmental conditions can vary markedly, even among closely related species. Studies of chipmunks (*Tamias* spp.) in Yosemite National Park provide an important opportunity to explore the reasons for this variation in response. While the alpine chipmunk (*T. alpinus*) has undergone a significant elevational range contraction over the past century, the congeneric and partially sympatric lodgepole chipmunk (*T. speciosus*) has not experienced an elevational range shift during this period. As a first step toward identifying the factors underlying this difference in response, we examined evidence for dietary changes and changes in cranial morphology in these species over the past century. Stable isotope analyses of fur samples from modern and historical museum specimens of these species collected at the same localities indicated that signatures of dietary change were more pronounced in *T. alpinus*, although diet breadth did not differ consistently between the study species. Morphometric analyses of crania from these specimens revealed significant changes in cranial shape for *T. alpinus*, with less pronounced changes in shape for *T. speciosus*; evidence of selection on skull morphology was detected for *T. alpinus* but not *T. speciosus.* These results are consistent with growing evidence that *T. alpinus* is generally more responsive to environmental change than *T. speciosus* but emphasize the complex and often geographically variable nature of such responses. Accordingly, future studies that make use of the taxonomically and spatially integrative approach employed here may prove particularly informative regarding relationships between environmental conditions, range changes, and patterns of phenotypic variation.

Phenology

Biological processes are generally regulated by light and temperature, making them potentially sensitive to climate change. Long-term observations of seasonal biological events revealed some of the earliest evidence of how animals and plants are responding to changes in climate. Changes in phenology, the timing of life cycle events such as bird migration, breeding, and flowering, have been linked to climate change in many parts of the world. Many ecological interactions among species (e.g., pollination) may be affected by phenological mismatches as a result of differences in species' responses to changes in climate, leading to community-or ecosystem-level disruptions.

Effects of snow-related environmental variation on breeding schedules and productivity of a high-altitude population of dusky flycatchers (*ompidonax oberholseri*). Pereyra ME (2011). *Auk*, 128(4): 746-758. http://www.bioone.org/doi/pdf/10.1525/auk.2011.10144

Geographic Location: California/Sierra nevada
Type of Reference: Research Paper

Abstract: Reproductive schedules of Dusky Flycatchers (*Empidonax oberholseri*) at Tioga Pass, in the central Sierra Nevada of California, varied considerably among years. Dates of earliest laying ranged from 29 May to 1 July and varied with snow depth, melt dates, and other factors associated with snowpack. A small apparent advance in laying date over the course of the study (0.52 days year per year over 15 years) was associated with extremes in winter snowpack and spring melt that were related to wet-dry cycles in the Sierra Nevada. Spring snowpack acted on reproductive timing through direct and indirect effects of temperature, melt schedule, and phenological changes in habitat availability. The influence of these variables on laying dates was greatest on the first females to lay (most in early June) and declined through mid-July, when breeding terminated. Clutch size and fledgling production varied between years of heavy and light snowpack as a direct consequence of delayed egg laying in years of heavy snow. In years of light snowpack, females that laid eggs by mid -June produced larger clutches, fledged more young per nest, and were more likely to re-nest if nest failure occurred. Only two females attempted two broods in a single season, and both were among the first to breed. Seasonal declines in sensitivity to local environmental conditions may constrain the ability of Dusky Flycatchers to adjust breeding schedules to match phenological delays produced by changes in winter temperature, precipitation, and snowpack, and may limit range expansion to areas with arid winters and earlier spring melt.

Timing of seasonal migration in mule deer: effects of climate, plant phenology, and life-history characteristics. Monteith KL, Bleich VC, Stephenson TR, Pierce BM, Conner MM, Klaver RW, et al. (2011). *Ecosphere*, 2(4). http://www.esajournals.org/doi/full/10.1890/ES10-00096.1

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Phenological events of plants and animals are sensitive to climatic processes. Migration is a life-history event exhibited by most large herbivores living in seasonal environments, and is thought to occur in response to dynamics of forage and weather. Decisions regarding when to migrate, however, may be affected by differences in life-history characteristics of individuals. Long-term and intensive study of a population of mule deer (*Odocoileus hemionus*) in the Sierra Nevada, California, USA, allowed us to document patterns of migration during 11 years that encompassed a wide array of environmental conditions. We used two new techniques to properly account for interval-censored data and disentangle effects of broad-scale climate, local weather patterns, and plant phenology on seasonal patterns of migration, while incorporating effects of individual life-history characteristics. Timing of autumn migration varied

substantially among individual deer, but was associated with the severity of winter weather, and in particular, snow depth and cold temperatures. Migratory responses to winter weather, however, were affected by age, nutritional condition, and summer residency of individual females. Old females and those in good nutritional condition risked encountering severe weather by delaying autumn migration, and were thus risk-prone with respect to the potential loss of foraging opportunities in deep snow compared with young females and those in poor nutritional condition. Females that summered on the west side of the crest of the Sierra Nevada delayed autumn migration relative to east-side females, which supports the influence of the local environment on timing of migration. In contrast, timing of spring migration was unrelated to individual life-history characteristics, was nearly twice as synchronous as autumn migration, differed among years, was related to the southern oscillation index, and was influenced by absolute snow depth and advancing phenology of plants. Plasticity in timing of migration in response to climatic conditions and plant phenology may be an adaptive behavioral strategy, which should reduce the detrimental effects of trophic mismatches between resources and other life-history events of large herbivores. Failure to consider effects of nutrition and other life-history traits may cloud interpretation of phenological patterns of mammals and conceal relationships associated with climate change.

Population abundance and ecological interactions

Many physiological processes are temperature and water-dependent. Marine species are also influenced by physical factors associated with ocean processes such as the El Niño/Southern Oscillation and the Pacific Decadal Oscillation. Organisms may adapt to climate-related changes in temperature and water availability through the responses discussed earlier—migration to suitable habitats, changes in behavior such as in the timing of life cycle events, or changes in morphology. Species unable to adapt to changing climate conditions may be at risk of significant population declines. In addition to the physical factors associated with climate, biological factors and interactions such as the availability of food or prey, diseases, and parasite infestations, can affect growth, survival, reproduction and ultimately, population size.

The linkages between climate change and population size, as well as interactions among species whose populations have been impacted by climate change, are the subject of papers summarized in this section. Many of the papers that address marine population impacts present a multi-species or ecosystem-level discussion, rather than a single-species focus.

Terrestrial

Climate change effects on walnut pests in California. Luedeling E, Steinmann KP, Zhang MH, Brown PH, Grant J and Girvetz EH (2011). *Global Change Biology*, 17(1): 228-238. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02227.x/abstract

See abstract in: *Impacts on plants: Agricultural crops*

A complete record from colonization to extinction reveals density dependence and the importance of winter conditions for a population of the silvery blue, *Glaucopsyche lygdamus*. Forister ML, Fordyce JA, McCall AC and Shapiro AM (2011). *Journal of Insect Science*, II(130). http://jinsectscience.oxfordjournals.org/content/11/1/130.abstract

Geographic Location: California/Davis Area
Type of Reference: Research Paper

Abstract: Butterflies in the family Lycaenidae are often the focus of conservation efforts. However, our understanding of lycaenid population dynamics has been limited to relatively few examples of long-term monitoring data that have been reported. Here, factors associated with population regulation are investigated using a complete record of a single population of the silvery blue, *Glaucopsyche lygdamus* Doubleday (Lepidoptera: Lycaenidae). Adults of *G. lygdamus* were first observed in an annual grassland near Davis, California, in 1982 and were last seen in 2003. Relationships between inter-annual variation in abundance and climatic variables were examined, accounting for density dependent effects. Significant effects of both negative density dependence and climatic variation were detected, particularly precipitation and temperature during winter months. Variation in precipitation, the strongest predictor of abundance, was associated directly and positively with butterfly abundance in the same year. Winter temperatures had a negative effect in the same year, but had a lagged, positive effect on abundance in the subsequent year. Mechanistic hypotheses are posed that include climatic effects mediated through both larval and adult plant resources.

Climate change refugia for biodiversity in the Klamath-Siskiyou Ecoregion. Olson D, Dellasala DA, Noss RF, Strittholt JR, Kass J, Koopman ME, et al. (2012). *Natural Areas Journal*, 32(1): 65-74. http://www.bioone.org/doi/abs/10.3375/043.032.0108

Geographic Location: Northern California
Type of Reference: Research Paper

Abstract: The Klamath-Siskiyou Ecoregion has been a refuge for species during past climate change events, but current anthropogenic stressors are likely compromising its effectiveness as a refugium for this century's projected changes. Reducing non-climate stressors and securing protection for large, complex landscapes are important long-term actions to alleviate climate change impacts on biodiversity. Equally important is the immediate protection of a network of climate change microrefugia, particularly old growth and intact forests on north-facing slopes and in canyon bottoms, lower- and middle-elevations, wetter coastal mountains, and along elevational gradients. Such areas provide local opportunities for vulnerable species to persist within the ecoregion. We identify a provisional set of 22 highest-priority and 40 high-priority microrefugia that occur mostly outside of existing protected areas and along wetter and lower elevations of the ecoregion. Proposed reserve designs, if fully implemented, would capture most of the recommended microrefugia, although we found 11 important gaps. Most of the

region's biodiversity, endemic species, and species vulnerable to climate change are invertebrates, non-vascular plants, and fungi that are largely restricted to persistently cool and moist late-successional forests. Opportunities for climate change response for vulnerable taxa will necessarily be local due to a limited capacity of many species to move to new habitat, even over relatively small distances where land use practices create inhospitable conditions. The ecoregion's distinctive and endemic serpentine-substrate flora also is at risk and possible refugia are sites that will retain wet soil conditions, such as seeps and bogs.

How does climate change cause extinction? Cahill AE, Aiello-Lammens ME, Fisher-Reid MC, Hua X, Karanewsky CJ, Yeong Ryu H, et al. (2012). *Proceedings of the Royal Society B: Biological Sciences*.
http://rspb.royalsocietypublishing.org/content/early/2012/10/15/rspb.2012.1890.abstract

Geographic Location: Global
Type of Reference: Research Paper

Abstract: Anthropogenic climate change is predicted to be a major cause of species extinctions in the next 100 years. But what will actually cause these extinctions? For example, will it be limited physiological tolerance to high temperatures, changing biotic interactions or other factors? Here, we systematically review the proximate causes of climate-change related extinctions and their empirical support. We find 136 case studies of climatic impacts that are potentially relevant to this topic. However, only seven identified proximate causes of demonstrated local extinctions due to anthropogenic climate change. Among these seven studies, the proximate causes vary widely. Surprisingly, none show a straightforward relationship between local extinction and limited tolerances to high temperature. Instead, many studies implicate species interactions as an important proximate cause, especially decreases in food availability. We find very similar patterns in studies showing decreases in abundance associated with climate change, and in those studies showing impacts of climatic oscillations. Collectively, these results highlight our disturbingly limited knowledge of this crucial issue but also support the idea that changing species interactions are an important cause of documented population declines and extinctions related to climate change. Finally, we briefly outline general research strategies for identifying these proximate causes in future studies.

Morphological Adaptations for Digging and Climate-Impacted Soil Properties Define Pocket Gopher (*Thomomys* spp.) Distributions. Marcy AE, Fendorf S, Patton JL and Hadly EA (2013). *Plos One*, 8(5).
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0064935

Geographic Location: California
Type of Reference: Research Paper

Abstract: Species ranges are mediated by physiology, environmental factors, and competition with other organisms. The allopatric distribution of five species of northern Californian pocket gophers (*Thomomys spp*.) is hypothesized to result from competitive

exclusion. The five species in this environmentally heterogeneous region separate into two subgenera, *Thomomys* or *Megascapheus*, which have divergent digging styles. While all pocket gophers dig with their claws, the tooth-digging adaptations of subgenus *Megascapheus* allow access to harder soils and climate-protected depths. In a Northern Californian locality, replacement of subgenus *Thomomys* with subgenus *Megascapheus* occurred gradually during the Pleistocene-Holocene transition. Concurrent climate change over this transition suggests that environmental factors - in addition to soil - define pocket gopher distributional limits. Here we show 1) that all pocket gophers occupy the subset of less energetically costly soils and 2) that subgenera sort by percent soil clay, bulk density, and shrink-swell capacity (a mineralogical attribute). While clay and bulk density (without major perturbations) stay constant over decades to millennia, low precipitation and high temperatures can cause shrink-swell clays to crack and harden within days. The strong yet underappreciated interaction between soil and moisture on the distribution of vertebrates is rarely considered when projecting species responses to climatic change. Furthermore, increased precipitation alters the weathering processes that create shrink-swell minerals. Two projected outcomes of ongoing climate change-higher temperatures and precipitation-will dramatically impact hardness of soil with shrink-swell minerals. Current climate models do not include factors controlling soil hardness, despite its impact on all organisms that depend on a stable soil structure.

