RECENT RESEARCH ON CLIMATE CHANGE:

An annotated bibliography with an emphasis on California

October 2013

Integrated Risk Assessment Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

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Air, Community and Environmental Research Branch
Office of Environmental Health Hazard Assessment
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Introduction

The intensity of climate change research and the resulting increased volume of publications make it challenging to keep abreast of new findings relating to climate change, its causes, and its impacts. At the same time, today's policy decisions require timely, credible scientific information to support the formulation of mitigation and adaptation strategies.

To assist the California Environmental Protection Agency in its efforts to address climate change, 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 relevant to climate change and its impacts on California. OEHHA has prepared this annotated bibliography, which covers publications from mid-2009 to 2012, as a means of organizing and presenting data and information from these sources. The bibliography will be periodically updated.

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)

The bibliography is intended to be useful as a source of current and emerging climate change information for environmental and public health agencies, the research community, non-government organizations, and the public. The findings in the references can, in some cases, be used as the basis for a separate effort by OEHHA to compile indicators of climate change in California (*Indicators of Climate Change in California* (OEHHA, 2013)). Although OEHHA took every effort to be comprehensive in its literature search, relevant papers may have been missed. The absence of references on a given subject should not be interpreted as an indication of its lack of relevance or significance to California. Periodic updates will allow us to include useful references that we may have overlooked, and suggestions from readers are welcome.

Identifying and selecting references

This annotated bibliography was compiled following a literature search guided by the following considerations:

- *Topics*. References describe past and current data, or new or modified scientific understanding about:
  - changes in climate
  - the causes or drivers of climate change
  - impacts of climate change on the environment and humans

Specifically **excluded** are references that primarily present future scenarios or projections, or that discuss measures to mitigate human-influenced drivers of climate change or to adapt to the environmental impacts of climate change.

- *Geographic coverage*. References about the state of California were specifically targeted. Recognizing that the state is affected by conditions beyond its boundaries and that scientific findings from studies elsewhere can apply to California, OEHHA also searched for references that cover broader geographic areas, in the following order of preference: the western U.S., the U.S. as a whole, North America, the Northern Hemisphere, and the world.

- *Timeframe*. References published between mid-2009 to the fall of 2012 are included. Specific subjects, including those addressed in OEHHA's indicators report may not have been addressed in this bibliography due to the lack of published literature during the period covered by the search.

- *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.

The absence of references on a given subject should not be interpreted as an indication of its lack of relevance or significance to California.

Structure of the report

References are organized into five categories, four of which are used for the indicators presented in OEHHA's report, *Indicators of Climate Change in California* (OEHHA, 2013). The following define the categories presented in this bibliography:

Authoritative reports
Certain national and international scientific organizations are generally recognized to be authoritative because they are comprised of scientists and other researchers with well-known, established expertise. These organizations, typically affiliated with government entities, publish reports, assessments or periodic updates that focus on a single topic or cover multiple climate change-related topics. Examples include the Intergovernmental Panel on Climate Change, the National Oceanic and Atmospheric Administration, and the U.S. Global Change Research Program.

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) alter the energy balance of the climate system and are drivers of climate change.

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. Changes in climate can be tracked based on observational data for these parameters.

Impacts of climate on physical systems
Climate is a key factor affecting the characteristics of natural physical systems. These systems include snow, ice, streams, rivers, lakes and the ocean. Globally, physical systems are being affected by regional climate change, particularly temperature increases.

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

The summaries

The information presented for each reference generally includes:

- The full citation
- Either the geographical area discussed (e.g., global, California), or the word "methodology" if the reference describes a method or approach
- Keywords
- Background/Purpose
- Methods
- Results
- Conclusions

The last four bulleted items are combined into a summary for reports that cover an expansive amount of information, such as those in the *Authoritative Reports* chapter and papers based on research sponsored by the California Energy Commission's Public Interest Energy Research Program.

Within each category in the chapters, the references are arranged by publication date, from the earliest to most recent.

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.

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Authoritative Reports

This chapter presents summaries of publications by national and international scientific organizations generally recognized to be authoritative in topics relating to climate change. The best known authoritative body is the Intergovernmental Panel for Climate Change (IPCC) established by the United Nations Environment Programme and the World Meteorological Organization. In the United States, the U.S. Global Change Research Program was established to coordinate and integrate federal research on changes in the global environment. Thirteen departments and agencies participate in the program, which is responsible for the National Climate Assessments. At a broader scale, the National Academies (the collective name for the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine and the National Research Council) enlist the nation's top scientists, engineers and other experts to provide independent advice to the government on science and technology issues that frequently affect policy decisions. Finally, certain international, federal and state agencies are widely acknowledged as authoritative by virtue of the high level of expertise and the nature of the scientific work they carry out.

State of the Climate: National Overview for Annual (*for years 2009 to 2011*). National Oceanic and Atmospheric Administration, National Climatic Data Center (2009, 2010, 2011). http://www.ncdc.noaa.gov/sotc/national/

UNITED STATES

Annual 2009 (http://www.ncdc.noaa.gov/sotc/2009/13)
Annual 2010 (http://www.ncdc.noaa.gov/sotc/2010/13)
Annual 2011 (http://www.ncdc.noaa.gov/sotc/2011/13)

Keywords: temperature, cyclones, drought, extreme events, flood, heat wave, La Niña/El Niño precipitation, ocean, wildfires, drought, climate extremes, land use, North Atlantic Oscillation, North Pacific Ocean, ocean conditions, Pacific Decadal Oscillation (PDO), precipitation/rain

Summary: 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) and, in 2010 and 2011, a list of the year's top ten weather or climate events in the United States, and a discussion of the Climate Extremes Index. A few highlights from the each annual report follow:

2009

- The average annual temperature of the contiguous United States in 2009 was 53.1^{o}F, 0.3^{o}F above the 20th century average.

- 2009 was the 18th wettest year in the 1895-2000 record. 2009 had the 22nd driest winter (nationally), 18th wettest spring (for the contiguous U.S.), and 13th wettest autumn (for the contiguous U.S.) in the record.
- The U.S. Climate Extremes Index measures the occurrence of several types of climate extremes, such as record or near-record warmth, dry spells or rainy periods. In 2009, extremes in both temperature and precipitation were observed around the country.
- There was significant fire activity early in the year, but wetter conditions later in 2009 coupled with effective fire management helped restrain fire activity. Los Angeles experienced the largest fire on record in Los Angeles County, although arson was determined to be the cause.

2010

- The average annual temperature of the contiguous United States in 2010 was 53.8°F, 1.0°F above the 20th century average. The year was the 23rd warmest on record.
- The nationally averaged precipitation was the ninth wettest in 116 years, 1.09 inches above the long term average.
- The U.S. Climate Extremes Index measures the occurrence of several types of climate extremes, such as record or near-record warmth, dry spells or rainy periods. In 2010, extremes in both temperature and precipitation were observed around the country.
- Every month in 2010 experienced below average fire acreage burned.

2011

- The average annual temperature of the contiguous United States in 2011 was 53.8°F, 1.0°F above the 20th century average. The year was the 23rd warmest on record.
- Precipitation across the contiguous states was 0.36 inch below the long-term average; precipitation has been increasing at a rate of about 0.18 inch per decade. Although the year was drier than average, it was a record wet year for several states and cities.
- The U.S. Climate Extremes Index measures the occurrence of several types of climate extremes, such as record or near-record warmth, dry spells or rainy periods. In 2011, extremes in both temperature and precipitation were observed around the country.
- The year 2011 is the third most active wildfire season in terms of acres burned, and sixth least active in terms of number of fires.

State of the Climate: Global Analysis for Annual (*for years 2009 to 2011*). National Oceanic and Atmospheric Administration, National Climatic Data Center (2012). http://www.ncdc.noaa.gov/sotc/global/

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Annual 2009. http://www.ncdc.noaa.gov/sotc/global/2009/13
Annual 2010: http://www.ncdc.noaa.gov/sotc/global/2010/13

Annual 2011. http://www.ncdc.noaa.gov/sotc/global/2011/13

Keywords: temperature, precipitation, climate extremes, cyclones, drought, extreme events, flood, heat wave, La Niña/El Niño, land use, North Atlantic Oscillation, North Pacific Ocean, ocean conditions, Pacific Decadal Oscillation (PDO), precipitation/rain, precipitation,

Summary: 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, above. 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, in 2010 and 2011, a list of the year's top ten global weather or climate events. A few highlights from each annual report follow:

2009:

- Global land and ocean surface temperatures were the fifth warmest in the 1895-2009 record.
- 2009 was projected to be one of the ten warmest years on record.
- The 2000-2009 decade was expected to be the warmest on record.
- Ocean surface temperatures through October were the sixth warmest on record, and land surface temperatures through October were the fifth warmest on record.

2010:

- The combined global land and ocean surface temperature tied with 2005 as the warmest year on record.
- The combined global land and ocean surface temperature for the Northern Hemisphere was also the warmest on record.
- The global land surface temperature tied with 2005 as the third warmest on record.
- There was a moderate-to-strong El Niño at the beginning of the year, which transitioned to a moderate-to-strong La Niña by the end of November.

2011:

- 2011 tied 1997 as the 11th warmest year since records began in 1880. 2011 is also the 35th consecutive year, since 1976, that annual global temperature was above average. Warmest years on record are 2010 and 2005.
- The 2011 global average land surface temperature was the eighth warmest on record.
- The global average ocean temperature was the 11th warmest on record.
- 2011 was the second wettest year on record, behind 2010. Precipitation varied globally.
- La Niña was present during much of 2011. The beginning of 2011 saw a relatively strong phase of La Niña, which dissipated in the spring and then emerged again in October and lasted until the end of 2011.

- The 2011 global surface temperature was the warmest observed during a La Niña year on record.
- La Niña contributed to significant drought in the Horn of Africa. La Niña also contributed to Australia's third wettest year during its 112 years of record.

State of the Climate in 2009. American Meteorological Society (2009). Arndt DS, Baringer MO, and Johnson MR (Eds.), Bulletin of the American Meteorology Society, 91 (7): S1–S224.
http://www.ncdc.noaa.gov/bams-state-of-the-climate/2009.php

State of the Climate in 2010. American Meteorological Society (2011). Blunden J, Arndt DS, and Baringer MO (Eds.), Bulletin of the American Meteorology Society, 92 (6): S1–S266.
http://www.ncdc.noaa.gov/bams-state-of-the-climate/2010.php

State of the Climate in 2011. American Meteorological Society (2012). Blunden J and Arndt DS (Eds.), Bulletin of the American Meteorology Society, 93(7): S1-S265.
http://www.ncdc.noaa.gov/bams-state-of-the-climate/2011.php

GLOBAL

Keywords: climate, temperature, precipitation, carbon dioxide, salinity, sea level, snow and ice cover, albedo

Summary: Reports for the years 2009 through 2011 are the 20th through the 22nd edition of the annual State of the Climate. The annual report documents the weather and climate events of the year and places them into accurate historical perspective. The report provides information on the state, trends, and variability of the climate system.

Chapters present information on: global-scale climate variables (Chapter 2); global oceans (Chapter 3), tropical climate phenomena (Chapter 4), the Arctic and Antarctic (Chapters 5 and 6); and regional perspectives authored by that region's climate specialists, including a section on North America (Chapter 7).

The series uses several "essential climate variables" to provide a broad representation of the climate system, including:

- **Fully monitored** variables that are observed and analyzed across much of the world, with a sufficiently long-term dataset with peer-reviewed documentation.
  - Atmospheric surface: air temperature, precipitation, air pressure, water vapor (added in 2010 report)
  - Atmospheric upper air: earth radiation budget, temperature, water vapor, cloud properties
  - Atmospheric composition: carbon dioxide, methane, ozone, nitrous oxide, ozone-depleting gases (chlorofluorocarbons) and their replacements

(hydrochlorofluorocarbons and hydrofluorocarbons), sulfur hexafluorides, perflurocarbons, aerosols
    - Ocean surface: temperature, salinity, sea level, sea ice, current, ocean color
    - Ocean subsurface: temperature, salinity (added in 2010 report)
    - Terrestrial: snow and ice cover, albedo (added in 2011 report); 2009 report also included lake levels, fraction of absorbed photosynthetically active radiation
- **Partially monitored** variables, meeting some but not all of the above requirements
    - Atmospheric surface: wind speed and direction
    - Atmospheric composition: long-lived greenhouse gases not listed above
    - Ocean surface: carbon dioxide; 2009 report included partial pressure
    - Ocean subsurface: current, carbon
    - Terrestrial: soil moisture (2009 report included wetness), permafrost, glaciers and ice sheets, river discharge; 2010 and 2011 reports included biomass, fire disturbance, groundwater, lake levels, fraction of absorbed photosynthetically-active radiation
- **Expected to be added in the future**:
    - Atmospheric surface: surface radiation budget
    - Atmospheric upper air: wind speed and direction
    - Ocean surface: sea state
    - Ocean subsurface: nutrients, ocean tracers, phytoplankton
    - Terrestrial: surface ground temperature, subsurface temperature and moisture, water use, land cover, leaf area index

A few highlights from the annual reports follow:

<u>2009</u>:

- A waning La Niña transitioned to a strengthening El Niño
- Over the last three decades, global average surface and lower-troposphere temperatures have been progressively warmer than previous decades. The 2000s was the warmest decade on record.
- CO_2 concentrations in the atmosphere increased at a rate above the 1978-2008 average
- Extreme warmth occurred across large parts of South America, southern Asia, Australia, and New Zealand
- Global tropical cyclone activity was the lowest since 2005
- In the Arctic, summer minimum ice extent was the third lowest on record since 1979
- As in previous years, the Antarctic Peninsula warmed at a rate five times higher than the global mean warming

2010:

- In 2010, a transition from a warm El Niño to cool La Niña contributed to significant events like record wetness in Australia
- The average global land and ocean surface temperature was among the two warmest years on record
- Annual land precipitation was about 5% above the norm
- In the Arctic, the annual minimum ice extent was the third lowest reached since 1979. In the Antarctic, averaged sea ice extent reached an all-time record maximum.
- In a decade-long record, Greenland glaciers lost more mass in 2010 than in any other year

2011:

- In 2011, a moderate-to-strong La Niña contributed to historical droughts in East Africa, the southern United States and northern Mexico, as well as the wettest two-year period in Australia.
- Combined average temperature across global land and ocean surfaces was the coolest since 2008, but was also among the 15 warmest years on record above the 1981-2010 average.
- The cooling influences of La Niña also gave rise to a cooling of global sea surface temperatures by 0.1^{o}C compared to 2010.
- Atmospheric carbon dioxide concentrations increased by 2.10 ppm, exceeding 390 ppm for the first time since instrumental records began.
- The noticeable drop in global sea level in mid-2010 that reached a local minimum in 2011 has been linked to the La Niña conditions; global sea level increased sharply during the second half of 2011.

Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change. Hegerl GC, Hoegh-Guldberg O, Casassa G, Hoerling MP, Kovats RS, Parmesan C, et al. (2010). In: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Detection and Attribution of Anthropogenic Climate Change. [Stocker TF, Field CB, Qin D, Barros V, Plattner G-K, Tignor M, et al. (Eds.)], IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland. http://www.ipcc.ch/pdf/supporting-material/ipcc_good_practice_guidance_paper_anthropogenic.pdf **METHODOLOGY**

Keywords: detection, attribution, external forcing, external drivers, detection (signal vs. noise)

Summary: To understand climate change, reliable detection and attribution of changes in climate and its effects are needed. Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event, with an assignment of statistical confidence. This report clarifies

methods, definitions and terminology used by two of the working groups of the Intergovernmental Panel on Climate Change (IPCC): Working Group I (WGI) conducts assessments of the physical aspects of the climate system and climate change; and Working Group II (WGII) conducts assessments of the impacts of climate change on natural and socio-economic systems. The report is based on discussions and conclusions from a joint Expert Meeting of the IPCC WGI and WGII on "Detection and Attribution related to Anthropogenic Climate Change," held in Geneva, Switzerland on September 14-16, 2009.

The report provides guidelines for assessing the relative quality of studies and offers recommendations for good practice in detection and attribution studies, including criteria for assessing confidence, data requirements, and methods for handling confounding factors. These guidelines will ensure robust and consistent assessment of attribution results in WGI and WGII assessments. Among other things, the guidelines emphasize the need to specifically state the causal factor to which a particular change is being attributed, and to identify whether the attribution in question concerns a response to a change in climate and/or environmental conditions and/or other external drivers and forcings. Robust quantification of the effects of a causal factor and a firm understanding of the processes involved in a proposed causal link increase confidence in the assessments.

Monitoring Climate Change Impacts: Metrics at the Intersection of the Human and Earth Systems. National Research Council. Washington, D.C: The National Academies Press (2010). http://www.nap.edu/catalog.php?record_id=12965 **GLOBAL**

Keywords: public health, water, natural disasters, atmosphere, indicators, sustainability, agriculture, cryosphere, ecosystem impacts, extreme events, hydrology, ocean conditions, sea level, storms

Summary: This report was prepared by the Committee on Indicators for Understanding Global Climate Change. The Committee's charge was to propose an illustrative suite of indicators, measurements, and metrics most important for understanding global climate change and for providing insight into environmental sustainability. While traditional climate change indicators generally highlight the fundamental physical science of climate processes and their associated impacts on the natural world, the proposed indicators highlight the human dimensions of climate change. These indicators consider how climate change threatens the sustainability of various components of the Earth system and, consequently, humans. They inform how climate change affects the five domains of human vulnerability: water, food, energy, health, and shelter.

Eight panels provided input on the cryosphere, land-surface and terrestrial ecosystems, hydrology and water resources, the atmosphere, human health, oceans, and natural disasters. From these components, a suite of indicators were developed. Certain characteristics were considered to make a metric particularly useful including:

- Direct (such as loss of ice sheet mass leading to rising sea level)

- Significant (represents a large change in one or more resources)
- Dominant (outweighs others factors and processes)
- Measurable (capable of being quantified)
- Historical (provides the foundation of understanding and measurement)
- Well documented (data are complete and consistent).

The report attempts to provide representative lists of metrics that appear likely to be affected by foreseeable disruptions over the next 20-25 years, and is not intended to represent an exhaustive analysis of all the human-environment interactions. Examples of indicators include: sea level rise, soil moisture change, land ice dynamics, temperature climate normal, water quality, severe storms, and food security and agriculture. Cumulatively, the indicators presented in this report illuminate how climate has affected the environment in the past and will affect it in the future, and how human communities can be impacted by climate change.

Advancing the Science of Climate Change. National Research Council. Washington, D.C: The National Academies Press (2010).
http://www.nap.edu/openbook.php?record_id=12782 **UNITED STATES**

Keywords: current science; scientific advances; mitigation; adaptation; recommendations

Summary: The *Panel on Advancing the Science of Climate Change* was charged with providing an overview of past, present and future climate change and recommending steps (e.g., research programs, new models) to advance our current understanding. Both the natural climate system and human activities contributing to climate change are considered. Also considered are the scientific advances needed to better understand the effectiveness of actions taken to limit the magnitude of future climate change and adaptation measures.

The report is organized into 17 chapters as follows:

- Chapter 1: Science for understanding and responding to climate change
- Chapter 2: What we know about climate change and its interactions with people and the environment
- Chapter 3: Identifies scientific advances that could improve our present understanding of climate change or the effectiveness of mitigation and adaptation efforts
- Chapter 4: Integrative themes for climate change research
- Chapter 5: Recommendations for meeting the challenge of climate change research
- Chapters 6-17: Technical chapters providing details of current knowledge of climate change across all sectors

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Workshop Report of the Intergovernmental Panel on Climate Change Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems. Field CB, Barros V, Stocker TF, Qin D, Mach KJ, Plattner G-K, et al. (Eds.) (2011). IPCC Working Group II Technical Support Unit, Carnegie Institution, Stanford, California. http://www.ipcc-wg2.gov/meetings/workshops/OceanAcidification_WorkshopReport.pdf

GLOBAL

Keywords: acidification, ocean, carbon dioxide, ecosystem, water chemistry, uncertainties, attribution

Summary: Climate scientists consider the effects of increasing atmospheric carbon dioxide (CO_2) concentrations on ocean chemistry and its impacts on marine biology as important to our scientific understanding of global change. Because ocean acidification research is advancing rapidly, the IPCC Working Groups I and II are evaluating the effects of atmospheric CO_2 on ocean chemistry and the resulting biological impacts. This report summarizes the body of science on ocean acidification and its marine impacts based on discussions at a January 2011 workshop in Okinawa, Japan. The core topics at this workshop were: (1) changing chemistry of the oceans, (2) impacts of ocean acidification for individual organisms, and (3) scaling up responses from individual organisms to ecosystems. This information will be included in the Fifth IPCC Assessment Report.