Changes in occurrence, richness, and biological traits of dragonflies and damselflies (Odonata) in California and Nevada over the past century. Ball-Damerow JE, M'Gonigle LK and Resh VH (2014). *Biodiversity and Conservation*. 23(8): 2107-2126. http://link.springer.com/article/10.1007/s10531-014-0707-5

Geographic Location: California/Northwestern Nevada
Type of Reference: Research Paper

Abstract: Increases in water demand, urbanization, and severity of drought threaten freshwater ecosystems of the arid western United States. Historical assessments of change in assemblages over time can help determine the effects of these stressors but, to date, are rare. In the present study, we resurveyed 45 sites originally sampled in 1914–1915 for Odonata (dragonflies and damselflies) adults throughout central California and northwestern Nevada, USA. We examined changes in species occurrence rates, taxonomic richness, and biological trait composition in relation to climate changes and human population increases. While species richness at individual sites did not change significantly, we found that odonate assemblages have become more similar across sites. Homogenization is a result of the expansion of highly mobile habitat generalists, and the decline of both habitat specialists and species with an overwintering diapause stage. Using a multi-species mixed-effects model, we found that overall occurrences of Odonata increased with higher minimum temperatures. Habitat specialists and species with a diapause stage, however, occurred less often in warmer regions and more often in areas with higher precipitation. Habitat specialists occurred less often in highly populated sites. Life history traits of Odonata, such as dispersal ability, habitat specialization, and diapause, are useful predictors of species-specific responses to urbanization and climate change in this region.

Contribution of urban expansion and a changing climate to decline of a butterfly fauna. Casner KL, Forister ML, O'Brien JM, Thorne J, Waetjen D and Shapiro AM (2014). *Conservation Biology*, 28(3): 773-782.
http://onlinelibrary.wiley.com/doi/10.1111/cobi.12241/abstract

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: Butterfly populations are naturally patchy and undergo extinctions and recolonizations. Analyses based on more than two decades of data on California's Central Valley butterfly fauna show a net loss in species richness through time. We analyzed 22 years of phenological and faunistic data for butterflies to investigate patterns of species richness over time. We then used 18-22 years of data on changes in regional land use and 37 years of seasonal climate data to develop an explanatory model. The model related the effects of changes in land-use patterns, from working landscapes (farm and ranchland) to urban and suburban landscapes, and of a changing climate on butterfly species richness. Additionally, we investigated local trends in land use and climate. A decline in the area of farmland and ranchland, an increase in minimum temperatures during the summer and maximum temperatures in the fall negatively affected net species richness, whereas increased minimum temperatures in the spring and greater precipitation in the previous summer positively affected species richness. According to the model, there was a threshold between 30 percent (%) and 40% working-landscape area below which further loss of working-landscape area had a proportionally greater effect on butterfly richness. Some of the isolated effects of a warming climate acted in opposition to affect butterfly richness. Three of the four climate variables that most affected richness showed systematic trends (spring and summer mean minimum and fall mean maximum temperatures). Higher spring minimum temperatures were associated with greater species richness, whereas higher summer temperatures in the previous year and lower rainfall were linked to lower richness. Patterns of land use contributed to declines in species richness (although the pattern was not linear), but the net effect of a changing climate on butterfly richness was more difficult to discern.

Climatic variation and tortoise survival: Has a desert species met its match?
Lovich JE, Yackulic CB, Freilich J, Agha M, Austin M, Meyer KP, et al. (2014). *Biological Conservation*, 169: 214-224.
http://www.sciencedirect.com/science/article/pii/S0006320713003443

Geographic Location: California/Sonoran Desert
Type of Reference: Research Paper

Abstract: While demographic changes in short-lived species may be observed relatively quickly in response to climate changes, measuring population responses of long-lived species requires long-term studies that are not always available. We analyzed data from a population of threatened Agassiz's desert tortoises (*Gopherus*

agassizii) at a 2.59 square kilometer (km^2) study plot in the Sonoran Desert ecosystem of Joshua Tree National Park, California, USA from 1978 to 2012 to examine variation in apparent survival and demography in this long-lived species. Transect-based, mark-recapture surveys were conducted in 10 of those years to locate living and dead tortoises. Previous modeling suggested that this area would become unsuitable as tortoise habitat under a warming and drying climate scenario. Estimated adult population size declined greatly from 1996 to 2012. The population appeared to have high apparent survival from 1978 to 1996 but apparent survival decreased from 1997 to 2002, concurrent with persistent drought. The best model relating apparent survivorship of tortoises ≥18 centimeters (cm) over time was based on a three year moving average of estimated winter precipitation. The postures and positions of a majority of dead tortoises found in 2012 were consistent with death by dehydration and starvation. Some live and many dead tortoises found in 2012 showed signs of predation or scavenging by mammalian carnivores. Coyote (*Canis latrans*) scats and other evidence from the site confirmed their role as tortoise predators and scavengers. Predation rates may be exacerbated by drought if carnivores switch from preferred mammalian prey to tortoises during dry years. Climate modeling suggests that the region will be subjected to even longer duration droughts in the future and that the plot may become unsuitable for continued tortoise survival. Our results showing wide fluctuations in apparent survival and decreasing tortoise density over time may be early signals of that possible outcome.

Radiocarbon dating of American pika fecal pellets provides insights into population extirpations and climate refugia. Millar CI, Heckman K, Swanston C, Schmidt K, Westfall RD and Delany DL (2014). *Ecological Applications*, 24(7): 1748-1768. http://onlinelibrary.wiley.com/doi/10.1890/13-0520.1/abstract

Geographic Location: Great Basin, including California
Type of Reference: Research Paper

Abstract: The American pika (*Ochotona princeps*) has become a species of concern for its sensitivity to warm temperatures and potential vulnerability to global warming. We explored the value of radiocarbon dating of fecal pellets to address questions of population persistence and timing of site extirpation. Carbon was extracted from pellets collected at 43 locations in the western Great Basin, USA, including three known occupied sites and 40 sites of uncertain status at range margins or where previous studies indicated the species is vulnerable. We resolved calibrated dates with high precision (within several years), most of which fell in the period of the mid-late 20^{th} century bomb curve. The two-sided nature of the bomb curve renders far- and near-side dates of equal probability, which are separated by one to four decades. We document methods for narrowing resolution to one age range, including stratigraphic analysis of vegetation collected from pika haypiles. No evidence was found for biases in atmospheric Carbon 14 levels due to fossil-derived or industrial carbon dioxide (CO_2) contamination. Radiocarbon dating indicated that pellets can persist for >59 years; known occupied sites resolved contemporary dates. Using combined evidence from field observations and radiocarbon dating, and the Bodie Mountains as an example, we propose a historical biogeographic scenario for pikas in minor Great Basin mountain

ranges adjacent to major cordillera, wherein historical climate variability led to cycles of extirpation and recolonization during alternating cool and warm centuries. Using this model to inform future dynamics for small ranges in biogeographic settings similar to the Bodie Mountains in California, extirpation of pikas appears highly likely under directional warming trends projected for the next century, even while populations in extensive cordillera (e.g., Sierra Nevada, Rocky Mountains, Cascade Range) are likely to remain viable due to extensive, diverse habitat and high connectivity.

A hierarchical perspective on the diversity of butterfly species' responses to weather in the Sierra Nevada Mountains. Nice CC, Forister ML, Gompert Z, Fordyce JA and Shapiro AM (2014). *Ecology*, 95(8): 2155-2168. http://www.esajournals.org/doi/abs/10.1890/13-1227.1

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: An important and largely unaddressed issue in studies of biotic-abiotic relationships is the extent to which closely related species, or species living in similar habitats, have similar responses to weather. We addressed this by applying a hierarchical, Bayesian analytical framework to a long-term data set for butterflies which allowed us to simultaneously investigate responses of the entire fauna and individual species. A small number of variables had community-level effects. In particular, higher total annual snow depth had a positive effect on butterfly occurrences, while spring minimum temperature and El Niño-Southern Oscillation (ENSO) sea-surface variables for April-May had negative standardized coefficients. Our most important finding was that variables with large impacts at the community-level did not necessarily have a consistent response across all species. Species-level responses were much more similar to each other for snow depth compared to the other variables with strong community effects. This variation in species-level responses to weather variables raises important complications for the prediction of biotic responses to shifting climatic conditions. In addition, we found that clear associations with weather can be detected when considering ecologically delimited subsets of the community. For example, resident species and non-ruderal species had a much more unified response to weather variables compared to non-resident species and ruderal species, which suggests local adaptation to climate. These results highlight the complexity of biotic-abiotic interactions and confront that complexity with methodological advances that allow ecologists to understand communities and shifting climates while simultaneously revealing species-specific variation in response to climate.

Vulnerability of birds to climate change in California's Sierra Nevada. Siegel RB, Pyle P, Thorne JH, Holguin AJ, Howell CA, Stock S, et al. (2014). *Avian Conservation and Ecology*, 9(1). http://www.ace-eco.org/vol9/iss1/art7/

Geographic Location: California
Type of Reference: Research Paper

Abstract: In a rapidly changing climate, effective bird conservation requires not only reliable information about the current vulnerability of species of conservation concern, but also credible projections of their future vulnerability. Such projections may enable managers to preempt or reduce emerging climate-related threats through appropriate habitat management. We used NatureServe's Climate Change Vulnerability Index (CCVI) to predict vulnerability to climate change of 168 bird species that breed in the Sierra Nevada mountains of California, USA. The CCVI assesses species-specific exposure and sensitivity to climate change within a defined geographic area, through the integration of (a) species' range maps, (b) information about species' natural history traits and ecological relationships, (c) historic and current climate data, and (d) spatially explicit climate change projections. We conducted the assessment under two different downscaled climate models with divergent projections about future precipitation through the middle of the 21st century. Assessments differed relatively little under the two climate models. Of five CCVI vulnerability ranking categories, only one species, White-tailed Ptarmigan (*Lagopus leucura*), received the most vulnerable rank, Extremely Vulnerable. No species received the second-highest vulnerability ranking, Highly Vulnerable. Sixteen species scored as Moderately Vulnerable using one or both climate models: Common Merganser (*Mergus merganser*), Osprey (*Pandion haliaetus*), Bald Eagle (*Haliaeetus leucocephalus*), Northern Goshawk (*Accipiter gentilis*), Peregrine Falcon (*Falco peregrinus*), Prairie Falcon (*Falco mexicanus*), Spotted Sandpiper (*Actitis macularius*), Great Gray Owl (*Strix nebulosa*), Black Swift (*Cypseloides niger*), Clark's Nutcracker (*Nucifraga columbiana*), American Dipper (*Cinclus mexicanus*), Swainson's Thrush (*Catharus ustulatus*), American Pipit (*Anthus rubescens*), Gray-crowned Rosy-Finch (*Leucosticte tephrocotis*), Pine Grosbeak (*Pinicola enucleator*), and Evening Grosbeak (*Coccothraustes vespertinus*). Species associated with alpine/subalpine habitats and aquatic habitats received significantly more vulnerable rankings than birds associated with other habitats. In contrast, species of foothill, sagebrush, and chaparral habitats ranked as less vulnerable than other species, and our results suggest these species may respond to climate change in the region with population increases or range expansions.

Aquatic (Marine and Freshwater)

Decadal-scale changes in southern California sciaenids under different levels of harvesting pressure. Miller EF, Pondella DJ, Beck DS and Herbinson KT (2011). *Ices Journal of Marine Science*, 68(10): 2123-2133. http://icesjms.oxfordjournals.org/content/68/10/2123.full

Geographic Location: Pacific Ocean/Southern California
Type of Reference: Research Paper

Abstract: A unique 38-year time-series of power-plant entrapment data collected across similar to 170 kilometers of the southern California coastline was examined to describe the decadal-scale trends in common Southern California Bight sciaenid abundance in relation to oceanographic conditions. Adult catches for five of seven species declined at differing rates and severity. Declines of up to 94 percent (%) were

detected in historically common species such as *Genyonemus lineatus*, whereas historically less abundant species have increased dramatically, e. g. *Umbrina roncador* (2626%). Over time, the entrapped community became increasingly influenced by species with more southerly distributions, indicated by a significant decline in the average latitudinal midpoint of the community. This shift was significantly related to rising ocean temperature and took place in the early to mid-1980s. The observed species-specific abundance changes in all species except *Atractoscion nobilis* were significantly correlated with sea surface temperature, nearshore plankton volumetric biomass, *G. lineatus* or *Seriphus politus* nearshore larval density, or a combination of these. Patterns in *A. nobilis* abundance were the most isolated, likely reflecting its standing as an intensively fished species, unlike the other six species evaluated. The consistent relationship with environmental indices strongly supported the notion of a faunal shift driven by bottom-up forcing.