Fourteen keynote presentations summarized the scientific understanding surrounding the three core topics. Abstracts are provided in the report and include the following:

- Changes in ocean carbon chemistry since pre-industrial times and future projections of carbon chemistry
- Acidification impacts on for coral reefs and coral reef organisms
- Life history impacts and evolutionary responses on non-coral reef invertebrates and fishes
- Scaling up to ecosystems from natural and experimental responses
- Socioeconomic impacts of ocean acidification

In six Breakout Groups, participants addressed questions relating to cross-cutting themes. Short reports of breakout group discussions are provided and include the following:

- Detection and attribution of ocean acidification and its impacts
- Reconciling contradictory observations
- Spatial and temporal scales of variability and rates of change
- Learning from the past/present to predict the future
- Understanding the roles of multiple stressors
- The socioeconomic impacts of ocean acidification

Current research projects and results were presented by participants during two poster sessions. Poster abstracts are provided in the report and include the following topics:

- Predictive relationships for pH and carbonate saturation in the Southern California Current System using oxygen and temperature data

- Potential of radionuclides to detect large scale impacts of ocean acidification
- Complete inhibition of spawning by CO_2 and temperature increases in the sea urchin Hemicentrotus pulcherrimus
- Animal performance in a changing ocean: synergistic effects of climate-related variables
- Integrated assessment of ocean acidification within coral reef ecosystems

The authors state that this report will stimulate further collaboration across the working groups and provide important information for the fifth IPCC report and the broader research community.

Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. The National Academies Press, Washington D.C. (2012). http://www.nap.edu/openbook.php?record_id=13389 **WESTERN U.S.**

Keywords: sea level rise, coastal retreat, plate tectonics, glaciers, gravitational pull

Summary: As part of a Governor's Executive Order directing California state agencies to plan for sea level rise and coastal impacts, the National Research Council was asked to evaluate sea level rise in 2030, 2050, and 2100. Three federal agencies and the States of Oregon and Washington joined the study. No comprehensive assessments of the rate of sea level rise off the west coast of the United States had been carried out prior to this assessment.

This report summarizes the IPCC's findings on global sea level change, updating these with more recent results, and presents an analysis of relevant data and model results used to derive projections of global and local sea level rise.

- The rise in global sea level is attributed to warming oceans leading to thermal expansion increasing ocean volumes and melting ice transferring water to the oceans—both responses to a warming climate. New research results indicate that melting land ice is currently the largest contributor to global sea level rise, accounting for about 65 percent of the total rise from 1993 to 2008.

- Along the West Coast, regional factors that affect sea level include:

    - Climate patterns such as the El Niño-Southern Oscillation and Pacific Decadal Oscillation that affect wind and ocean circulation: Local sea level rises during El Niño's warm phases, and lowers during cool phases.

    - Gravitational pull and deformational effects associated with large masses of glaciers and ice sheets: Melting from Alaska and Greenland causes relative sea level to fall at decreasing rates from northern Washington to southern California; melting from Antarctica causes relative sea level to rise in the three states.

- Vertical land motions: uplift, subsidence or other land movement due to geological processes and tectonics, as well as due to human activities such as water or hydrocarbon extraction.

- Global sea level has been rising since the late 19th or early 20th century. This coincides with a period of increasing global temperatures. Over the 20th century, sea level rose an average of about 1.7 mm per year, based on tide gage measurements from around the world. For the period from 1993-2003, rates increased to about 3.1 mm per year, based on satellite altimetry measurements confirmed by tide gage records. To rule out the role of natural climate variability, a longer record is needed to determine whether this higher rate represents an acceleration in the long-term sea level trend.

- Global sea level is estimated to rise, relative to 2000 levels, by 8-23 cm by 2030, 18-48 cm by 2050, and 50-140 cm by 2100.

- Sea level projections for the West Coast differ from global projections. The projections for California are slightly higher than the global projections, primarily because much of the coastline is subsiding. The transition from land subsidence—which increases sea level rise—occurs in California at Cape Mendocino, to land uplift—which decreases sea level rise—in Oregon and Washington. South of Cape Mendocino, sea level rise is projected to rise, relative to the year 2000, 4 to 30 cm (1.6 to 11.8 inches) by 2030, 12 to 61 cm (4.7 to 24 inches) by 2050, and 42 to 167 cm (16.5 to 65.7 inches) by 2100. North of Cape Mendocino, sea level is projected to change -4 to 23 cm by 2030, -3 to 48 cm by 2050, and 10 to 143 cm by 2100.

- The confluence of large waves, storm surges, and high astronomical tides during a strong El Niño causes most of the damage along the West Coast. The extent to which these impacts will be magnified by sea level rise need to be better understood for coastal planning.

- Partial protection against sea level rise and storms is provided by the coastal cliffs, beaches and dunes. These have, however, been eroding over the long term due to storm waves. Rates of coastline retreat are expected to increase with rising sea level, likely accelerating if waves become higher.

- Marshes and mudflats that protect inland areas by storing flood waters and damping wave height and energy must be able to maintain their elevation relative to sea level and move inland in places where they are subject to erosion at the seaward edge. Frequent storms and floods in central and southern California may provide enough sediment for marshes to keep pace with the sea level rise projected for 2030 and 2050. To mitigate the projected rise in 2100, marshes will need room to migrate, a high sediment supply, and uplift or low subsidence.

National Climate Assessment: Process Workshops, United States Global Change Research Program (2010-2011). http://www.globalchange.gov/what-we-do/assessment/nca-activities/workshop-and-meeting-reports **UNITED STATES**

Keywords: adaptation, coastal impacts, ecosystem impacts, regional climate, snowmelt, socioeconomic factors, vulnerability, extreme events, greenhouse gases, precipitation/rain, sea level, snowpack

Summary: Federal law requires a national climate assessment to be submitted every four years to the President and Congress. The U.S. Global Change Research Program (USGCRP), a collaboration of 13 federal science agencies, is responsible for preparing the assessment. The national climate assessment integrates, evaluates and interprets the findings of the U.S. Global Change Research Program; analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and analyzes current trends in global change, both human-induced and natural, and projects major trends for the next 25 to 100 years.

The third national climate assessment is due in 2013. As part of the process of preparing the assessment, a series of regional, sectoral and process-related workshops were held in 2010 and 2011. Summaries of these workshops comprise an eight-volume series, as follows:

- Volume 1: *Midwest Regional workshop*
  Development of the strategic plan for the next assessment, and discussion of climate information for the U.S. and for the Midwest, key sectoral and regional issues and questions; options for adaptation and mitigation, and associated barriers and information needs; development of the regional components and stakeholder engagement methods of the national climate assessment

- Volume 2: *Strategic Planning workshop*
  Development of the strategic plan for the next assessment, including preliminary mission, goals, principles and structure of the assessment; identification of key partners and engagement strategies; suggestions for governance (administration, technical, financial) structure; timeline and assessments for the assessment and related output; topic; and desired outcomes

- Volume 3: *Knowledge Management workshop*
  Identification of approaches and methodologies for managing the large quantities of data to be developed or redeployed in the context of the assessment, as well as ways of archiving and retrieving the information; discussion of issues related to transparency, quality assurance and documentation.

- Volume 4: *Planning Regional and Sectoral Assessments for the National Climate Assessment*
  Discussion of the design of the regional and sectoral elements of the National Climate Assessment and ways to develop sustained assessment capacity at local to national scales.

- Volume 5a: *Ecosystem Responses to Climate Change: Selecting Indicators and Integrating Observational Networks*
  Discussion of a process for selecting indicators that represent the impacts of climate change on the nation's ecosystems for use in the ongoing assessment of impacts of climate change; identification of opportunities for collaboration and coordination among existing and potential future observational networks to improve the understanding of the impacts of climate change on the nation's ecosystems.

- Volume 5b: *Monitoring Climate Change and its Impacts: Physical Climate Indicators*
  Identification of broad categories of potential physical climate indicators (using a set of priorities developed by the National Climate Assessment); justification for how these would inform the nation about climate change; input on the overall framework for selecting indicators; and methodologies to construct indicators.

- Volume 5c: *Climate Change Impacts and Responses: Societal Indicators for the National Climate Assessment*
  Identification of categories of societal indicators for the National Climate Assessment; alternative approaches to constructing indicators; requirements and criteria for implementing the indicators; and sources of data.

- Volume 6: *Scenarios for Research and Assessment of Our Climate Future: Issues and Methodological Perspectives for the U.S. National Climate Assessment*
  Definition of key terms and establishment of a conceptual framework for developing consistent scenarios across different end uses and spatial scales; review of the scientific underpinnings of scenarios and the application of scenarios in past National Climate Assessments; and identification of potential users of and future needs for scenarios.

- Volume 7: *Climate Modeling and Downscaling: Issues and Methodological Perspectives for the U.S. National Climate Assessment*
  Discussion of questions and issues regarding the use of mathematical models for the National Climate Assessment; complex issues that arise when data and models are applied at multiple spatial and temporal scales; and guidance for future research in the use of models.

- Volume 8: *Valuation Techniques and Metrics for Climate Change Impacts, Adaptation, and Mitigation Options: Methodological Perspectives for the U.S. National Climate Assessment*
  Discussion of the capabilities, readiness and applicability of methodologies for quantitatively valuing climate impacts and adaptation in the context of the upcoming National Climate Assessment.

Explaining extreme events of 2011 from a climate perspective. Peterson TC, Stott PA and Herring S (2012). *Bulletin of the American Meteorological Society*, 93(7): 1041-1067. http://dx.doi.org/10.1175/BAMS-D-12-00021.1 **GLOBAL**

Keywords: extreme events, attribution, case studies, climate variability, flood, precipitation/rain, temperature

Summary: Despite research advances in climate science, attributing anthropogenic climate change to extreme events remains a challenge. Investigators from the National Oceanic and Atmospheric Administration and the Met Office Hadley Centre, United Kingdom address the issue of attribution by illustrating approaches to understanding the human role in extreme events, and the relative role of natural factors. Six global extreme events in 2011 present a range of methods used to analyze possible anthropogenic contribution to climate-related events.

Attribution observations made from analysis of extreme events include:

- The 2011 floods in Thailand were unprecedented; however, the available data show that the amount of rain that fell in the catchment area was not unusual. Other factors such as changes in the hydrography or flow characteristics of the river (for example, river height at some points were much higher than expected for the flow rate), conversion of agricultural land to industrial use, and reservoir operations policies, were more important in setting the scale of the disaster.

- In 2011, Texas experienced an extraordinary heat wave and drought. Investigators concluded that conditions leading to this drought are, at least in the case of temperature, distinctly more probable than they were 50 years ago. However, they could not say that the drought and heat wave was “extremely unlikely” to have occurred before this recent warming.

- In the United Kingdom, the winter of 2010/11 experienced the coldest December dating back to 1910 and the second coldest December in the Central England Temperature (CET) record dating back to 1659. The investigators noted that while the odds of such an event have increased as a result of human influence on climate, such unlikely events can still happen.

The authors concluded by stating that much work remains to be done in attribution science, including developing better observational datasets, improved methodologies, and progress on understanding and improving climate models.

Climate Change Indicators in the United States, 2012. U.S. Environmental Protection Agency (2012). 2nd edition.
http://www.epa.gov/climatechange/science/indicators/download.html **UNITED STATES**

Keywords: greenhouse gases, temperature, precipitation, drought, cyclones, oceans, ocean conditions, ice, snowfall, snow cover, snowpack, streamflow, ragweed, bloom, wintering, heat-related deaths, mortality (humans), glaciers, ocean acidification, sea surface temperature, temperature related mortality

Summary: This is the second edition of U.S. Environmental Protection Agency's report on climate change indicators, updating the first report issued in 2010. It presents 26 indicators describing observed trends in the United States related to the causes and effects of climate change, including: greenhouse gas emissions; atmospheric concentrations of greenhouse gases; temperature; precipitation; heavy precipitation; drought; ocean heat; sea surface temperature; sea level; ocean acidity; glaciers; snowfall; snow cover; snowpack; ragweed pollen; leaf and bloom dates; and heat-related deaths.

Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. IPCC, Cambridge University Press, Cambridge, UK, and New York (2012). Field CB, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, et al. (Eds.).
http://www.ipcc-wg2.gov/SREX/images/uploads/SREX-All_FINAL.pdf **GLOBAL**

Summary: This special report of the Intergovernmental Panel on Climate Change is a collaborative effort of Working Group I (the physical science basis) and Working Group II (impacts, adaptation and vulnerability), along with experts in disaster recovery, disaster risk management and disaster risk reduction. The report focuses on the relationship between climate change and extreme weather and climate events, the impacts of such events, and the strategies to manage the associated risks. It consists of nine chapters covering risk management; observed and projected changes in extreme weather and climate events; exposure vulnerability to such events as well as to resulting losses; adaptation options from the local to the international scale; the role of sustainable development in modulating risks; and insights from specific case studies.

A changing climate changes the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events. While the climate extremes themselves are a factor, the character and severity of their resulting impacts also depend on the exposure and vulnerability of natural and human systems. These three determinants of impact are, in turn, affected by a wide range of factors, including anthropogenic climate change, natural climate variability, and socioeconomic development.

Among the key findings of the report are:

- Exposure and vulnerability to climate extremes vary across temporal and spatial scales. They depend upon economic, social, geographic, demographic, cultural, institutional, governance and environmental factors.

- Because extreme events are rare, there are few data for assessments regarding changes in their frequency or intensity. However, the observational record since 1950 provides evidence of change in some extremes. For example:

    - It is very likely that there has been an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale.

    - There have been statistically significant trends in the number of heavy precipitation events in some regions, with increases likely in more regions than decreases.

- Some extremes have changed as a result of anthropogenic influences, including increases in atmospheric greenhouse gas concentrations.

- Economic losses from weather- and climate-related disasters have increased, mostly due to increasing exposure of people and economic assets.

- Inequalities influence local coping and adaptive capacity.

- Models project substantial warming in temperature extremes by the end of the 21st century, and it is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.

Drivers of Climate Change

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. In addition to its unprecedented levels in the atmosphere, increasing amounts of carbon dioxide have dissolved in sea water, making the oceans more acidic.

Greenhouse gases and aerosols

The primary greenhouse gases are carbon dioxide, methane, halogenated hydrocarbons, nitrous oxide, and ozone-depleting gases with varying global warming potentials. Recent studies summarized below examine other anthropogenic emissions for their potential role in climate warming, including fossil-fuel soot, biofuel soot, sulfates, black carbon and halocarbons. In addition, new findings suggest that carbon dioxide emissions can have local, in addition to global, impacts.

Halocarbon emissions from the United States and Mexico and their global warming potential. Millet DB, Atlas EL, Blake DR, N. J. Blake, Diskin GS, Holloway JS, et al. (2009). *Environmental Science & Technology*, 43(4): 1055-1060. http://dx.doi.org/10.1021/es802146j **GLOBAL**

Keywords: greenhouse gases, emissions, halocarbons, chlorofluorocarbon (CFCs), halons, carbon tetrachloride (CCl_4), methylchloroform, global warming potential, ozone-depleting substances

Background/Purpose: Halocarbons (carbon-based compounds containing chlorine, bromine, fluorine or other halogens) are potent greenhouse gases that can also deplete ozone in the atmosphere. Under the Montreal Protocol, some of these compounds, specifically chlorofluorocarbons (CFCs), halons (widely used in fire extinguishers), carbon tetrachloride (CCl_4) and methylchloroform (MCF) were banned or phased out beginning in 1996. Nevertheless, emissions may still occur from stockpiling, recycling, and possible illegal production. This study quantifies the global warming potential associated with emissions of halocarbons from the United States and Mexico.

Methods: Aircraft measurements taken in 2004 and 2006 of a comprehensive suite of anthropogenic halocarbons, carbon monoxide, and related tracers were used, along with a chemical transport model (GEOS-Chem) to derive halocarbon and CO emission rates for each country.

Results: When compared to emission estimates using "bottom-up" or emission inventories, the emissions estimates in the study underestimated some compounds and

overestimated others. MCF emissions from the U.S. were estimated at 2.8 gigagrams (Gg)/year in 2004-2006, more than 50 times the U.S. EPA estimate from "bottom-up" calculations (<0.05Gg/year); Mexican MCF emissions were minor. Estimated CFC-11 and CFC-12 emissions were consistent with earlier estimates (including the US EPA's), however estimated CFC-115 emissions were higher. By comparison, CFC emissions estimated for Mexico are 3 to 5 times higher than reported annual Mexican consumption since 1999. Halon-1211 emissions estimated for the US were consistent with US EPA estimates; H-1301 emissions were undetectable in this study, compared to the US EPA estimate of 1.5 Gg in 2004. U.S. emissions of hydrochlorofluorocarbon HCFC-22, the single largest contributor to the US halocarbon global warming potential, are estimated at 46 Gg/year—45 percent lower than US EPA's estimate; study estimates for HCFC-141B and 142B emissions were 15 and 60 percent higher, respectively, than US EPA values. Mexico generally had lower emissions than the U.S. The study estimated U.S. emissions of hydrofluorocarbons at levels significantly lower than EPA's.

Conclusions: On a 20-year time scale, halocarbon emissions at current levels are estimated to make up the third largest component of the overall long-lived greenhouse gas source from both countries, after CO_2 and methane and before N_2O, making up an estimated 9 percent and 32 percent of equivalent carbon dioxide emissions for the U.S. and Mexico, respectively. Ongoing halocarbon emissions in the U.S. and Mexico still make up an important fraction of the overall greenhouse gas source of these countries, despite the effectiveness of the Montreal Protocol in reducing global emissions of these ozone-depleting substances. By targeting these halocarbons, both countries can make a sizeable cut in their greenhouse gas emissions.

Enhancement of local air pollution by urban CO_2 domes. Jacobson MZ (2010). *Environmental Science & Technology*, 44(7): 2497-2502.
http://dx.doi.org/10.1021/es903018m **CALIFORNIA**

Keywords: urban CO_2 domes, ozone, air pollution, health, mortality (humans), urban impacts

Background/Purpose: Although carbon dioxide is generally well-mixed in the atmosphere, data indicate that its levels are higher in cities, resulting in urban domes. Air pollution regulations and mitigation policies are generally based on the premise that such domes have no local impacts—that is, CO_2 impacts are the same regardless of where emissions occur. This study shows, for the first time, that local CO_2 emissions may play a role in local air pollution and, consequently human health.

Methods: A nested model (GATOR-GCMOM) was used to examine the effects of locally emitted CO_2 on local climate and air pollution. A nested model scales from a larger to a smaller geographic area. In this case, three paired baseline and sensitivity simulations were run: from the globe to California for one year (2006); from the globe to California to Los Angeles for two sets of three months (Feb-Apr, Aug-Oct in 2006);and from the globe to the United States for two sets of three months (Jan-Mar, Jul-Sep) in

2006. An additional one-year (2007) simulation was run for California to test interannual variability. The simulations are designed to identify effects due solely to changes in locally emitted CO_2.

Results: CO_2 domes were evident over Los Angeles, the San Francisco Bay Area, and the Southern Central Valley. Observed increases in cities were higher than the largest surface CO_2 increases elsewhere. CO_2 domes had greater temperature impacts where the CO_2 was emitted (and where people lived). In addition to temperature, local ambient CO_2 changes affected other parameters, including atmospheric stability, water vapor, humidity, winds and precipitation. There did not appear to be interannual variation, as the results of the simulations for 2007 were similar to those for 2006. Finally, the data suggest that local CO_2 emissions may increase local ozone and particulate matter, and thus may increase premature mortality.

Conclusion: The findings contradict the current assumption that CO_2 emissions have little local impacts. They indicate the need to control CO_2 based on potential local health impacts, and suggest that cap and trade policies consider the location from which emissions occur.

Warming influenced by the ratio of black carbon to sulphate and the black-carbon source. Ramana MV, Ramanathan V, Feng Y, Yoon SC, Kim SW, Carmichael GR, et al. (2010). *Nature Geoscience*, 3(8): 542-545. http://dx.doi.org/10.1038/ngeo918

GLOBAL

Keywords: fossil fuels, biomass, black carbon, sulfates (sulphates), warming, cooling, absorption

Background/Purpose: Burning of fossil fuels and biomass generates black carbon, which absorbs solar radiation, contributing to climate warming. The extent of warming from black carbon depends on sulphate and organic aerosol levels and the origin of black carbon. Sulphate and organic aerosol reflect solar radiation and cool the surface. The net radiative forcing is determined by the relative amounts of black carbon and sulfate. This study investigates the impact of black-carbon-to-sulphate ratios on net warming in China.