Physical and ecological responses of sandy beaches to the 1997-98 El Niño. Revell DL, Dugan JE and Hubbard DM (2011). *Journal of Coastal Research*, 27(4): 718-730. http://www.bioone.org/doi/abs/10.2112/JCOASTRES-D-09-00179.1

See abstract in *Impacts on Physical Systems: Sea level rise*

Hidden signals of climate change in intertidal ecosystems: What (not) to expect when you are expecting. Helmuth B, Yamane L, Lalwani S, Matzelle A, Tockstein A and Gao N (2011). *Journal of Experimental Marine Biology and Ecology*, 400(1-2): 191-199. http://www.sciencedirect.com/science/article/pii/S0022098111000529

Geographic Location: Pacific Ocean /Central California Coast
Type of Reference: Research Paper

Abstract: One of the most significant biological impacts of global climate change is through alterations of organismal body temperature, which ultimately drives almost all physiological processes. Using a simple heat budget model ground-truthed using ~five years of in situ temperature data collected using biomimetic sensors, we explored the sensitivity of aerial (low tide) mussel body temperature at three tidal elevations to changes in air temperature, solar radiation, wind speed, wave height, and the timing of low tide at a site in central California, USA (Bodega Bay). Results suggest that while increases in air temperature and solar radiation can significantly alter the risk of exposure to stressful conditions, especially at upper intertidal elevations, patterns of risk can be substantially reduced by convective cooling such that even moderate increases in mean wind speed (~ one meter per second) can theoretically counteract the effects of substantial (2.5°Celsius) increases in air temperature. Simulations further suggest that shifts in the timing of low tide (+one hour), such as occur moving to different locations along the coast of California, can have very large impacts on sensitivity to increases in air temperature. Depending on the timing of low tide, at some sites increases in air temperature will primarily affect animals in the upper intertidal zone, while at other sites animals will be affected across all tidal elevations. Field measurements and model predictions show that animal temperatures are often high even when air temperatures

are not, confirming the importance of solar radiation in the heat budgets of intertidal ectotherms. Conversely, body temperatures are not always elevated even when low tide air temperatures are extreme due to the combined effects of convective cooling and wave splash. The results of these simulations, coupled with ongoing field measurements, suggest that the timing and magnitude of warming will be highly variable at coastal sites, and can be driven to a large extent by local oceanographic and meteorological processes. Moreover, they strongly caution against the use of single environmental metrics such as air temperature as indicators of past, current and future physiological stress on the west coast of North America, and instead advocate for approaches that consider the interactive roles of multiple physical drivers.

Patterns and processes of compositional change in a California epibenthic community. Sorte CJB and Stachowicz JJ (2011). *Marine Ecology Progress Series*, 435: 63-74. http://www.int-res.com/abstracts/meps/v435/p63-74/

Geographic Location: Pacific Ocean/Central California Coast
Type of Reference: Research Paper

Abstract: As human modifications of the earth's systems have increased, so has interest in understanding past changes in order to predict future ecological trajectories. We compared historical (1969–1971) and contemporary (2005–2009) abundances of species in the marine epibenthic community of Bodega Harbor, California, USA. Between these two time periods, we found a decrease in the abundance of native species and an increase in non-native dominance, including of several species that were either rare or absent ~35 years ago and whose introduction was likely human-mediated. This compositional shift was concurrent with an increase in local water temperature of ~1°Celsius over the same interval. To address the potential role of ocean warming in facilitating the increase of the new dominant species and maintaining compositional shifts, we evaluated the correlation between temperature and recruitment for 15 species. We found that recruitment timing and magnitude were positively related to temperature for non-native species but not for native species overall. Combined with previous results suggesting effects of ocean warming on the relative performance of native vs. non-native species in this community, our study indicates the potential for continued dominance of non-native species in Bodega Harbor due to local temperature increases. Simultaneously, anthropogenic transport has been responsible for several recent introductions of competitively dominant species, and shifts in contaminant loads or other factors between the two time periods could also contribute to compositional shifts, both historically and in the future. Our results highlight the need for studies of these additional factors, as well as the mechanisms underlying their effects on compositional shifts, in order to predict future changes.

Marine mammal response to interannual variability in Monterey Bay, California. Burrows JA, Harvey JT, Newton KM, Croll DA and Benson SR (2012). *Marine Ecology Progress Series*, 461: 257-271. http://www.int-res.com/abstracts/meps/v461/p257-271/

Geographic Location: Pacific Ocean/Monterey Bay, California
Type of Reference: Research Study

Abstract: The coastal upwelling ecosystem near Monterey Bay, California, is a productive yet variable ecosystem and an important foraging area for many mobile apex predators, such as marine mammals. Long-term studies are necessary to better understand how wide-ranging predators respond to temporal environmental variability; however, few of these studies exist. We conducted monthly shipboard line-transect surveys in Monterey Bay from 1997 to 2007. We identified 22 species of marine mammals, and calculated monthly and annual densities for the 12 most commonly sighted (focal) species. Species richness remained relatively constant from 1997 to 2006. Focal species were most evenly distributed but least dense during the anomalous upwelling conditions of 2005, and least even but dense during the 1997/1998 El Niño event. There were no statistically significant differences in the densities of marine mammal species between warmer and cooler years. The community and species-specific responses of marine mammals to warm-water years differed depending on the mechanism of oceanographic variability. During the 1997/1998 El Niño (a basin-wide event), marine mammals aggregated in nearshore areas, such as Monterey Bay, with relatively greater productivity than offshore regions, whereas during anomalous upwelling conditions of 2005 (a more localized oceanographic event), marine mammals redistributed away from Monterey Bay to areas less affected by the anomaly.

Introduction. Seabirds and climate change: roadmap for the future. Sydeman WJ, Thompson SA and Kitaysky A (2012). *Marine Ecology Progress Series*, 454: 107-117. http://www.int-res.com/abstracts/meps/v454/p107-117/

Geographic Location: Global
Type of Reference: Meta-Analysis

Abstract: Based in part on a symposium held at the first World Seabird Conference in September, 2010 in Victoria, BC, Canada, we present a Theme Section (TS) on the topic of seabirds and climate change. We introduce this TS with a meta-analysis of key attributes of the current seabird-climate literature, based on 108 publications representing almost 3000 seabird-climate associations (mostly correlations) published up to 2011. Using the papers in this TS and our meta-analysis, a brief roadmap for the future of seabird-climate change research is presented. Seabird studies have contributed substantially to the literature on marine climate effects. To improve our understanding of climate change effects on seabirds at the global scale, however, additional low-latitude, mechanistic, and 'end-to-end' modeling studies, including integration of climatic, oceanographic, food web, and population dynamics models, should be conducted. This approach will enhance our understanding of the relationship between climate and population dynamics, and facilitate seabird conservation in a changing world.

State of the California Current 2012-13: No Such Thing as an "Average" Year. Wells BK, Schroeder ID, Santora JA, Hazen EL, Bograd SJ, Bjorkstedt EP, et al. (2013). California Cooperative Oceanic Fisheries Investigations Reports, 54: 37-71. http://www.calcofi.org/publications/calcofireports/v54/Vol_54_StateOfCurrent_37-71.pdf

See abstract in *Physical Systems: Changes in ocean temperature and circulation*

Synthesis of Pacific Ocean Climate & Ecosystem Dynamics. Di Lorenzo E, Combes V, Keister J, Strub T, Franks TA, et al. (2013). *Oceanograpy,* 26(4):68-81. http://tos.org/oceanography/assets/docs/26-4_di_lorenzo2.pdf

See abstract in *Physical Systems: Changes in ocean temperature and circulation*

Taking the Pulse of Marine Ecosystems. The Importance of Coupling Long-Term Physical and Biological Observations in the Context of Global Change Biology. Hofmann GE, Blanchette CA, Rivest EB and Kapsenberg L (2013). *Oceanography*, 26(3): 140-148. http://tos.org/oceanography/article/taking-the-pulse-of-marine-ecosystems-the-importance-of-coupling-long-term-

Geographic Location: Global and California
Type of Reference: Research Paper

Abstract: Research programs that co-locate environmental sensors with "biology" can enable the linking of environmental data with changes in biological or ecological processes. The coastal and marine Long Term Ecological Research (LTER) programs use this strategy, measuring parameters such as air and sea temperature, wave and storm energy, and seawater chemistry along with biological responses to them. This investment in technology has proven to be valuable and a major scientific asset for understanding how climate change, and environmental change in general, might alter marine populations and communities. Such a strategy can also aid in studies of global change biology of critical species, helping to place laboratory experiments and predictions of response in a broader environmental context. This coupling of long-term *physical* and biological observations has already detected fingerprints of change in sites such as the Palmer LTER situated on the western Antarctic Peninsula. In addition, new autonomous pH sensors recently deployed at two marine LTERs-Santa Barbara Coastal and Moorea Coral Reef-are generating long-term data sets that highlight the responses of their marine communities to rapidly changing ocean conditions.

Modeling Physical-Biological Responses to Climate Change in the California Current System. Franks PJS, Di Lorenzo E, Goebel NL, Chenillat F, Riviere P, Edward CA, et al. (2013). *Oceanography*, 26(3): 26-33. http://tos.org/oceanography/article/modeling-physical-biological-responses-to-climate-change-in-the-californiac

See abstract in *Physical Systems: Changes in ocean temperature and circulation*

Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Katz J, Moyle PB, Quinones RM, Israel J and Purdy S (2013). *Environmental Biology of Fishes*, 96(10-11): 1169-1186. http://link.springer.com/article/10.1007%2Fs10641-012-9974-8

Geographic Location: Pacific Ocean and Fresh Water/California
Type of Reference: Review Article

Abstract: California contains the southernmost native populations of most Pacific Coast salmon and trout, many of which appear to be rapidly headed toward extinction. A quantitative protocol was developed to determine conservation status of all salmonids native to the state. Results indicate that if present trends continue, 25 (78 percent) of the 32 taxa native to California will likely be extinct or extirpated within the next century, following the bull trout (*Salvelinus confluentus*), which was extirpated in the 1970s. California's salmonids are adapted to living in a topographically diverse region with a Mediterranean climate, characterized by extreme seasonal and inter-annual variability in streamflow. Consequently, California salmonids have evolved extraordinary life history diversity to persist in the face of stressful conditions that often approach physiological limits. The spatial distributions of California salmonids vary from wide-ranging anadromous forms to endemic inland forms persisting in only a few kilometers of stream. Eighty-one percent of anadromous taxa are threatened with extinction and 73 percent inland taxa are either threatened or already extinct. Although specific drivers of decline differ across species, major causes of decline are related to increasing competition with humans for water, human degradation of watersheds, and adverse effects of hatchery propagation. Climate change, interacting with the other causes of decline, is increasing the trajectory towards extinction for most populations. Bringing all of California's salmonid fishes back from the brink of extinction may not be possible. If there are bold changes to management policy, however, self-sustaining populations of many species may be possible due to their inherent ability to adapt to changing conditions.

Effects of fluctuations in sea-surface temperature on the occurrence of small cetaceans off Southern California. Henderson EE, Forney KA, Barlow JP, Hildebrand JA, Douglas AB, Calambokidis J, et al. (2014). *Fishery Bulletin*, 112(2-3): 159-177. http://fishbull.noaa.gov/1122_3/henderson.pdf

Geographic Location: Pacific Ocean/Southern California
Type of Reference: Report

Abstract: The link between ocean temperature and spatial and temporal distribution patterns of eight species of small cetaceans off Southern California was examined during the period 1979-2009. Averages and anomalies of sea-surface temperatures (SSTs) were used as proxies for SST fluctuations on three temporal scales: seasonal, El Niño-Southern Oscillations (ENSO), and Pacific Decadal Oscillations (PDO). The hypothesis that cetacean species assemblages and habitat associations in southern California waters co-vary with these periodic changes in SST was tested by using generalized additive models. Seasonal SST averages were included as a predictor in the models for Dall's porpoise (*Phocoenoides dalli*), and common dolphins (*Delphinus spp*.), northern right whale dolphin (*Lisso-delphis borealis*), and Risso's dolphin (*Grampus griseus*). The ENSO index was included as a predictor for northern right whale, long-beaked common (*Delphinus capensis*), and Risso's dolphins. The PDO index was selected as a predictor for Dall's porpoise and Pacific white-sided (*Lagenorhynchus obliquidens*), common, and bottlenose (*Tursiops truncatus*) dolphins. A metric of bathymetric depth was included in every model, and seafloor slope was included in five of the nine models, an indication of a distinctive spatial distribution for each species that may represent niche or resource partitioning in a region where multiple species have overlapping ranges. Temporal changes in distribution are likely a response to changes in prey abundance or dispersion, and these patterns associated with SST variation may foreshadow future, more permanent shifts in distribution range that are due to global climate change.