Methods: Authors collected surface and aircraft measurements of aerosol plumes from Beijing, Shanghai and the Yellow Sea. Surface measurements were collected in spring 2007, and aircraft measurements were collected in summer 2008. Aircraft also provided observations for determining the dependence of warming or cooling from mixtures of absorbing and scattering aerosols on black carbon and on black carbon-to-sulphate ratios.

Results: The Beijing plumes had the highest ratio of black-carbon-to-sulphate, and exerted a strong positive influence on the net warming. Solar-absorption efficiency was positively correlated with the ratio of black carbon to sulphate. Fossil fuel-dominated

black carbon plumes were about 100% more efficient warming agents than biomass burning-dominated plumes.

Conclusions: Because of its short lifetime, black carbon offers the greatest potential for slowing down climate change in the coming decades. Reductions in SO_2 emissions worldwide will likely be accompanied by larger reductions in black carbon, decreasing the black-carbon-to-sulphate ratio. In addition to slowing warming, these reductions will have significant co-benefits to human health.

Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health. Jacobson MZ (2010). *Journal of Geophysical Research*, 115(D14): D14209.
http://dx.doi.org/10.1029/2009JD013795 **GLOBAL**

Keywords: black carbon, fossil fuels, biofuels, soot, methane, warming, air pollution, clouds, mortality (humans), temperature, absorption

Background/Purpose: Combustion of fossil-fuels (such as diesel, jet fuel and kerosene) and solid biofuels (wood and organic waste) generates soot with different chemical composition and physical properties, particularly the ability to absorb light. Soot absorbs sunlight, converting it to infrared (heat) radiation, which is emitted to the surrounding air. Soot reduces the albedo of snow or sea ice, increasing solar radiation to the ground. Soot between cloud drops or crystals warms the cloud air relative to the surface, reducing the local relative humidity and reducing cloudiness. Soot is also associated with adverse impacts on human health. Understanding the effects of fossil-fuel soot, solid-biofuel soot and gases, and methane on global and Arctic temperatures, cloudiness, precipitation, and atmospheric composition will help inform strategies to reduce Arctic ice loss and global warming.

Methods: This study examined the short-term (~15-year) effects of controlling fossil-fuel soot, solid-biofuel soot and gases, and methane using a model (GATOR-GCMOM). Modeled simulations included effects on snow, sea ice and albedo, aerosol/cloud absorption, temperature, humidity and cloud properties, lightning and surface air quality.

Results: The 15-year climate response simulations resulted in a reduction in air temperatures when fossil-fuel soot, fossil-fuel soot with solid biofuel soot and gases, and CH_4 were each eliminated. Removal of both fossil-fuel soot and solid biofuel soot and gases had the greatest cooling effect. Fossil fuel soot is a stronger contributor to warming per unit mass of soot emission than solid biofuel soot and gases. (The latter, however, may cause ~8 times more human mortality because emissions occurred substantially in heavily populated countries, compared to fossil fuel.) Fossil fuel soot with solid biofuel soot may be the second leading cause of warming after CO_2.

Conclusions: Both fossil fuel soot and solid biofuel soot and gases significantly contribute to warming. Fossil fuel soot has a greater warming influence, while solid

biofuel soot and gases can have a greater health impact. The simulations suggest that controlling both may help to reduce Arctic ice loss and global warming faster than controlling methane or carbon dioxide. Future research is needed to improve emission inventories, perform simulations at higher resolutions, and to better model physical, chemical and radioactive processes that can help elucidate the impact of soot on the climate.

Non-CO_2 greenhouse gases and climate change. Montzka SA, Dlugokencky EJ and Butler JH (2011). *Nature*, 476(7358): 43-50. http://dx.doi.org/10.1038/nature10322

GLOBAL

Keywords: greenhouse gases, emissions, warming, mitigation, methane, ozone-depleting substances, nitrous oxide, fossil fuels

Background/Purpose: This review addresses human activities and natural processes that serve as sources of, and sinks for greenhouse gases other than carbon dioxide (CO_2)—specifically methane, nitrous oxide and ozone-depleting substances. This information, along with data on the warming influence of these chemicals (also called climate forcing or radiative forcing) and their contributions to total climate forcing, will help inform emission reduction strategies.

Methods: Studies investigating the influence of the non-CO_2 gases methane, nitrous oxide, ozone-depleting substances and their substitutes on the climate were reviewed. Global trends in greenhouse gas emissions, potential changes in these trends, and mitigation strategies are discussed.

Results: During the 1980s, human-derived, non-CO_2 greenhouse gas emissions were comparable to CO_2 emissions from fossil fuel combustion. Since 1990, reductions in the emissions of ozone-depleting substances under the Montreal Protocol led to a decline in total emissions of non-CO_2 greenhouse gases, for a time offsetting increases in other greenhouse gas emissions. Since 2003, however, continued increases in fossil fuel CO_2 have exceeded these offsets. In 2008, the contribution from non-CO_2 greenhouse gases accounted for 30 percent of all human-related long-lived greenhouse gas emissions.

A better understanding of the sources, sinks, processes and mechanisms associated with non- CO_2 emissions can reveal opportunities for mitigation. If non-CO_2 greenhouse gas emissions were to remain constant, reducing CO_2 emissions by 80 percent could eventually stabilize climate forcing from all long-lived greenhouse gases. By contrast, reducing all non- CO_2 emissions by 80 percent would cause a substantial decrease in radiative forcing, not just stabilization. This is mainly due to the rapid response of atmospheric methane levels to emissions decreases, given its large contribution to present forcing and its relatively short lifetime.

Conclusions: The paper highlights certain important principles and scientific needs to consider in managing future climate forcing. These include the following:

- since non-CO_2 greenhouse gases presently account for one-third of total CO_2 equivalent emissions and 35 to 45 percent of total climate forcing from all long-lived greenhouse gases, cuts in their emissions could substantially lessen future climate forcing;
- cuts in emissions of the shorter-lived, non- CO_2 greenhouse gases, primarily methane, could cause a rapid decrease in the radiative forcing attributable to these gases;
- the potential benefits of cuts in non- CO_2 greenhouse gas emissions have limits, as they may not sufficiently offset continued CO_2 increases at present rates; and
- scientific advances in the understanding of the sensitivities of natural greenhouse gas fluxes to climate change and in the ability to quantify both natural and anthropogenic greenhouse gas fluxes will better enable the overall effectiveness of mitigation efforts to be assessed and optimized.

Radiative absorption enhancements due to the mixing state of atmospheric black carbon. Cappa CD, Onasch TB, Massoli P, Worsnop DR, Bates TS, Cross ES, et al. (2012). *Science*, 337(6098): 1078-1081.
http://www.sciencemag.org/content/337/6098/1078.abstract **CALIFORNIA**

Keywords: black carbon, absorption, warming, biomass, urban impacts

Background/Purpose: Black carbon in the atmosphere warms Earth's climate, and has been identified as a target for near-term climate mitigation. Model estimates of the warming (radiative forcing) caused by atmospheric black carbon assume mixing with other aerosol components that enhance its ability to absorb sunlight by up to a factor of two. Such model estimates have yet to be validated through atmospheric observational data. This study provides direct measurements of black carbon sunlight absorption and of average mixing state of black carbon in the atmosphere for two California regions.

Methods: Data reported from two field campaigns were used in the study: the 2010 CalNex study and the Carbonaceous Aerosols and Radiative Effects Study (CARES). CalNex measurements were taken 18 meters above the ocean surface onboard the vessel *R/V Atlantis*, which was deployed in San Diego and finished in San Francisco, with a significant amount of time spent around the Los Angeles region. CARES measurements were taken at a ground site in the Sacramento urban area.

Results: The observed black carbon absorption enhancement was small (6 percent on average), and increases weakly with photochemical aging. The study indicates that black carbon emitted from large to medium-sized urban centers, which are dominated by fossil fuel emissions, does not exhibit a substantial absorption enhancement when internally mixed with non-black carbon material. This is in stark contrast to laboratory measurements and model calculations. It is possible that non-fossil-derived black carbon, such as from biomass burning, may have considerably different internal

morphology or amounts of brown carbon than the ambient particles in this study, thus exhibiting different absorption enhancement values.

Conclusion: Current climate models may be overestimating warming from black carbon. The understanding of radiative forcing by atmospheric black carbon is still uncertain with respect to particle mixing state.

Acidification

Covering most of the Earth's surface, oceans are a vast reservoir for carbon dioxide. By absorbing nearly one quarter of the carbon dioxide released into the atmosphere by human activities every year, oceans reduce greenhouse gas forcings on the climate. As atmospheric levels of carbon dioxide 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 carbon dioxide 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.

Workshop Report of the Intergovernmental Panel on Climate Change Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems. Field CB, Barros V, Stocker TF, Qin D, Mach KJ, Plattner G-K, et al. (Eds.) (2011). IPCC Working Group II Technical Support Unit, Carnegie Institution, Stanford, California. http://www.ipcc-wg2.gov/meetings/workshops/OceanAcidification_WorkshopReport.pdf

GLOBAL

See summary under *Authoritative Reports*, page 13.

Detecting regional anthropogenic trends in ocean acidification against natural variability. Friedrich T, Timmermann A, Abe-Ouchi A, Bates NR, Chikamoto MO, Church MJ, et al. (2012). *Nature Climate Change*, 2(3): 167-171. http://dx.doi.org/10.1038/nclimate1372

GLOBAL

Keywords: ocean acidification, natural variability, climate variability, detection (signal vs. noise), ocean conditions, marine impacts

Background/Purpose: Ocean acidification threatens calcifying (shell- or skeleton-forming) marine species. One measure of acidification is the seawater concentration (or more precisely, the "saturation state") of aragonite, the more soluble form of calcium carbonate that shells or skeletons are made of. As ocean uptake of anthropogenic carbon dioxide (CO_2) increases, marine organisms become exposed to aragonite saturation states outside the range of natural variability that they have successfully adapted to during pre-Industrial times. It is thus important to distinguish anthropogenic acidification from natural variability. Since long-term observation data are sparse, the

investigators used model simulations to determine the range of natural variability in ocean carbonate chemistry

Methods: Modeling simulations over 1,300 years (800-2099 AD) using a coupled carbon cycle-climate model (MPI-ESM) estimated global atmospheric CO_2 concentrations and surface aragonite saturation states. In addition, the effect of the CO_2 increase during the Last Glacial Maximum on surface aragonite saturation was studied using two different Earth system models (LOVECLIM and MIROC). This allowed aragonite saturation state trends in the twentieth century to be compared with trends between the Last Glacial Maximum and pre-Industrial times.

Results: Current levels of aragonite saturation state are considerably lower than the long-term pre-Industrial mean. Across the globe, the simulated ratios between the anthropogenic change and the natural variability in acidification differ substantially on a regional scale. Current regional anthropogenic trends in ocean acidification exceed the level of natural variability by up to 30 times. Current rates of ocean acidification at monitoring sites in the Atlantic and Pacific oceans are greater than those experienced during the last glacial termination by up to two orders of magnitude. Other simulations estimate that the anthropogenic impact will be detectable in almost the entire ocean by the year 2010, except for the tropical eastern Pacific (which has high natural variability) and certain areas near the poles (the frontal regions near the subpolar gyres).

Conclusions: Anthropogenic trends in ocean acidification exceed natural variability and are detectable in many parts of the ocean. These are likely to have significant impacts on marine ecosystems. An important goal in the future is translating human-induced acidification trends to effects on marine ecosystems.

Changes in Climate

The atmosphere, land surface, snow and ice, oceans and other bodies of water and living things make up the complex, interactive climate system. Climate, often defined as "average weather," is measured in terms of temperature, precipitation, atmospheric pressure, and wind over a period of time (generally 30 years). Long-term changes in these and other parameters are used to track changes in climate.

Attribution

Attribution is the process of establishing the most likely causes for a detected change in climate[1]*. It relies on observational data and model outputs. Models can simulate natural internal variability of the climate system on time scales of years to centuries. Their outputs can incorporate historical estimates of changes in key anthropogenic and natural forcings, such as greenhouse gases, volcanic aerosols and solar irradiation.*

Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change. Hegerl GC, Hoegh-Guldberg O, Casassa G, Hoerling MP, Kovats RS, Parmesan C, et al. IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland. (2010). Stocker TF, Field CB, Qin D, Barros V, Plattner G-K, Tignor M, et al. (Eds.), Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Detection and Attribution of Anthropogenic Climate Change. http://www.ipcc.ch/pdf/supporting-material/ipcc_good_practice_guidance_paper_anthropogenic.pdf **METHODOLOGY**

See summary under *Authoritative Reports*, page 10.

Detection and attribution of climate change: a regional perspective. Stott PA, Gillett NP, Hegerl GC, Karoly DJ, Stone DA, Zhang X, et al. (2010). *Wiley Interdisciplinary Reviews: Climate Change*, 1(2): 192-211. http://dx.doi.org/10.1002/wcc.34 **GLOBAL**

Keywords: anthropogenic, atmosphere, attribution, circulation, atmosphere circulation, climate variability, detection, fingerprint, regional, temperature, hydrological cycle, cryosphere, circulation, detection (signal vs. noise), external forcing/drivers, land use, ocean, ocean conditions, regional climate, extremes, salinity, sea level, snowmelt, temperature,

[1] IPCC, 2007. *Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

Background/Purpose: While there is a wealth of observational evidence on climate change and of the human influence on such changes at a global scale, only recently have studies focused on evidence at a regional scale.

Methods: The authors reviewed evidence in the literature for the detection of changes in temperatures, the hydrological cycle, the cryosphere, circulation, ocean, and weather extremes at the regional level, and the extent to which these changes are influenced by human activity (attribution)**.**

Results: A number of studies found detectable, anthropogenically induced change in decadal mean temperatures over the 20th century in the six populated continents, and over the past 50 years in Antarctica. More recent studies detected warming at subcontinental scales and seasonally. At even smaller scales (~500 km), significant warming trends outside the range of natural variability have been found, and determined to be consistent with anthropogenically induced change (full attribution analysis, in which all plausible forcing factors are considered, was not done). Attribution at regional scales is limited by the relatively lower signal-to-noise ratios, the wider range of possible forcing factors at these scales, and limitations of models in capturing some characteristics of regional climate variability.

Hydrologic cycle: The water holding capacity of—and hence the amount of water vapor in—the lower troposphere increases with warming. Anthropogenic forcing has had a detectable influence on observed changes in global land precipitation. Generally, low signal-to–noise ratios and poor observational coverage make detection and attribution of regional precipitation changes difficult.

Changes in runoff are even more difficult to monitor and understand. The residual difference between precipitation and evaporation and soil moisture are poorly observed and are affected by many factors (e.g., changes in climate, land use, stream management, water withdrawal and water use efficiency by plants). Nevertheless, there has been an overall global increase in dry areas (largely associated with increased temperatures rather than changes in precipitation), a change attributed to anthropogenic influence. Continental runoff has increased through the 20th century. The observed trends toward earlier center timing of snowmelt-driven streamflows in the western U.S. are detectably different from natural variability. Snow cover duration has the strongest sensitivity to variations in climate; maritime climates with extensive winter snowfall (e.g., the coastal mountains of western North America) are most sensitive, and the continental interior climates with relatively cold, dry winters, the least. There has also been a reduction in the ratio of precipitation falling as snow in the western U.S., which has been attributed to anthropogenic forcings.

Circulation changes: Only recently did studies formally detect the influence of external forcings on sea level pressure; however the effects of anthropogenic and natural influences have not been distinguished.

Oceanic changes: Over 80 percent of the excess heat built up in the climate system by anthropogenic forcing is estimated to have accumulated in the global oceans. Warming of the upper ocean during the latter half of the 20th century was likely due to anthropogenic forcing; the subsurface ocean has been sparsely observed in many regions. Changes in salinity integrate changes in precipitation and evaporation at the surface. At low latitudes, increases in salinity have been detected and attributed to human influence; high-latitude trends are unclear and found to be consistent with internal variability.

Extremes: Observed changes in globally collected indices of climate extremes are broadly consistent with changes expected with global warming. There are still many gaps in the understanding of changes in extremes and the ability to attribute observed changes to particular causes.

Conclusions: There is increasing evidence that human influence on temperature is becoming significant below continental scales. Attributed changes in atmospheric moisture content and precipitation patterns have been found to be consistent with theoretical expectations. Major challenges still remain in obtaining robust attribution results at the regional scales needed for the evaluation of impacts. Attribution studies will help improve climate model predictions.

Sensitivity of the attribution of near surface temperature warming to the choice of observational dataset. Jones GS and Stott PA (2011). *Geophysical Research Letters*, 38(21): L21702. http://dx.doi.org/10.1029/2011GL049324 **GLOBAL**

Keywords: detection (signal vs. noise), greenhouse gases, temperature

Background/Purpose: Earlier studies using a variety of climate models have demonstrated that much of the recent warming of near surface temperatures is attributable to increases in anthropogenic greenhouse gases. Equivalent studies using different observational datasets, however, have not been conducted. The authors repeated earlier analyses, using four different observational datasets to examine whether the choice of dataset has an impact on the results.

Methods: Four globally gridded datasets of temperature near the Earth's surface were selected (HadCRUT3v, GISS, NCDC and JMA). Two climate models were used to analyze the contributions of (1) changes in historic greenhouse gas concentrations alone; (2) changes in historic anthropogenic factors, namely greenhouse gases, sulphate aerosol and ozone; and (3) changes in natural factors, namely solar irradiance and stratospheric volcanic aerosol. Temperatures are reported in Kelvin (K).

Results: Over the 20st century, all four datasets analyzed suggest that warming attributable to greenhouse gases is around 0.1K per decade, greater than the observed warming trend of about 0.06K/decade during the century. The combination of greenhouse gases, sulphate aerosol and ozone produced cooling at -0.06K per decade.

Natural factors—which showed a slight warming followed by a cooling over the century—had very little contribution to the overall trend. The contributions of all these factors were found to be consistent with the observed trend, although they added up to a slightly lower warming of about 0.05K per decade.

The second half of the century (1950-1999) reflected larger contributions from both greenhouse gases alone and in combination with sulphate aerosols and ozone. While the magnitude of the trends in this study were slightly larger compared to earlier analyses, all findings were consistent in demonstrating that greenhouse gases alone produce warming more than the observations, and both natural factors and greenhouse gases sulphate aerosols and ozone produce cooling.

Conclusion: While the results of the analyses were not identical to earlier detection and attribution studies, they were all very similar and consistent. The choice of observational dataset analyzed did not change the conclusion that anthropogenic greenhouse gases are the major driver of changes in near surface temperatures over the 20th century, with a greater influence over the last 50 years.

Climate variability

The term "climate variability" refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes) describing climate. It may be due to natural internal processes within the climate system, or to variations in natural or anthropogenic external forcing.[2] Natural processes (such as ocean circulation regimes) produce substantial seasonal, year-to-year and even decade-to-decade variations that are superimposed on the long-term trend. These processes can also produce substantial regional differences.

Long-term natural variability and 20th century climate change. Swanson KL, Sugihara G and Tsonis AA (2009). *Proceedings of the National Academy of Sciences*, 106(38): 16120-16123. http://dx.doi.org/10.1073/pnas.0908699106

GLOBAL, METHODOLOGY

Keywords: climate variability, external forcing/drivers, internal variability, attribution, ocean conditions, warming, sea surface temperature, sulfates (sulphates), temperature

Background/Purpose: Global mean surface temperature responds to external forcings (e.g., anthropogenic greenhouse gases) and to natural modes of variability (primarily ocean conditions) internal to the climate system. This paper attempts to objectively identify the component of inter-decadal global mean surface temperature that is attributable to natural long-term climate variability. Removing the hidden variability from

[2] IPCC, 2007. *Annex I, Glossary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-annexes.pdf

the actual observed mean surface temperatures will help delineate anthropogenic climate influences that have accelerated warming during the 20th century.

Methods: Authors derived annual mean surface temperature from ten multicentury preindustrial control climate simulations using coupled ocean-atmosphere models. These values were used in further analyses to predict global mean temperature fluctuations solely due to internal variability associated with sea surface temperatures within a given model.

Results: The global mean surface temperature responses to sea surface temperature anomalies predicted by the ten models were largely consistent. All but two of the models showed a cooling from 1900-1915, a warming from 1915-1940, a cooling from 1940 to the late 1970s, and a return to neutral afterwards.