Non-stationary seabird responses reveal shifting ENSO dynamics in the northeast Pacific. Schmidt AE, Botsford LW, Eadie JM, Bradley RW, Di Lorenzo E and Jahncke J (2014). *Marine Ecology Progress Series*, 499: 249-258. http://www.int-res.com/abstracts/meps/v499/p249-258/

Geographic Location: Pacific Ocean/Central California
Type of Reference: Research Paper

Abstract: The impacts of the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) on the ecology of the northeast Pacific are well known. However, recently there has been a shift in the dominance of El Niño events from the eastern Pacific (canonical) El Niño, to the central Pacific (Modoki) El Niño, concurrent with a strengthening of the North Pacific Gyre Oscillation (NPGO). Our examination of ocean conditions and seabird reproductive success in central California shows that the way these physical factors affect the pelagic food web is also changing. Reproduction of Cassin's auklet *Ptycoramphus aleuticus* and Brandt's cormorant *Phalacrocorax penicillatus*, species that forage at different trophic levels, responded primarily to ENSO variability from the 1970s to the 1990s. By 1995, however, NPGO had become the dominant variable determining Cassin's auklet reproductive success. Eventually, NPGO also became correlated with Brandt's cormorant success but in the opposite direction to Cassin's auklet. Thus, during the mid-1990s, the correlation between the reproduction of these two species weakened and eventually became inversely correlated. This shift from coherent reproduction, presumably bottom-up driven, to an inverse relationship between the two species suggests that the structure of the local marine food web changed as the equatorial forcing changed. This non-stationary response of seabirds to

physical forcing is cause for concern since predictions of future ecosystem productivity and effects of climate change rely on the assumption that a species' response to environmental conditions is consistent over time.

State of the California Current 2013-2014: El Niño Looming. (2014). California Cooperative Fisheries Investigative (CalCOFI) *Reports*, 55:51-87. http://www.calcofi.org/publications/calcofireports/v55/Vol_55_SOTCC_51-87.pdf

See abstract in *Physical Systems: Upwelling*

Climate change and decadal shifts in the phenology of larval fishes in the California Current ecosystem. Asch RG (2015). *Proceedings of the National Academy of Sciences*, 112(30): E4065-E4074. http://www.pnas.org/content/112/30/E4065.abstract

Geographic Location: California Current
Type of Reference: Research Paper

Abstract: In terrestrial ecosystems, earlier phenology (i.e., seasonal timing) is a hallmark organismal response to global warming. Less is known about marine phenological responses to climate change, especially in Eastern Boundary Current Upwelling (EBCU) ecosystems that generate >20 percent of fish catch. The phenology of 43 EBCU fish species was examined over 58 years; 39 percent of phenological events occurred earlier in recent decades, with faster changes than many terrestrial ecosystems. Zooplankton did not shift their phenology synchronously with most fishes. Fishes that aren't changing their phenology synchronously with zooplankton may be subject to mismatches with prey, potentially leading to reduced recruitment to fisheries. Adjusting the timing of seasonal management tactics (e.g., fishery closures, hatchery releases) may help ensure that management remains effective.

Impacts on plants

Like animals, plant species have unique requirements for climate and environmental conditions. Globally, a growing number of studies have demonstrated plant responses to changing climatic conditions. Such responses include: changes in the timing of life-cycle events (such as blooming); changes in range boundaries or the distribution of the population within their ranges (generally to higher elevations or latitudes); and changes in species abundance.

The papers addressing impacts on plants are grouped below under three separate headings: agricultural crops, terrestrial and aquatic vegetation (in general) and wildfires.

Agricultural crops

California produces nearly half of the fruits, nuts and vegetables grown in the United States and purchased across the nation. Agricultural crops can be affected by changes in temperature, CO_2 levels and precipitation. Warming may affect crop yields both beneficially (as a result, for example, of the lengthening of the growing season) and adversely (for example, due to a reduction in the magnitude and length of winter chill needed for fruit and nut production). Warmer temperatures and increased humidity may also promote the growth of weeds, insects and fungi that can adversely impact crop production. Finally, crop damage can result from extremes in heat, frost or precipitation.

Currently, there is little evidence of the observed impacts of climate change on agricultural crops. This may be due to non-climate factors, particularly management practices and technological improvements designed to maximize productivity.

Climate change effects on walnut pests in California. Luedeling E, Steinmann KP, Zhang MH, Brown PH, Grant J and Girvetz EH (2011). *Global Change Biology*, 17(1): 228-238. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02227.x/abstract

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: Increasing temperatures are likely to impact ectothermic pests of fruits and nuts. This paper aims to assess changes to pest pressure in California's US $0.7 billion walnut industry due to recent historic and projected future temperature changes. For two past (1950 and 2000) and 18 future climate scenarios (2041-2060 and 2080-2099; each for three General Circulation Models and three greenhouse gas emissions scenarios), 100 years of hourly temperature were generated for 205 locations. Degree-day models were used to project mean generation numbers for codling moth (*Cydia pomonella* L.), navel orangeworm (*Amyelois transitella* Walker), two-spotted spider mite (*Tetranychus urticae* Koch), and European red mite (*Panonychus ulmi* Koch). In the Central Valley, the number of codling moth generations predicted for degree days accumulated between April 1 and October 1 rose from 2-4 in 1950 to 3-5 among all future scenarios. Generation numbers increased from 10-18 to 14-24 for two-spotted spider mite, from 9-14 to 14-20 for European red mite, and from 2-4 to up to five for navel orangeworm. Overall pest pressure can thus be expected to increase substantially. Our study did not include the possibility of higher winter survival rates, leading to higher initial pest counts in spring, or of extended pest development times in the summer, factors that are likely to exacerbate future pest pressure. On the other hand, initiation of diapause may prevent an extension of the season length for arthropods, and higher incidence of heat death in summer may constrain pest population sizes. More information on the impact of climate change on complex agroecological food webs and on the response of pests to high temperatures is needed for improving the reliability of projections.

Effect of vineyard-scale climate variability on Pinot noir phenolic composition. Nicholas KA, Matthews MA, Lobell DB, Willits NH and Field CB (2011). *Agricultural and Forest Meteorology*, 151(12): 1556-1567. http://www.sciencedirect.com/science/article/pii/S0168192311002036

Geographic Location: California/North Coast
Type of Reference: Research Paper

Abstract: The sensitivity of agricultural crops to climate change is a major area for climate impact studies. The relationship between climate and three key phenolic compounds in grape skins important to premium wine quality (anthocyanins, tannins, and total phenolics) has not been well-studied. Here we conducted a three-year field study to collect and analyze berry samples from Pinot noir vineyards in the Carneros and Sonoma Valley American Viticultural Areas of California's North Coast wine country, and correlate phenolic measurements with climate statistics derived from hourly temperature measures at each vineyard site. We used several statistical approaches to identify key phenologically-based periods influencing phenolic concentration at maturity, including classification and regression trees, factor screening, principal component analysis, and pairwise correlations. The results from these statistical models showed that cool conditions following harvest the year before maturity, warm temperatures from budburst to bloom, and cool temperatures from bloom to veraison (the onset of ripening) were positively correlated with concentrations of all three classes of phenolics, although not all trends were statistically significant. Anthocyanins were positively and significantly correlated with temperatures between 16 and 22°Celsius from veraison to harvest. Tannins were significantly increased by warm nights preceding budburst and warm days from budburst to bloom. We measured relatively high levels of light interception (35 percent of incident photosynthetically active radiation), and we found that increased light interception was significantly correlated with lower levels of all three classes of phenolic compounds in this study. For the Pinot noir sites in this study, warm temperatures from budburst to bloom appear to increase phenolic concentrations, which is likely beneficial for wine quality. However, warmer periods during the preceding fall and summer during ripening appear to offset these effects. Given projections for greater summer warming in California with climate change, the overall impact of climate change on winegrowing is likely to be negative.

Differential responses of trees to temperature variation during the chilling and forcing phases. Luedeling E, Guo L, Dai JH, Leslie C and Blanke MM (2013). *Agricultural and Forest Meteorology*, 181: 33-42. http://www.sciencedirect.com/science/article/pii/S0168192313001780

Geographic Location: Global/China, Germany, California
Type of Reference: Research Paper

Abstract: Temperate-zone trees must fulfill cultivar-specific chilling and heat requirements during the dormant period, in order to produce leaves and flowers in the following growing season. Timing and accumulation rate of chill and heat are understood to determine the timing of spring events, but both processes are difficult to observe in dormant tree buds. Where long-term phenological observations are

available, Partial Least Squares (PLS) regression offers a statistical opportunity to delineate phases of chill and heat accumulation and determine the climatic requirements of trees. This study uses PLS regression to explore how the timing of spring events of chestnut in China, cherry in Germany and walnut in California is related to variation in the daily rates of chill and heat accumulation, as calculated with horticultural models. Dependent variables were 39 years of flowering dates for chestnuts in Beijing (China), 25 years of cherry bloom in Klein-Altendorf (Germany) and 54 years of walnut leaf emergence in Davis (California, USA). These were related to daily accumulation rates of chill, calculated with the Dynamic Model, and heat, calculated with the Growing Degree Hours Model. Compared to an earlier version of the procedure, in which phenological dates were related to unprocessed temperature data, delineation of chilling and forcing phases was much clearer when using horticultural metrics to quantify chill and heat. Chestnut bloom in the cold-winter climate of Beijing was found to depend primarily on the rate of heat accumulation, while cherry bloom in the temperate climate of Germany showed dependence on both chill and heat accumulation rates. The timing of walnut leaf emergence in the mild-winter climate of California depended much more strongly on chill accumulation rates. Chilling (in Chill Portions = CP) and heat (in Growing Degree Hours = GDH) requirements determined based on PLS regression were 79.8 +/- 5.3 CP and 13,466 +/- 1918 GDH for chestnut bloom in Beijing, 104.2 +/- 8.9 CP and 2698 +/- 1183 GDH for cherry bloom in Germany, and 37.5 +/- 5.0 CP and 11,245 +/- 1697 GDH for walnut leaf emergence in California. Spring phases of cherry in Klein-Altendorf and especially chestnut in Beijing will likely continue to advance in response to global warming, while for walnut in California, inadequate chilling may cause delays in flowering and leaf emergence. Such delays could serve as an early-warning indicator that future productivity may be threatened by climate change. The R package 'chillR' makes the method used in this study available for wider use.

Winter fog is decreasing in the fruit growing region of the Central Valley of California. Baldocchi D and Waller E (2014). *Geophysical Research Letters*, 41(9):3251-3256. http://onlinelibrary.wiley.com/doi/10.1002/2014GL060018/abstract

See abstract in: *Changes in climate: temperature*

Yield potential analysis to model dormancy requirements in pistachio. Pope KS, Brown PH, Dose V, Da Silva D and DeJong TM (2014). *Acta Horticulturae*. 1028: 103-106. http://www.actahort.org/books/1028/1028_16.htm

Geographic Location: California/Central Valley
Type of Reference: Research Paper

Abstract: Chilling requirements will affect how yield of temperate perennial crops responds to climate change, yet they remain difficult to quantify. Researchers have attempted to quantify the chilling requirement of pistachio (*Pistacia vera*) by forcing or modeling bud break. Both approaches assume that the timing or percentage of bud break is predictive of yield. However, given the low number of flowers that result in

harvested nuts even in a high chill year, bud break requirements may be very different from the amount of chill necessary for sustainable yields. We approached the question of chilling requirements by analyzing historic chill and county yield records in California's Central Valley. Preliminary results showed that in pistachio, above average yields were achieved with as little as 58 chill portions, at least 30 percent less than the bud break-derived chilling requirement estimation. These initial results indicate that processes beyond bud break may need to be considered in estimating chilling requirements and that failure to do so may cause researchers to overstate the potential impacts of climate change on temperate tree crops such as pistachio.

Modeling the effects of local climate change on crop acreage. Lee H & Sumner DA (2016). *California Agriculture*, 70(1):9-14. https://ucanr.edu/repositoryfiles/cav7001p9-160231.pdf

Geographic Location: California/Yolo County
Type of Reference: Research Paper

Abstract: The impacts of climate change on agriculture depend on local conditions and crops grown. For instance, warmer winter temperatures in a given area would reduce chill hours, potentially cutting yields for some crops but extending the growing season for others. Using a century of climate data and six decades of acreage data, we established quantitative economic relationships between the evolution of local climate and acreage of 12 important crops in Yolo County. We then used the historical trend in climate change to project future crop acreages in the county. Only marginal changes in acreage in 2050 were projected for tree and vine crops there, in part because chill hours, although lower, remained above critical values. Walnuts were the most vulnerable tree crop, and the projections indicated some cultivars might be marginal in years with particularly warm winters. Processing tomato acreage might increase, due to a longer growing season, and also alfalfa acreage, if water availability and other factors remain constant.

Vegetation

Like animals, plant species have unique requirements for climate and environmental conditions. Globally, a growing number of studies have demonstrated plant responses to changing climatic conditions. Such responses include: changes in the timing of life-cycle events (such as blooming); changes in range boundaries or the distribution of the population within their ranges (generally to higher elevations or latitudes); and changes in species abundance.

Terrestrial

Past and ongoing shifts in Joshua tree distribution support future modeled range contraction. Cole KL, Ironside K, Eischeid J, Garfin G, Duffy PB and Toney C (2011). *Ecological Applications*, 21(1): 137-149. http://onlinelibrary.wiley.com/doi/10.1890/09-1800.1/abstract

Geographic Location: Western United States, including California
Type of Reference: Research Paper

Abstract: The future distribution of the Joshua tree (*Yucca brevifolia*) is projected by combining a geostatistical analysis of 20th-century climates over its current range, future modeled climates, and paleoecological data showing its response to a past similar climate change. As climate rapidly warmed; similar to 11,700 years ago, the range of Joshua tree contracted, leaving only the populations near what had been its northernmost limit. Its ability to spread northward into new suitable habitats after this time may have been inhibited by the somewhat earlier extinction of megafaunal dispersers, especially the Shasta ground sloth. We applied a model of climate suitability for Joshua tree, developed from its 20th-century range and climates, to future climates modeled through a set of six individual general circulation models (GCM) and one suite of 22 models for the late 21st century. All distribution data, observed climate data, and future GCM results were scaled to spatial grids of; similar to one kilometer (km) and; similar to four km in order to facilitate application within this topographically complex region. All of the models project the future elimination of Joshua tree throughout most of the southern portions of its current range. Although estimates of future monthly precipitation differ between the models, these changes are outweighed by large increases in temperature common to all the models. Only a few populations within the current range are predicted to be sustainable. Several models project significant potential future expansion into new areas beyond the current range, but the species' historical and current rates of dispersal would seem to prevent natural expansion into these new areas. Several areas are predicted to be potential sites for relocation/assisted migration. This project demonstrates how information from paleoecology and modern ecology can be integrated in order to understand ongoing processes and future distributions.

Fine-scale patterns of soil and plant surface temperatures in an alpine fellfield habitat, White Mountains, California. Graham E, Rundel P, Kaiser W, Lam Y, Stealey M and Yuen E (2012). *Arctic, Antarctic, and Alpine Research*, 44(3): 288-295. http://www.bioone.org/doi/abs/10.1657/1938-4246-44.3.288

Geographic Location: California/White Mountains
Type of Reference: Research Paper

Abstract: Within alpine environments the interactions of air temperature, solar irradiance, wind, surface albedo, microtopography, and biotic traits all influence patterns of soil and plant canopy temperatures. The resulting mosaic of surface temperatures has a profound impact on ecosystem processes, plant survival, and ecophysiological

performance. Previous studies have documented large and persistent variations in microhabitat temperatures over mesoscale alpine terrains. We have used a novel mobile system to examine changes in soil and plant canopy surface temperatures at spatial scales of centimeters and temporal scales of minutes in an alpine fellfield habitat in the White Mountains of California. In the middle of a summer day, the mean surface temperature differences between points 2, 5, and 10 centimeters apart were 2.9, 5.4, and 9.0°Celsius (C), respectively, and extreme differences of 18°C or more were found over distances of a few centimeters. These thermal patterns are due not only to substrate material but also to biotic conditions of plant canopy architecture and ecophysiological traits of individual species. The magnitude of temperature variation at these fine scales is greater than the range of warming scenarios in Intergovernmental Panel on Climate Change (IPCC) projections, suggesting that these habitats offer the capacity of significant thermal heterogeneity for plant survival.

Forest mortality in high-elevation whitebark pine (*Pinus albicaulis*) forests of eastern California, USA; influence of environmental context, bark beetles, climatic water deficit, and warming. Millar CI, Westfall RD, Delany DL, Bokach MJ, Flint AL and Flint LE (2012). *Canadian Journal of Forest Research*, 42(4): 749-765. http://www.nrcresearchpress.com/doi/abs/10.1139/x2012-031#.VyJ00mGFN3c

Geographic Location: California/Eastern Mountains
Type of Reference: Research Paper

Abstract: Whitebark pine (*Pinus albicaulis* Engelm.) in subalpine zones of eastern California experienced significant mortality from 2007 to 2010. Dying stands were dense (mean basal area 47.5 square meters per hectare), young (mean 176 years), and even-age; mean stand mortality was 70 percent (%). Stands were at low elevations (mean 2993 meters), on northerly aspects, and experienced warmer, drier climates relative to the regional species distribution. White pine blister rust was not observed; mountain pine beetle infestations were extensive. Ring widths were negatively correlated with climatic water deficit and positively correlated with water-year precipitation. Although trees that survived had greater growth during the 20th century than trees that died, in the 19th century trees that eventually died grew better than trees that survived, suggesting selection for genetic adaptation to current climates as a result of differential tree mortality. Air surveys (2006–2010) in the Sierra Nevada, Mt. Shasta, and Warner Mountains showed similar trends to the intensive studies. Observed mortality from air surveys was highest in the Warner Mountains (38%) and lowest in the Sierra Nevada (5%); northern aspects at lower elevations within each mountain region had the highest probabilities of mortality and dying stands had higher climatic water deficit. Scenarios for the future of whitebark pine in California are discussed.

Growth-climate relationships for six subalpine tree species in a Mediterranean climate. Dolanc CR, Westfall RD, Safford HD, Thorne JH and Schwartz MW (2013). *Canadian Journal of Forest Research*, 43(12): 1114-1126. http://www.nrcresearchpress.com/doi/abs/10.1139/cjfr-2013-0196#.VyJ0bmGFN3c

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: A better understanding of the growth-climate relationship for subalpine trees is key to improving predictions about their future distributions under climate change. In subalpine regions of Mediterranean mountains, drought is an annual event, yet many sites can have long-lasting snowpack. We analyzed the growth-climate relationship from 1896 to 2006 for the six most abundant subalpine tree species (red fir (*Abies magnifica* A. Murray bis), whitebark pine (*Pinus albicaulis* Engelm.), Sierra/Cascade lodgepole pine (*Pinus contorta* var. murrayana (Balf.) Engelm.), Jeffrey pine (*Pinus jeffreyi* Balf.), western white pine (*Pinus monticola* Douglas ex D. Don), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carriére)) of the central Sierra Nevada, California, USA, a region with deep spring snowpack followed by strong summer drought. Chronologies for the six species exhibited a high degree of synchrony in their response to annual fluctuations in temperature and precipitation. For all six species, cool, wet conditions in the year prior to growth are conducive to good radial growth, as well as warm springs with sufficient moisture during the year of growth. For species more common on protected slopes, such as mountain hemlock, deep spring snowpack can limit growth. Although predictions of future precipitation trends in the region are uncertain, drought stress appears to already be increasing. If this trend continues, radial growth is likely to be inhibited for most or all species in our study. Trees growing where snowpack is deep may be least likely to suffer reduced growth.

Interactive effects of anthropogenic nitrogen enrichment and climate change on terrestrial and aquatic biodiversity. Porter EM, Bowman WD, Clark CM, Compton JE, Pardo LH and Soong JL (2013). *Biogeochemistry*, 114(1-3): 93-120. http://link.springer.com/article/10.1007/s10533-012-9803-3

Geographic Location: Global, Includes California
Type of Reference: Research Paper

Abstract: Biodiversity has been described as the diversity of life on earth within species, among species, and among ecosystems. The rate of biodiversity loss due to human activity in the last 50 years has been more rapid than at any other time in human history, and many of the drivers of biodiversity loss are increasing, including habitat loss, overexploitation, invasive species, climate change, and pollution, including pollution from reactive nitrogen (Nr). Of these stressors, climate change and Nr from anthropogenic activities are causing some of the most rapid changes. Climate change is causing warming trends that result in poleward and elevational range shifts of flora and fauna, and changes in phenology, particularly the earlier onset of spring events and migration, and lengthening of the growing season. Nitrogen (N) enrichment can enhance plant growth, but has been shown to favor, fast-growing, sometimes invasive, species over native species adapted to low N conditions. Although there have been only

a few controlled studies on climate change and N interactions, inferences can be drawn from various field observations. For example, in arid ecosystems of southern California, elevated N deposition and changing precipitation patterns have promoted the conversion of native shrub communities to communities dominated by annual non-native grasses. Both empirical studies and modeling indicate that N and climate change can interact to drive losses in biodiversity greater than those caused by either stressor alone. Reducing inputs of anthropogenic Nr may be an effective mitigation strategy for protecting biodiversity in the face of climate change.

Faster growth in warmer winters for large trees in a Mediterranean-climate ecosystem. Bigelow SW, Papaik MJ, Caum C and North MP (2014). *Climatic Change*, 123(2): 215-224. http://link.springer.com/article/10.1007%2Fs10584-014-1060-0

Geographic Location: California/Sierra Nevada and Cascades
Type of Reference: Research Paper

Abstract: Large trees (>76 centimeters breast-height diameter) are vital components of Sierra Nevada/Cascades mixed-conifer ecosystems because of their fire resistance, ability to sequester large amounts of carbon, and role as preferred habitat for sensitive species such as the California spotted owl. To investigate the likely performance of large trees in a rapidly changing climate, we analyzed growth rings of five conifer species against 20th century climate trends from local weather stations. Over the local station period of record, there were no temporal trends in precipitation, but maximum temperatures increased by 0.10 to 0.13 °Celsius (C)/decade (summer and autumn), and minimum temperatures increased by 0.11 to 0.19 °C/decade in all seasons. All species responded positively to precipitation, but more variation was explained by a significant positive response to minimum winter temperatures. High maximum summer temperature adversely affected growth of two species, and maximum spring temperatures in the year prior to ring formation were negatively associated with growth of one species. The strong coherent response to increasing minimum temperatures bodes well for growth of large trees in Sierra/Cascades region mixed conifer forest under continued climatic warming, but these trees will still be under threat by the increased fire intensity that is an indirect effect of warming.

Shifts in plant species elevational range limits and abundances observed over nearly five decades in a western North America mountain range. Kopp CW and Cleland EE (2014). *Journal of Vegetation Science*, 25(1): 135-146. http://onlinelibrary.wiley.com/doi/10.1111/jvs.12072/abstract

Geographic Location: California/White Mountains
Type of Reference: Research Paper

Abstract: Question: Have there been shifts in abundance and distribution of alpine and sub-alpine plant species along an elevational gradient in an arid North American mountain range during the last half-century? Location: Elevational gradient in the White Mountains, California, USA (37°30' North, 118°10' West). Methods: We conducted a 49 year re-survey of plant species distribution and abundance in areas originally

surveyed in 1961. Species abundance data were collected along line transects between elevations of 2900 and 4000 meters. We evaluated the degree of plant community shift over time across elevations; specifically, we expected species ranges to shift upward such that species peak abundances would be observed higher in elevation in 2010 than in 1961. To address this expectation we conducted a permutational multivariate linear model analysis with elevation, soil type and year as factors. We further performed single-species analyses to evaluate how focal species contributed to the multivariate community-level shifts between 2010 and 1961, and how these varied across elevations and soil types. Growing season climate data (June 1 through October 31) collected between 1961 and 2010 were analysed to quantify the change in annual mean temperature and precipitation at this site. Results: We found that *Artemisia rothrockii* increased in abundance at the upper reaches of its distribution between the 2010 and 1961 surveys. Additionally, we recorded significant declines in abundances in the lower elevation ranges of three alpine cushion plants: *Trifolium andersonii*, *Phlox condensata* and *Eriogonum ovalifolium*. These shifts coincided with a 0.98 °Celsius increase in mean growing season temperatures and a 53 millimeter decrease in mean annual precipitation between 1961 and 2010. Conclusions: These results suggest that rising temperatures and decreasing precipitation are negatively impacting alpine plant species while promoting expansion of sub-alpine species, possibly signaling the transition of this alpine plant community to sagebrush steppe.

Climate, weather, and recent mountain pine beetle outbreaks in the western United States. Creeden EP, Hicke JA and Buotte PC (2014). *Forest Ecology and Management*, 312(0): 239-251.
http://www.sciencedirect.com/science/article/pii/S0378112713006658

Geographic Location: Western United States
Type of Reference: Research Paper

Abstract: Recent outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) have impacted large areas of western North America. Climate and weather conditions influence beetle population dynamics, and managers and policymakers are concerned about the potential effects of climate change on outbreaks. Here we studied five locations with extensive outbreaks in lodgepole pine (*Pinus contorta*) forests across the western United States. Using observations and modeling, we quantified means and changes relative to prior years of three climate or weather factors associated with outbreaks: (1) year-round temperatures that affect adaptive seasonality; (2) low temperatures that induce mortality of overwintering beetles; and (3) drought stress of host trees. Climate variable means varied among locations, indicating the beetle's tolerance to different climate during outbreaks. Analyses of climate or weather factors as outbreaks progressed revealed that year-round temperatures during outbreaks were typically higher than in prior years, and outbreak years lacked very low winter temperatures that often occurred in prior years. Drought was present at each location during some time of an outbreak, and increases in beetle-caused tree mortality at lower beetle population levels (as indicated by killed trees) were usually coincident with drought. Furthermore, drought was not required to maintain large outbreaks; in several locations, relief from drought during periods of high tree mortality did not cause

subsequent declines in tree mortality. We did not find strong evidence that maladaptive seasonality, cold-induced mortality, or drought stress was responsible for decreases in tree mortality, suggesting the role of host depletion. Large variability in the relationships between climate or weather variables and outbreaks suggests that different climate and weather factors may have been limiting outbreaks at different times and that these factors did not influence beetle-caused tree mortality similarly among locations. Our results increase understanding of the climate and weather factors that influence beetle outbreaks and their variability in space and time and will lead to more accurate predictions of future patterns of outbreaks that consider future climate.