Removing internal variability from the observed global mean temperature record resulted in a nearly monotonic warming of the global mean surface temperature throughout the 20th century that closely resembles a quadratic fit to the actual global mean temperatures. The results suggest that interdecadal temperature deviations during the century—such as the accelerated warming during 1910-1940 previously attributed to an unverifiable increase in solar irradiance, and the observed mid-40s to mid-1970s cooling previously attributed to enhanced sulfate aerosol activity—may instead be due to natural variability. A fraction of the post-1970s warming may also be due to natural variability.

Conclusions: The monotonic increase in global temperatures throughout the 20th century—following removal of the contribution of internal variability—suggests increasing greenhouse gas consistently dominating the influence of sulfate aerosols. Nevertheless, internal climate variability appears to have influenced the trajectory of 20th century global mean surface temperature.

Current climate models have difficulty reproducing interdecadal internal variability, primarily due to their deficiencies in capturing ocean dynamics, thus presenting significant challenges to near-term climate prediction. Since a variable climate is more sensitive to imposed forcings, current models may underestimate climate sensitivity.

Regional precipitation trends: Distinguishing natural variability from anthropogenic forcing. Hoerling M, Eischeid J and Perlwitz J (2010). *Journal of Climate*, 23: 2131–2145. http://dx.doi.org/10.1175/2009JCLI3420.1 **GLOBAL**

Keywords: adaptation**,** climate variability, regional precipitation, natural variability, anthropogenic forcing, greenhouse gases (GHG), ocean conditions, precipitation/rain, sea surface temperature (SST), sulfates (sulphates)

Background/Purpose: Distinguishing human influences on regional precipitation from natural variability is important to guide adaptation and mitigation strategies. Earlier

assessments have concluded that regional precipitation trends were unlikely due to human influences alone. This study examines regional precipitation during 1977-2006 to diagnose the factors contributing to the observed trends. The mid-1970s is a period of anthropogenic warming of the climate system, including a substantial increase in global sea surface temperatures. The study investigates whether regional precipitation trends have been consistent with sea surface temperature changes and, where such associations exist, whether they are symptomatic of natural variability or human influence.

Methods: Datasets and climate model simulations were used. Observational datasets from the Global Precipitation Climatology Project (GPCP) and Global Precipitation Climatology Centre (GPCC) were analyzed for ocean and land regions, respectively. Simulations from the Atmospheric Model Intercomparison Project (AMIP) and the Coupled Model Intercomparison Project (CMIP) were used to investigate the causes of the observed precipitation trends. The study focused on a decrease in annual rainfall over the equatorial east Pacific Ocean, the subtropical North and South Pacific, and the adjacent western portions of the Americas; rainfall changes for the Eastern Hemisphere; and drying over southeast Australia.

Results: Regional precipitation trends were found to be consistent with atmospheric response to observed sea surface temperature variability. In particular, simulations using changes in sea surface temperature were generally found not to be consistent with effects attributable to human-induced emissions of greenhouse gases and aerosols. Simulated rainfall trends using variations in greenhouse gases, tropospheric sulfate aerosol, solar irradiance and volcanic activity were weaker than both sea surface temperature simulations and observed trends. Further the spatial pattern of simulated rainfall changes was different from the observed changes; additional analysis showed that this was due mostly from the differences between simulated and observed changes in sea surface temperature over 30 years. Only weak rainfall sensitivity is found to occur in response to the uniform distribution of sea surface temperature warming induced by greenhouse gas and aerosols; on the other hand, the sea surface temperature gradient (that is, the increased contrast in sea surface temperature between the east Pacific and the Indian Ocean, and the strong regional warming of the North Atlantic Ocean) was a key driver of regional rainfall trends.
Conclusions: The study found that major features of regional trends in annual precipitation during 1977-2006 are consistent with an atmospheric response to observed sea surface temperature variability, and are not generally symptomatic of human-induced emissions of greenhouse gases and aerosols. It is likely that sea surface temperature changes will continue to strongly influence the pattern of regional precipitation changes. The challenge lies in predicting future trends in sea surface temperatures.

Separating signal and noise in atmospheric temperature changes: The importance of timescale. Santer BD, Mears C, Doutriaux C, Caldwell P, Gleckler PJ, Wigley TML, et al. (2011). *Journal of Geophysical Research*, 116(D22): D22105. http://dx.doi.org/10.1029/2011JD016263 **GLOBAL**

Keywords: climate variability, detection (signal vs. noise), signal to noise, natural variability, human activity, temperature

Background/Purpose: The warming "signal" caused by human-induced changes in the atmospheric concentrations of greenhouse gases is embedded in the "noise" of natural climate variability. The signal-to-noise ratio is timescale dependent: "noise" from most meteorological and oceanographic time series is largest on daily to annual timescales, becoming smaller over longer averaging periods. Separating human influences from natural variability requires information on signal and noise properties over a range of timescales.

Methods: Observed and simulated trends in global-scale lower tropospheric temperatures were compared on multiple timescales, rather than over a single time period, as in most previous work. Timescales used in the analyses ranged from 10 to 32 years. Authors then compared all possible observed temperature trends on each timescale with corresponding multi-model (Coupled Model Intercomparison Project or CMIP-3 and 20CEN/A1B) distributions of forced and unforced trends. Estimates of the signal were based on observed temperature trends; estimates of noise were based on simulated trends.

Results: Ten-year trends produced signal-to-noise ratios of less than 1, compared to ratios over 3.9 for 32-year trends. The signal-to-ratio timescale dependence was found to be strong, mainly due to the large decrease in natural variability with longer time periods. On all timescales examined the observed temperature trends were not statistically unusual relative to model-based distributions of externally forced trends.

Conclusions: Multi-decadal records (a minimum of 17 years) are required for identifying human effects on tropospheric temperature. Minimal warming over a single decade does not disprove the existence of a slowly-evolving anthropogenic warming signal.

Regional Climate Change

There is increasing evidence that the human influence on climate is becoming significant below continental scales. In some cases, local factors, rather than large-scale climatological phenomena, are playing a larger role in observed changes. Agriculture, forestry and other land management practices can influence regional temperature and precipitation. Heat in urban areas may be enhanced by the presence of heat-absorbing surfaces, heat emitting vehicles, and heating and cooling devices.

Have large dams altered extreme precipitation patterns? Hossain F, Jeyachandran I and Pielke R (2009). *Eos*, 90(No. 48): 453-468. http://dx.doi.org/10.1029/2009EO480001 **UNITED STATES**

Keywords: dams, extreme events, extreme precipitation, flood, dams, land use and land cover (LULC), convective available potential energy (CAPE), regional climate, storms, water cycle

Background/Purpose: Questions have been raised about the extent to which large dams alter precipitation patterns. With about 75,000 large dams in the United States, an issue of particular concern is whether aging dams can withstand extreme precipitation events that they may generate. This paper investigates the changes triggered by large dams on land use and land cover (LULC) and how these changes, as well as the greater availability of moisture through evaporation from irrigated lands and from the dams themselves, may lead to extreme changes in regional hydroclimatology.

Methods: Case studies, atmospheric model-based studies and theoretical investigations were presented to examine the impact of large dams and of land use and land cover on extreme precipitation.

Results: Changes in land use and land cover have been shown to alter regional hydroclimatology, showing that atmospheric moisture added by irrigation does increase rainfall under certain conditions. Both dam-driven land coverage and downstream urbanization have also been suggested to initiate changes in extreme precipitation patterns.

Conclusions: Changes in extreme precipitation patterns, which may in part be influenced by the presence of large dams and the land use and land cover changes associated with them, may compromise the flood-safety of dams. Current knowledge on the mechanisms for altering extreme precipitation remains limited. Therefore more research is needed to ensure a sustainable and structurally sound approach to future dam design and operations against invariable extreme precipitation patterns.

Regional precipitation trends: Distinguishing natural variability from anthropogenic forcing. Hoerling M, Eischeid J and Perlwitz J (2010). *Journal of Climate*, 23: 2131–2145. http://dx.doi.org/10.1175/2009JCLI3420.1 **GLOBAL**

See summary under *Climate Variability*, page 33.

The influence of large dams on surrounding climate and precipitation patterns. Degu AM, Hossain F, Niyogi D, Pielke R, Shepherd JM, Voisin N, et al. (2011). *Geophysical Research Letters*, 38(L04405). http://dx.doi.org/10.1029/2010GL046482 **CALIFORNIA**

Keywords: dams, extreme events, land use, precipitation, regional climate, storms

Background/Purpose: Large dams often trigger large scale changes in land use and land cover, for example by providing irrigation for agricultural uses or by supplying power and reducing flood risk for increased urbanization. These changes can lead to the increased availability of moisture, affecting local atmospheric circulation and consequently precipitation. The impacts of climate variability and change on dams have been studied at local and regional scales, yet the impacts of dams on local or regional climate have not.

Methods: The authors selected 92 large dams located in various climate zones in the United States. Data on climate variables relevant to precipitation were studied: (1) convective available potential energy (CAPE), the amount of energy a small amount of air would have if lifted upwards through the atmosphere, has been correlated with extreme precipitation; (2) specific humidity; and (3) surface evaporation. Daily averages over a 30-year period from 1979 to 2009 were obtained, and studied for three areas: (a) over the reservoir; (b) near the shoreline; and (c) away from the shoreline. The objective was to identify detectable changes in the long-term magnitude of these variables and examine gradients relative to their proximity to the dam. To examine the impact of irrigation on local climate, the variables were also studied as a function of growing season (April to October) and non-growing season (November to March). Finally, the authors explored the corresponding influence on precipitation patterns using daily rainfall data (from the Global Historical Climate Network) for stations selected based on certain considerations.

Results: Large dams in Mediterranean climates (such as California's) exert the strongest influence on local climate, while those in humid subtropical climates had negligible effects; this influence was generally greatest closest to the shoreline. For dams located in Mediterranean climates, changes in CAPE were accentuated during the growing season, and the growing season changes in all three variables were largest between the shoreline and the region farthest from it.

Conclusions: Large dams were found to have the greatest influence on local climate in Mediterranean and semi-arid climates. Precipitation-related variables—namely, CAPE, specific humidity and surface evaporation—measured near dams exhibited clear spatial gradients, decreasing in value with increasing distance from dams. The findings in this study indicate that dams can modify local climate and precipitation patterns.