The Big Pine Creek watershed and climate change: A trend analysis of Landsat surface reflectance and PRISM datasets over the last 3 decades. Sawyer PS and Stephen H (2014). *Advances in Space Research*. 54(1): 37-48. http://www.sciencedirect.com/science/article/pii/S0273117714001690

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Recent variations in normal meteorological conditions indicate the earth's climate is changing in ways that may impact delicate ecological balances in sensitive regions. Identifying how those changes are affecting the biosphere is essential if we are going to be able to adapt to those changes and to potentially mitigate their harmful consequences. This paper presents a time series study of an alpine ecosystem in the Big Pine Creek watershed in California's Eastern Sierra Nevada Mountain's. Raw Landsat data covering the years 1984 through 2011 is converted to observed surface reflectance and analyzed for trends that would indicate a change in the ecosystem. We found that over the time period of the study, observed surface reflectance shows a general decline across the spectrum while our analysis of environmental data demonstrates statistically significant increases in temperatures. While declining reflectance in the visible and short wave bands are indicators of increased surface cover, the fact that the infrared band also shows declines is consistent with a decline in tree density. This study provides a useful insight into the ecological response of the Big Pine Creek watershed to recent climate change. These findings suggest that alpine ecosystems are particularly sensitive to increasing temperatures. If these results are replicated in other alpine watersheds it will demonstrate that the biosphere is already showing the effects of a warmer environment.

Climate change effect on Betula (birch) and Quercus (oak) pollen seasons in the United States. Zhang Y, Bielory L and Georgopoulos PG (2014). *International Journal of Biometeorology*, 58(5): 909-919. http://link.springer.com/article/10.1007/s00484-013-0674-7

Geographic Location: United States, Including California
Type of Reference: Research Paper

Abstract: Climatic change is expected to affect the spatiotemporal patterns of airborne allergenic pollen, which has been found to act synergistically with common air

pollutants, such as ozone, to cause allergic airway disease (AAD). Observed airborne pollen data from six stations from 1994 to 2011 at Fargo (North Dakota), College Station (Texas), Omaha (Nebraska), Pleasanton (California), Cherry Hill and Newark (New Jersey) in the US were studied to examine climate change effects on trends of annual mean and peak value of daily concentrations, annual production, season start, and season length of *Betula* (birch) and *Quercus* (oak) pollen. The growing degree hour (GDH) model was used to establish a relationship between start/end dates and differential temperature sums using observed hourly temperatures from surrounding meteorology stations. Optimum GDH models were then combined with meteorological information from the Weather Research and Forecasting (WRF) model, and land use land coverage data from the Biogenic Emissions Land use Database, version 3.1 (BELD3.1), to simulate start dates and season lengths of birch and oak pollen for both past and future years across the contiguous US (CONUS). For most of the studied stations, comparison of mean pollen indices between the periods of 1994-2000 and 2001-2011 showed that birch and oak trees were observed to flower one to two weeks earlier; annual mean and peak value of daily pollen concentrations tended to increase by 13.6 %-248 %. The observed pollen season lengths varied for birch and for oak across the different monitoring stations. Optimum initial date, base temperature, and threshold GDH for start date was found to be 1 March, 8 °Celsius, and 1,879 hours, respectively, for birch; 1 March, 5 °Celsius, and 4,760 hours, respectively, for oak. Simulation results indicated that responses of birch and oak pollen seasons to climate change are expected to vary for different regions.

Twentieth-century shifts in forest structure in California: Denser forests, smaller trees, and increased dominance of oaks. McIntyre P, Thorne JH, Dolanc CR, Flint AL, Flint LE, Kelly M, and Ackerly DD (2015). Proceedings of the National Academy of Sciences, 112(5): 1458-1463. http://www.pnas.org/content/112/5/1458.full.pdf

Geographic Location: California
Type of Reference: Research Paper

Abstract: We document changes in forest structure between historical (1930s) and contemporary (2000s) surveys of California vegetation through comparisons of tree abundance and size across the state and within several ecoregions. Across California, tree density in forested regions increased by 30 percent (%) between the two time periods, whereas forest biomass in the same regions declined, as indicated by a 19% reduction in basal area. These changes reflect a demographic shift in forest structure: larger trees (> 61 centimeters (cm) diameter at breast height) have declined, whereas smaller trees (<30 cm) have increased. Large tree declines were found in all surveyed regions of California, whereas small tree increases were found in every region except the south and central coast. Large tree declines were more severe in areas experiencing greater increases in climatic water deficit since the 1930s, based on a hydrologic model of water balance for historical climates through the 20th century. Forest composition in California in the last century has also shifted toward increased dominance by oaks relative to pines, a pattern consistent with warming and increased water stress, and also with paleohistoric shifts in vegetation in California over the last 150,000 years.

Altitudinal shifts of the native and introduced flora of California in the context of 20th-century warming. Wolf A, Zimmerman NB, Anderegg WRL, Busby PE, and Christensen J (2016). *Global Ecology and Biogeography,* 25(4): 418-429. http://onlinelibrary.wiley.com/doi/10.1111/geb.12423/abstract

Geographic Location: California
Type of Reference: Research Paper

Abstract: *Aim*- The differential responses of plant species to climate change are of great interest and grave concern for scientists and conservationists. One underexploited resource for better understanding these changes are the records held by herbaria. Using these records to assess the responses of different groups of species across the entire flora of California, we sought to quantify the magnitude of species elevational shifts, to measure differences in shifts among functional groups and between native and introduced species, and to evaluate whether these shifts were related to the conservation of thermal niches. *Location*- California. *Methods*- To characterize these shifts in California, we used 681,609 georeferenced herbarium records to estimate mean shifts in elevational and climatic space of 4426 plant taxa. We developed and employed a statistical method to robustly analyse the data represented in these records. *Results*- We found that 15 percent (%) of all taxa in California have ranges that have shifted upward over the past century. There are significant differences between range shifts of taxa with different naturalization statuses: 12% of endemic taxa show significant upward range shifts, while a greater proportion (27%) of introduced taxa have shifted upward. We found significant differences between the proportion of significant range shifts across taxa with different seed sizes, but did not find evidence for differences in shift based on life-form (annual versus perennial, herbaceous versus woody). *Main Conclusions*- Our analyses suggest that introduced species have disproportionately expanded their ranges upward in elevation over the past century when compared with native species. While these shifts in introduced species may not be exclusively driven by climate, they highlight the importance of considering the interacting factors of climate-driven range shifts and invasion to understand how floras are responding in the face of anthropogenic change.

Aquatic

Environmental controls of giant-kelp biomass in the Santa Barbara Channel, California. Cavanaugh KC, Siegel DA, Reed DC and Dennison PE (2011). *Marine Ecology Progress Series*, 429: 1-17. http://www.int-res.com/abstracts/meps/v429/p1-17/

Geographic Location: Pacific Ocean/Santa Barbara Channel
Type of Reference: Research Paper

Abstract: Synthesizing long-term observations at multiple scales is vital for understanding the environmental drivers of ecosystem dynamics. We assessed the role of several environmental drivers in explaining temporal and spatial patterns in the

abundance of giant kelp *Macrocystis pyrifera* in the Santa Barbara Channel between 1984 and 2009. We developed a novel method for estimating the canopy biomass of giant kelp from Landsat 5 Thematic Mapper satellite imagery, which allowed us to examine the dynamics of giant-kelp biomass on spatial scales ranging from hundreds (100s) of square meters to 100s of square kilometers and temporal scales ranging from several weeks to 25 years. Comparisons of changes in canopy biomass with oceanographic and climatic data revealed that winter losses of regional kelp canopy biomass were positively correlated with significant wave height ($r^2 = 0.50$), while spring recoveries were negatively correlated with sea surface temperature ($r^2 = 0.30$; used as a proxy for nutrient availability). On interannual timescales, regional kelp-canopy biomass lagged the variations in wave heights, sea surface temperatures, and the North Pacific Gyre Oscillation index by three years, indicating that these factors affect cycles of kelp recruitment and mortality. Results from cluster analysis showed that the response of kelp biomass to environmental conditions varied among different sub-regions of the Santa Barbara Channel. The dynamics of kelp biomass in exposed regions were related to wave disturbance, while kelp dynamics in sheltered regions tracked sea surface temperatures more closely. These results depict a high level of regional heterogeneity in the biomass dynamics of this important foundation species.

Long-term trends and causal factors associated with *Microcystis* abundance and toxicity in San Francisco Estuary and implications for climate change impacts.
Lehman PW, Marr K, Boyer GL, Acuna S and Teh SJ (2013). *Hydrobiologia*, 718(1): 141-158. http://link.springer.com/article/10.1007%2Fs10750-013-1612-8

Geographic Location: California/San Francisco Estuary
Type of Reference: Research Paper

Abstract: The impacts of climate change on *Microcystis* blooms in San Francisco Estuary are uncertain because factors associated with the abundance and distribution of *Microcystis* blooms since their inception in 1999 are poorly understood. Discrete and continuous data collected between 2004 and 2008 were used to assess what factors controlled bloom initiation and persistence, if there was an impact of the bloom on mesozooplankton abundance and toxicity or dissolved organic carbon concentration, and how these might vary with climate change. *Microcystis* abundance was greater in dry years than wet years and both total microcystins concentration and the microcystins content of mesozooplankton tissue increased with abundance. The bloom began in the upstream portions of the estuary and spread farther west during dry years. Bloom initiation required water temperature above 19°Celsius and surface irradiance in the visible range above 100 Watt per square meter. The bloom persisted during a wide range of water quality conditions but was closely correlated with low turbidity. The intensity of *Microcystis* blooms will likely increase with climate change due to increased water temperature and low streamflow during droughts. Elevated water temperature earlier in the spring could also extend the duration of *Microcystis* blooms by up to three months.

Recent (1975-2004) Vegetation Change in the San Francisco Estuary, California, Tidal Marshes. Watson EB and Byrne R (2012). *Journal of Coastal Research*, 28(1): 51-63. http://www.jcronline.org/doi/abs/10.2112/JCOASTRES-D-09-00137.1

Geographic Location: California/San Francisco Estuary
Type of Reference: Research Paper

Abstract: The establishment and monitoring of vegetation plots provide unique information on the spatiotemporal dynamics of plant distributions. In 1975, U.S. Geological Survey (USGS) scientists Atwater and Hedel established vegetation transects at six tidal marshes spanning the salinity gradient of the San Francisco Estuary, California, to establish a baseline against which future vegetation changes could be measured. Since 1975, estuarine salinity has increased because of water diversion, whereas sea level has risen at rates that exceed late-Holocene background levels. During the summers of 2003-04, we reoccupied these transects and measured plant composition to better understand the response of marsh vegetation to these hydrologic changes. Our results indicate that during the past 30 years, *Sarcocornia pacifica*, the most salt-tolerant plant species, increased in cover, whereas *Schoenoplectus californicus*, the least salt-tolerant plant species, decreased in cover. We hypothesize that increasing estuarine salinity resulted in these shifts. Additionally, *Distichlis spicata* has experienced large-scale replacement, predominantly by *Schoenoplectus americanus*. Because *Distichlis spicata* was found to be associated most strongly with high relative marsh elevations, we hypothesize that the decline in this species is a consequence of accelerated sea level rise. The vegetation changes observed in San Francisco Estuary marshes reported here are consistent throughout the estuary and have been observed in other studies and, therefore, serve as a guide to better understand the consequences of anthropogenically driven environmental change to estuarine wetlands.

Response of diatoms and silicoflagellates to climate change and warming in the California Current during the past 250 years and the recent rise of the toxic diatom *Pseudo-nitzschia australis*. Barron JA, Bukry D, Field DB and Finney B (2013). *Quaternary International*, 310: 140-154. http://www.sciencedirect.com/science/article/pii/S1040618212004764

Geographic Location: Pacific Ocean/Santa barbara
Type of Reference: Research Paper

Abstract: Diatoms and silicoflagellate assemblages were examined in two year-increments of varved samples spanning the interval from 1748 through 2007 in Santa Barbara Basin (SBB) box core SBBC0806 to determine the timing and impact of possible 20th century warming on several different components of the plankton. Diatoms (*Thalassionema nitzschioides*=TN) and silicoflagellates (*Distephanus speculum* s.l.=DS) indicative of cooler waters and a shallow thermocline begin to decline in the 1920s and persistently compose a lower percentage of the assemblage in the SBB by about 1940. Prior to 1940, TN constituted on average ~30 percent (%) of the *Chaetoceros*-free diatom sediment assemblage and DS on average ~36% of the silicoflagellate assemblage. Between 1940 and 1996, these relative abundances were

~20% (TN) and ~8% (DS). These results are consistent with results from planktonic foraminifera and radiolarians that indicate an influence of 20th century warming on marine ecosystems before most scientific observations began. Cooling of surface waters coincident with the one of the strongest La Niña events of the 20th century (and a return to negative Pacific Decadal Oscillation conditions) in late 1998 brought about a return to pre-1940 values of these cool water taxa (TN ~31%, DS ~25%). However, this recent regional cooling appears to have been accompanied by profound changes in the diatom assemblage. *Pseudo-nitzschia australis*, and *Pseudo-nitzschia multiseries*, diatom species associated with domoic acid, a neurotoxin that causes shellfish poisoning and marine mammal deaths, rapidly became dominant in the SBB sediment record at the time of the regional cooling (1999) and increased substantially in numbers as a bloom-forming taxon (relative to *Chaetoceros* spores) in 2003. Prior to 2003, diatom blooms recorded in the SBB sediment record consisted predominantly of *Chaetoceros* spores and less commonly of *Rhizosolenia*-related species (*Neocalyptrella robusta* and *Rhizosolenia setigera*). Fecal pellets dominated by valves of *P.australis*, however, were particularly abundant in both the 2003 and 2006 samples, coincident with recorded incidents of domoic acid increase and widespread shellfish poisoning in the SBB.

Interactive effects of anthropogenic nitrogen enrichment and climate change on terrestrial and aquatic biodiversity. Porter EM, Bowman WD, Clark CM, Compton JE, Pardo LH and Soong JL (2013). *Biogeochemistry*, 114(1-3): 93-120. http://dx.doi.org/10.1007/s10533-012-9803-3

Abstract summarized in: *Vegetation: Terrestrial*

Taking the Pulse of Marine Ecosystems. The Importance of Coupling Long-Term Physical and Biological Observations in the Context of Global Change Biology. Hofmann GE, Blanchette CA, Rivest EB and Kapsenberg L (2013). *Oceanography*, 26(3): 140-148. http://tos.org/oceanography/article/taking-the-pulse-of-marine-ecosystems-the-importance-of-coupling-long-term-

Abstract summarized in *Biological: Animals – Population abundance and ecological interactions.*

Wildfires

Changes in temperature and precipitation influence the availability of fuel, and hence the risk of wildfires. Warmer spring and summer temperatures, reduced snowpack and earlier spring snowmelt, and changes in wind patterns have been identified as factors that have caused the increase in wildfires in California. Fires have caused concern in recent years due to their severity and expanse of affected areas. Wildfires lead to changes in forest composition and density, thus affecting carbon sequestration. Scientists are developing models to predict future occurrence of wildfires to assist emergency planners and others in developing wildfire strategies at the local, regional and national levels.

Trends and causes of severity, size, and number of fires in northwestern California, USA. Miller JD, Skinner CN, Safford HD, Knapp EE and Ramirez CM (2012). *Ecological Applications*, 22(1): 184-203. http://www.esajournals.org/doi/abs/10.1890/10-2108.1?journalCode=ecap

Geographic Location: California
Type of Reference: Research Paper

Abstract: Research in the last several years has indicated that fire size and frequency are on the rise in western U.S. forests. Although fire size and frequency are important, they do not necessarily scale with ecosystem effects of fire, as different ecosystems have different ecological and evolutionary relationships with fire. Our study assessed trends and patterns in fire size and frequency from 1910 to 2008 (all fires > 40 hectares (ha)), and the percentage of high-severity in fires from 1987 to 2008 (all fires > 400 ha) on the four national forests of northwestern California. During 1910-2008, mean and maximum fire size and total annual area burned increased, but we found no temporal trend in the percentage of high-severity fire during 1987-2008. The time series of severity data was strongly influenced by four years with region-wide lightning events that burned huge areas at primarily low moderate severity. Regional fire rotation reached a high of 974 years in 1984 and fell to 95 years by 2008. The percentage of high-severity fire in conifer-dominated forests was generally higher in areas dominated by smaller-diameter trees than in areas with larger-diameter trees. For Douglas-fir forests, the percentage of high-severity fire did not differ significantly between areas that re-burned and areas that only burned once (10% vs. 9%) when re-burned within 30 years. Percentage of high-severity fire decreased to five % when intervals between first and second fires were >30 years. In contrast, in both mixed-conifer and fir/high-elevation conifer forests, the percentage of high-severity fire was less when re-burned within 30 years compared to first-time burned (12% vs. 16% for mixed conifer; 11% vs. 19% for fir/high-elevation conifer). Additionally, the percentage of high-severity fire did not differ whether the re-burn interval was less than or greater than 30 years. Years with larger fires and greatest area burned were produced by region-wide lightning events, and characterized by less winter and spring precipitation than years dominated by smaller human-ignited fires. Overall percentage of high-severity fire was generally less in years characterized by these region-wide lightning events. Our results suggest that, under certain conditions, wildfires could be more extensively used to achieve ecological and management objectives in northwestern California.

Relationships between climate and macroscale area burned in the western United States. Abatzoglou JT and Kolden CA (2013). *International Journal of Wildland Fire*, 22(7): 1003-1020. http://www.publish.csiro.au/?paper=WF13019

Geographic Location: Western United States, including California
Type of Reference: Research Paper

Abstract: Increased wildfire activity (e.g. number of starts, area burned, fire behaviour) across the western United States in recent decades has heightened interest in resolving

climate–fire relationships. Macroscale climate–fire relationships were examined in forested and non-forested lands for eight Geographic Area Coordination Centers in the western United States, using area burned derived from the Monitoring Trends in Burn Severity dataset (1984–2010). Fire-specific biophysical variables including fire danger and water balance metrics were considered in addition to standard climate variables of monthly temperature, precipitation and drought indices to explicitly determine their optimal capacity to explain interannual variability in area burned. Biophysical variables tied to the depletion of fuel and soil moisture and prolonged periods of elevated fire-danger had stronger correlations to area burned than standard variables antecedent to or during the fire season, particularly in forested systems. Antecedent climate–fire relationships exhibited inter-region commonality with area burned in forested lands correlated with winter snow water equivalent and emergent drought in late spring. Area burned in non-forested lands correlated with moisture availability in the growing season preceeding the fire year. Despite differences in the role of antecedent climate in preconditioning fuels, synchronous regional fire activity in forested and non-forested lands suggests that atmospheric conditions during the fire season unify fire activity and can compound or supersede antecedent climatic stressors. Collectively, climate–fire relationships viewed through the lens of biophysical variables provide a more direct link to fuel flammability and wildfire activity than standard climate variables, thereby narrowing the gap in incorporating top-down climatic factors between empirical and process-based fire models.

Human and biophysical influences on fire occurrence in the United States.
Hawbaker TJ, Radeloff VC, Stewart SI, Hammer RB, Keuler NS and Clayton MK (2013). *Ecological Applications*, 23(3): 565-582.
http://www.esajournals.org/doi/abs/10.1890/12-1816.1

Geographic Location: United States, Including California
Type of Reference: Research Paper

Abstract: National-scale analyses of fire occurrence are needed to prioritize fire policy and management activities across the United States. However, the drivers of national-scale patterns of fire occurrence are not well understood, and how the relative importance of human or biophysical factors varies across the country is unclear. Our research goal was to model the drivers of fire occurrence within ecoregions across the conterminous United States. We used generalized linear models to compare the relative influence of human, vegetation, climate, and topographic variables on fire occurrence in the United States, as measured by MODIS active fire detections collected between 2000 and 2006. We constructed models for all fires and for large fires only and generated predictive maps to quantify fire occurrence probabilities. Areas with high fire occurrence probabilities were widespread in the Southeast, and localized in the Mountain West, particularly in southern California, Arizona, and New Mexico. Probabilities for large-fire occurrence were generally lower, but hot spots existed in the western and south-central United States. The probability of fire occurrence is a critical component of fire risk assessments, in addition to vegetation type, fire behavior, and the values at risk. Many of the hot spots we identified have extensive development in the

wildland-urban interface and are near large metropolitan areas. Our results demonstrated that human variables were important predictors of both all fires and large fires and frequently exhibited nonlinear relationships. However, vegetation, climate, and topography were also significant variables in most ecoregions. If recent housing growth trends and fire occurrence patterns continue, these areas will continue to challenge policies and management efforts seeking to balance the risks generated by wildfires with the ecological benefits of fire.

Climate change, fire management, and ecological services in the southwestern US. Hurteau MD, Bradford JB, Fulé PZ, Taylor AH and Martin KL (2013). *Forest Ecology and Management,* 327(1):280-289.
http://www.sciencedirect.com/science/article/pii/S0378112713005343

Geographic Location: Southwestern United States, Including California
Type of Reference: Review Paper

Abstract: The diverse forest types of the southwestern US are inseparable from fire. Across climate zones in California, Nevada, Arizona, and New Mexico, fire suppression has left many forest types out of sync with their historic fire regimes. As a result, high fuel loads place them at risk of severe fire, particularly as fire activity increases due to climate change. A legacy of fire exclusion coupled with a warming climate has led to increasingly large and severe wildfires in many southwest forest types. Climate change projections include an extended fire season length due to earlier snowmelt and a general drying trend due to rising temperatures. This suggests the future will be warmer and drier regardless of changes in precipitation. Hotter, drier conditions are likely to increase forest flammability, at least initially. Changes in climate alone have the potential to alter the distribution of vegetation types within the region, and climate-driven shifts in vegetation distribution are likely to be accelerated when coupled with stand-replacing fire. Regardless of the rate of change, the interaction of climate and fire and their effects on Southwest ecosystems will alter the provisioning of ecosystem services, including carbon storage and biodiversity. Interactions between climate, fire, and vegetation growth provide a source of great uncertainty in projecting future fire activity in the region, as post-fire forest recovery is strongly influenced by climate and subsequent fire frequency. Severe fire can be mitigated with fuels management including prescribed fire, thinning, and wildfire management, but new strategies are needed to ensure the effectiveness of treatments across landscapes. We review the current understanding of the relationship between fire and climate in the Southwest, both historical and projected. We then discuss the potential implications of climate change for fire management and examine the potential effects of climate change and fire on ecosystem services. We conclude with an assessment of the role of fire management in an increasingly flammable Southwest.

Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. Mallek C, Safford H, Viers J and Miller J (2013). *Ecosphere*, 4(12):1-28. http://onlinelibrary.wiley.com/doi/10.1890/ES13-00217.1/abstract f

Geographic Location: California/Sierra Nevada and Cascades
Type of Reference: Research Paper

Abstract: Acute changes in ecological disturbance regimes can have major consequences for ecosystems and biota, including humans, living within them. Human suppression of fire in the western United States over the last century has caused notable changes to many ecosystems, especially in lower elevation, semiarid forest types dominated historically by fire tolerant taxa like *Pinus* and *Quercus*. Recent increases in fire activity in western US forests have highlighted the need for restoration of ecological structure and function, but management targets for restoration in different forest types remain uncertain. Working in the forests of eastern California, we evaluated the direction and magnitude of change in burned area and fire severity between the period prior to Euro-American settlement (similar to 1500-1850) and the "modern" period (1984-2009). We compared total annual area burned; proportional area burned at low-moderate severity and high severity; and annual area burned at low-moderate severity and high severity between the two time periods in seven forest types. We also examined modern trends in fire area and severity. We found that modern rates of burning are far below presettlement levels for all forest types. However, there were major differences between low to middle elevation forests and high elevation forests regarding the components of this departure. Low and middle elevation forests are currently burning at much higher severities than during the presettlement period, and the departure in fire area is overwhelmingly expressed in the low to moderate severity categories; in these forest types, mean annual area of high severity fire is not notably different between the modern and presettlement periods. In higher elevation forests on the other hand, the modern departure in fire area is expressed equally across fire severity categories. Our results underline the critical need for forest and fire restoration in the study area, especially in low and middle elevation forests adapted to frequent, low severity fire. Expanded management of naturally ignited fires for resource benefit is clearly needed, but in many parts of our study area, strategic reduction of forest fuels will likely be necessary before large-scale restoration of fire becomes ecologically, politically, and financially feasible.

Post-fire management regimes affect carbon sequestration and storage in a Sierra Nevada mixed conifer forest. Powers EM, Marshall JD, Zhang J and Wei L (2013). *Forest Ecology and Management*, 291: 268-277. http://www.treesearch.fs.fed.us/pubs/43418

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Forests mitigate climate change by sequestering carbon dioxide (CO_2) from the atmosphere and accumulating it in biomass storage pools. However, in dry conifer

forests, fire occasionally returns large quantities of CO_2 to the atmosphere. Both the total amount of carbon stored and its susceptibility to loss may be altered by post-fire land management strategies. Forest managers face a great challenge when asked to manage these lands for Carbon (C) sequestration and simultaneously reduce fire hazard. The objective of our study was to understand how differing post-fire management strategies affect C sequestration and the size of storage pools in the 10 years after a wildfire in a Sierra Nevada mixed-conifer forest. Post-fire management regimes included: (1) salvage-logged, planted, and intensively managed plantation (IM); (2) salvage-logged and planted (SP); (3) no salvage (NS); and (4) green canopy (GC), where fire burned through, but 95% of the overstory trees survived. Carbon sequestration and storage were estimated from measurements of individual ecosystem carbon pools. These pools included: aboveground trees, saplings, snags, stumps, and understory, coarse wood and fine wood, duff, and soil. We found total ecosystem carbon storage was 282±15 megagram per hectare ($Mgha^{-1)}$ of C in the NS treatment, 206±31 $Mgha^{-1}$ in the GC, 137±13 $Mgha^{-1}$ in the SP, and 101±15 $Mgha^{-1}$ in the IM treatment. There were no significant treatment differences in C storage among the pools that would constitute labile/fine fuels, but there were differences in recalcitrant (coarse fuel) C pools. The greatest C storage in recalcitrant C pools was 258±10 $Mgha^{-1}$ in the NS and 197±30 $Mgha^{-1}$ in the GC treatments. Post-fire carbon sequestration rates were 1.6±0.7 $Mgha^{-1}year^{-1}$ of C in the GC, 0.7±0.3 in the SP, 0.5±0.1 in the NS, and 0.5±0.1 in the IM treatments, but these differences were not statistically significant. Tree carbon sequestration rates were highest in the GC treatment and lowest in the NS treatment. Overall, our results suggest that a mature green-canopy stand provides most benefit in terms of C sequestration, wildfire resilience, and other ecosystem services at a point 10 years after severe wildfire. For forests that suffer high fire mortality, unsalvaged (NS) stands will retain the most carbon onsite.

Climatic stress increases forest fire severity across the western United States. van Mantgem PJ, Nesmith JCB, Keifer M, Knapp EE, Flint A and Flint L (2013). *Ecology Letters*, 16(9): 1151-1156. http://onlinelibrary.wiley.com/doi/10.1111/ele.12151/abstract

Geographic Location: Western United States, Including California
Type of Reference: Research Paper

Abstract: Pervasive warming can lead to chronic stress on forest trees, which may contribute to mortality resulting from fire-caused injuries. Longitudinal analyses of forest plots from across the western US show that high pre-fire climatic water deficit was related to increased post-fire tree mortality probabilities. This relationship between climate and fire was present after accounting for fire defenses and injuries, and appeared to influence the effects of crown and stem injuries. Climate and fire interactions did not vary substantially across geographical regions, major genera and tree sizes. Our findings support recent physiological evidence showing that both drought and heating from fire can impair xylem conductivity. Warming trends have been linked to increasing probabilities of severe fire weather and fire spread; our results suggest that warming may also increase forest fire severity (the number of trees killed) independent of fire intensity (the amount of heat released during a fire).

Fire weather and large fire potential in the northern Sierra Nevada. Collins BM (2014). *Agricultural and Forest Meteorology*, (189-190): 30-35. http://www.sciencedirect.com/science/article/pii/S0168192314000069

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Fuels, weather, and topography all contribute to observed fire behavior. Of these, weather is not only the most dynamic factor, it is the most likely to be directly influenced by climate change. In this study 40 years of daily fire weather observations from five weather stations across the northern Sierra Nevada were analyzed to investigate potential changes or trends in the frequency of high- to extreme-fire weather. The analysis demonstrated fairly strong upward trends in the occurrence of high- to extreme-fire weather, particularly since the mid-1990s. This increased occurrence of high fire weather conditions suggests that there is more opportunity for fires to grow rapidly and overwhelm initial suppression efforts, likely resulting in greater incidence of large fires throughout the region. This is particularly problematic in the northern Sierra Nevada, where there is a complex arrangement of land ownerships, including numerous human communities.

Is fire severity increasing in the Sierra Nevada, California, USA. Hanson CT and Odion DC (2014). *International Journal of Wildland Fire*, 23(1): 1-8. http://www.publish.csiro.au/nid/114/paper/WF13016.htm

Geographic Location: California/Sierra Nevada
Type of Reference: Research Paper

Abstract: Research in the Sierra Nevada range of California, USA, has provided conflicting results about current trends of high-severity fire. Previous studies have used only a portion of available fire severity data, or considered only a portion of the Sierra Nevada. Our goal was to investigate whether a trend in fire severity is occurring in Sierra Nevada conifer forests currently, using satellite imagery. We analyzed all available fire severity data, 1984-2010, over the whole ecoregion and found no trend in proportion, area or patch size of high-severity fire. The rate of high-severity fire has been lower since 1984 than the estimated historical rate. Responses of fire behavior to climate change and fire suppression may be more complex than assumed. A better understanding of spatiotemporal patterns in fire regimes is needed to predict future fire regimes and their biological effects. Mechanisms underlying the lack of an expected climate- and time since fire-related trend in high-severity fire need to be identified to help calibrate projections of future fire. The effects of climate change on high-severity fire extent may remain small compared with fire suppression. Management could shift from a focus on reducing extent or severity of fire in wildlands to protecting human communities from fire.

Contrasting controls on wildland fires in Southern California during periods with and without Santa Ana winds. Jin YF, Randerson JT, Faivre N, Capps S, Hall A and Goulden ML (2014). *Journal of Geophysical Research-Biogeosciences*, 119(3): 432-450. http://onlinelibrary.wiley.com/doi/10.1002/2013JG002541/abstract

Geographic Location: California/Southern
Type of Reference: Research Paper

Abstract: Wildland fires in Southern California can be divided into two categories: fall fires, which are typically driven by strong offshore Santa Ana winds, and summer fires, which occur with comparatively weak onshore winds and hot and dry weather. Both types of fire contribute significantly to annual burned area and economic loss. An improved understanding of the relationship between Southern California's meteorology and fire is needed to improve predictions of how fire will change in the future and to anticipate management needs. We used output from a regional climate model constrained by reanalysis observations to identify Santa Ana events and partition fires into those occurring during periods with and without Santa Ana conditions during 1959-2009. We then developed separate empirical regression models for Santa Ana and non-Santa Ana fires to quantify the effects of meteorology on fire number and size. These models explained approximately 58 percent (%) of the seasonal and interannual variation in the number of Santa Ana fires and 36% of the variation in non-Santa Ana fires. The number of Santa Ana fires increased during years when relative humidity during Santa Ana events and fall precipitation were below average, indicating that fuel moisture is a key controller of ignition. Relative humidity strongly affected Santa Ana fire size. Cumulative precipitation during the previous three winters was significantly correlated with the number of non-Santa Ana fires, presumably through increased fine fuel density and connectivity between infrastructure and nearby vegetation. Both relative humidity and the preceding wet season precipitation influenced non-Santa Ana fire size. Regression models driven by meteorology explained 57% of the temporal variation in Santa Ana burned area and 22% of the variation in non-Santa Ana burned area. The area burned by non-Santa Ana fires has increased steadily by 1.7% per year since 1959 ($p<0.006$); the occurrence of extremely large Santa Ana fires has increased abruptly since 2003. Our results underscore the need to separately consider the fuel and meteorological controls on Santa Ana and non-Santa Ana fires when projecting climate change impacts on regional fire.

Defining extreme wildland fires using geospatial and ancillary metrics. Lannom KO, Tinkham WT, Smith AMS, Abatzoglou J, Newingham BA, Hall TE, et al. (2014). *International Journal of Wildland Fire*, 23(3): 322-337. http://www.publish.csiro.au/paper/WF13065.htm

Geographic Location: Northwestern United States
Type of Reference: Research Paper

Abstract: There is a growing professional and public perception that ‘extreme’ wildland fires are becoming more common due to changing climatic conditions. This concern is heightened in the wildland–urban interface where social and ecological effects converge. ‘Mega-fires’, ‘conflagrations’, ‘extreme’ and ‘catastrophic’ are descriptors

interchangeably used increasingly to describe fires in recent decades in the US and globally. It is necessary to have consistent, meaningful and quantitative metrics to define these perceived 'extreme' fires, given studies predict an increased frequency of large and intense wildfires in many ecosystems as a response to climate change. Using the Monitoring Trends in Burn Severity dataset, we identified both widespread fire years and individual fires as potentially extreme during the period 1984–2009 across a 91.2×10^6-hectare (ha) area in the north-western United States. The metrics included distributions of fire size, fire duration, burn severity and distance to the wildland–urban interface. Widespread fire years for the study region included 1988, 2000, 2006 and 2007. When considering the intersection of all four metrics using distributions at the 90th percentile, less than 1.5 percent (%) of all fires were identified as potentially extreme fires. At the more stringent 95th and 99th percentiles, the percentage reduced to <0.5% and 0.05%. Correlations between area burnt and climatic measures (Palmer drought severity index, temperature, energy release component, duff moisture code and potential evapotranspiration) were observed. We discuss additional biophysical and social metrics that could be included and recommend both the need for enhanced visualisation approaches and to weigh the relative strength or importance of each metric.

Climate and very large wildland fires in the contiguous western USA. Stavros EN, Abatzoglou J, Larkin NK, McKenzie D and Steel EA (2014). *International Journal of Wildland Fire*, 23(7): 899-914. http://www.publish.csiro.au/nid/114.htm

Geographic Location: Western United States, Including California
Type of Reference: Research Paper

Abstract: Very large wildfires can cause significant economic and environmental damage, including destruction of homes, adverse air quality, firefighting costs and even loss of life. We examine how climate is associated with very large wildland fires (VLWFs ≥50,000 acres, or ~20,234 hectares) in the western contiguous USA. We used composite records of climate and fire to investigate the spatial and temporal variability of VLWF–climatic relationships. Results showed quantifiable fire weather leading up and up to three weeks post VLWF discovery, thus providing predictors of the probability that VLWF occurrence in a given week. Models were created for eight National Interagency Fire Center Geographic Area Coordination Centers (GACCs). Accuracy was good (area under curve > 0.80) for all models, but significant fire weather predictors of VLWFs vary by GACC, suggesting that broad-scale ecological mechanisms associated with wildfires also vary across regions. These mechanisms are very similar to those found by previous analyses of annual area burned, but this analysis provides a means for anticipating VLWFs specifically and thereby the timing of substantial area burned within a given year, thus providing a quantifiable justification for proactive fire management practices to mitigate the risk and associated damage of VLWFs.

APPENDIX
Search Methodology

Publications were identified and selected for inclusion in this bibliography using the following approach.

1. An initial literature search was conducted in Web of Science and SCOPUS using the following search query for publications released during the years 2011 through 2015:

   "climate change" AND "California"
   "climate change" AND "California" AND "impacts"

2. A separate Google Scholar search was conducted using the names of researchers who had contributed to OEHHA's climate change indicator reports, to identify any papers with recent monitoring data or research not captured in Web of Science or SCOPUS.

3. Staff routinely monitored environmental newsletters, websites of research institutions and government entities and the popular press. Several scientific papers and reports, including those published in 2016, were identified from these sources.

4. Search results and other identified references were screened to ensure they meet the following criteria:

   Credibility of source: References must be published in a peer-reviewed journal or issued as a report by a governmental agency, research institution or any other entity generally recognized as authoritative in the subject.

   Geographic coverage: California-specific references were targeted. However, documents reporting climate conditions or impacts in other geographic areas were included if findings are of global significance or are relevant to California.

   Topics included: new scientific understanding and observational data describing current or past conditions. References selected describe past or current observational data, or present new or modified scientific understanding about: changes in climate; the causes or drivers of climate change; and impacts of climate change on the environment, plants, animals and humans.

Topics excluded: future projections or policy measures. References that primarily present future scenarios or modelled projections, or that mainly discuss policy, mitigation or adaptation measures were excluded. References that report findings based on controlled experimental studies were also excluded.

5. Search results were organized into the following groups. Except for authoritative reports, the four groups are those used to categorize indicators in OEHHA's climate change indicator reports.
   - *Authoritative reports*
   - *Drivers of climate change*
   - *Changes in climate*
   - *Impacts of climate on physical systems*
   - *Impacts of climate on biological systems*