Detection and attribution of climate change: a regional perspective. Stott PA, Gillett NP, Hegerl GC, Karoly DJ, Stone DA, Zhang X, et al. (2010). *Wiley Interdisciplinary Reviews: Climate Change*, 1(2): 192-211.
http://dx.doi.org/10.1002/wcc.34 **GLOBAL**

See summary under *Attribution*, page 29.

Climatic context and ecological implications of summer fog decline in the coast redwood region. Johnstone JA and Dawson TE (2010). *Proceedings of the National Academy of Sciences*, online publication. http://dx.doi.org/10.1073/pnas.0915062107

CALIFORNIA

Keywords: California Current, clouds, coastal impacts, drought, ecosystem impacts, Pacific Decadal Oscillation (PDO), giant redwood tree, *Sequoia sempervirens*, temperature inversion

Background/Purpose: The coast redwood occupies a cloud-connected coastal ecosystem along a narrow belt in the Northeast Pacific rim. Its distribution is limited to the California Current upwelling zone, suggesting a reliance on cool, humid marine conditions. Changes in fog frequency and related variables may impact redwood tree physiology and ecosystem function.

Methods: Hourly records of cloud ceiling height were used to determine fog frequency; fog is defined as clouds with base heights at or below 400 meters in elevation. A fog frequency index was calculated as the mean of summertime (June through September) values from two Pacific coast stations with thorough records back to 1951, Arcata and Monterey. The relationship between fog frequency and selected variables—sea level pressure, wind, sea surface temperature, monthly averages of maximum temperature (Tmax), and the monthly Pacific Decal Oscillation index—were analyzed. Finally, the effects of fog on redwood environment and transpiration were studied at a field plot in Sonoma County for a period from June 7 to 18, 2003.

Results: Northern California coastal fog frequency varied around a mean of 45 percent from 1951 to 1975, followed by a gradual decline through the 1980s and 1990s. A partial recovery to pre-1977 levels has been observed since 1997. Fog frequency ranged from a maximum of 62 percent in 1951 to a minimum of 27 percent in 1997. Analysis of its relationship with other climate variables showed summer fog to be a regionally coherent climatic element on interannual to multidecadal time scales, systematically linked to the broader ocean-atmosphere system of the Northeast Pacific, including sea level pressure patterns, upwelling-favorable winds, and the Pacific Decadal Oscillation.

A strong link between fog and both vertical and coast-inland temperature gradients was also evident. Based on the relationship between coastal fog and the difference in maximum temperatures between the coast and inland, fog frequency was estimated to average 56 percent from 1901 to 1925—33 percent higher than observed for 1951-2008.

Finally, the authors found close agreement between tree-level transpiration and cloud levels at a nearby airport. This suggests that low clouds provide an atmospheric mechanism for redwood trees to conserve water during the dry summer seasons. Hence, fog decline may result in heightened drought sensitivity for coastal redwoods.

Coastal summer fog frequency appears to be a measure of the U.S. Pacific coastal climate. There are strong statistical connections to the wind-driven upwelling system of the California Current and the Pacific Decadal Oscillation. Authors found a 33 percent reduction in fog frequency since the early 20th century. Additionally, coast redwood and other ecosystems along the west coast may be increasingly stressed by drought under a summer climate with less fog and greater evaporative demand.

Conclusions: Fog is a dominant factor on the California coast, and closely reflects broader ocean-atmosphere systems in the Northeast Pacific. Long-term reductions in fog have likely impacted the water and carbon economy of redwoods and other coastal species.

Climate change in the Tahoe basin: regional trends, impacts and drivers. Coats R (2010). *Climatic Change*, 102: 435-466. http://dx.doi.org/10.1007/s10584-010-9828-3

WESTERN U.S.

Keywords: black carbon, climate variability, extreme events, hydrology, La Niña/El Niño, Pacific Decadal Oscillation (PDO), Tahoe, warming, snow, rain, precipitation/rain, snowmelt, snowpack, temperature

Background/Purpose: At the regional and local scales, there is considerable variation in the rates of climate change and its hydrologic and ecological impacts. This study documents the long-term changes in temperature and precipitation in the Tahoe basin, placing those changes in a regional context. The study also shows how climate change is affecting watershed hydrology and Lake Tahoe itself.

Methods: Climatic and hydrologic data for the area were analyzed for trends in: annual average temperature; monthly averages of maximum and minimum daily temperature; snowmelt timing in and around the Tahoe basin; the fraction of precipitation falling as snow (at Tahoe City); rainfall intensity; and average annual and deseasonalized average daily temperature of Lake Tahoe. In addition, the statistical relationships between local climatic variables and ocean circulation patterns (i.e., the Pacific Decadal Oscillation and the El Niño-Southern Oscillation) were also studied. Air temperature and precipitation data were from the Western Regional Climate Center. Six long-term weather stations in the Tahoe region provided the air temperature data; precipitation data were for Tahoe City. Hydrologic data were for nine gaging stations in and around the Tahoe basin, and lake water temperatures were calculated from data collected as part of ongoing monitoring of Lake Tahoe that began in 1969.

Results: The area around Lake Tahoe showed strong upward trends in annual and monthly air temperature, especially for monthly minimum temperatures at Reno and Tahoe City. Lake Tahoe waters warmed at an average rate of 0.013^{o}C per year between 1970 and 2007. Air temperature and precipitation data for Tahoe City showed a shift from snow to rain, a decline in the number of winter days below freezing, and an increase in the intensity of rainfall from 1910 to 2007. Between 1961 and 2005, peak

snowmelt runoff shifted toward earlier dates in the Tahoe basin, a shift not found at four streams outside the basin. Total annual precipitation at Tahoe City shows a slight upward, but not statistically significant trend; interannual variability increased, as did the frequency of intense rainfall. While trends in air temperature, snowmelt timing, and lake temperature (1970-2007) are statistically linked to the Pacific Decadal Oscillation, and to a smaller degree the El Niño-Southern Oscillation, these phenomena can explain only a small part of the variance.

The trends in air temperature and snowmelt timing suggest that the Tahoe basin is warming faster than the surrounding region. It is hypothesized that the lake itself may be enhancing the effects of greenhouse gases on warming trends in the basin. Another hypothesis involves changes in albedo (the fraction of solar energy reflected from earth back to space) caused by soot emissions from wood-burning stoves or traffic.

Conclusions: Strong upwards trends in air temperature, a shift from snow to rain, earlier snowmelt, increased rainfall intensity, increased interannual variability, and continued increase in the temperature of Lake Tahoe were found. Monitoring of black carbon in snow is needed to test the hypothesis about the role of black carbon in some of these observed changes. Studies linking lake processes to basin hydrology and regional climate may help in understanding the long-term impacts of climate change on the lake's water quality and aquatic life, and how the lake's heat budget interacts with the basin's climate.

Influences of climate change on California and Nevada regions revealed by a high-resolution dynamical downscaling study. Pan L-L, Chen S-H, Cayan D, Lin M-Y, Hart Q, Zhang M-H, et al. (2011). *Climate Dynamics*, 37(9-10): 2005-2020. http://dx.doi.org/10.1007/s00382-010-0961-5 **WESTERN U.S.**

Keywords: climate models; coastal impacts, desert, downscaling; extreme events, heat wave, precipitation/rain, regional effects, snowpack

Background/Purpose: The paper presents evidence of global climate change, citing numerous studies (including the western U.S.) and the use of various models to project temperature and precipitation changes. In this study, the investigators refined the understanding of regional changes in California and Nevada, especially those related to precipitation and extreme events (e.g., heat waves, heavy precipitation), through weather model dynamic downscaling.

Methods: The Weather Research and Forecasting Model was used to dynamically downscale the global model outputs so as to achieve finer resolution in the California and Nevada region. The influences of climate change on the California and Nevada regions were inferred using current observational results (1997-2006) and future (2047-2056) model inputs. (Discussions of use of models are highly technical.)

Results: For California, the influence of climate change showed increases in both precipitation and temperature. An upward shift of the freezing level was also predicted. More precipitation in the form of rain is predicted and therefore less snowpack. More extreme hot days are expected in the Central Valley and Mojave Desert. Increases in precipitation events are expected, mainly in the coastal regions of central California.

Conclusions: The authors note that the results are solely based on downscaling results of one regional model driven by outputs from one global climate model under one emission scenario. It is expected that the use of different models and/or emission scenarios will give different conclusions. Thus, an "ensemble approach", which uses combinations of different models and emission scenarios is encouraged for future studies.

I**mpacts of wind farms on land surface temperature.** Zhou L, Tian Y, Roy SB, Thorncroft C, Bosart LF and Hu Y (2012). *Nature Climate Change*, 2: 539-543. http://dx.doi.org/10.1038/nclimate1505 **UNITED STATES**

Keywords: energy, land use, regional climate, wind farms, temperature, warming, wind farms

Background/Purpose: Wind turbines modify surface-atmosphere exchanges and the transfer of energy, momentum, mass and moisture within the atmosphere—changes which may have noticeable impacts on local to regional weather and climate. Modeling studies have shown that wind farms can affect local meteorology by increasing surface roughness, changing the stability of the atmospheric boundary layer, and increasing turbulence in the rotor wakes. Long-term observational data on such effects are lacking, however. This study investigates the observational evidence of the impacts of wind farms on weather and climate on a local to regional scale.

Methods: The authors analyzed satellite data for the period 2003-2011 in an area with around 2,358 wind turbines in west-central Texas (where four of the world's largest wind farms are located). Satellite data (from MODIS, Moderate Resolution Imaging Spectroradiometer) for surface short wave albedos, land cover and land surface temperature (LST) were used. The spatial patterns of LST changes were examined, and temporal changes estimated based on the differences in LST between 2003 to 2005 (the period with least impacts, as most wind farms were built from 2005 to 2008) and 2009 to 2011 (the period with the most likely impacts).

Results: Land surface temperatures were much warmer where the wind farms were located and downwind of the wind turbines. Statistically significant warming trends of 0.724^{o}C per decade in June through August and 0.458^{o}C per decade in December through February from 2003 to 2011 were found in areas with wind farms relative to those without. On average, the warming is stronger and better coupled with wind farms during nighttime rather than daytime, and in June through August than December through February. The authors concluded that the diurnal and seasonal variations in

wind speed and the changes in near-surface atmospheric boundary layer conditions caused by wind farm operations are primarily responsible for these land surface temperature changes.

Conclusion: With the rapid expansion of wind power in the United States in recent years, it is important to understand its potential influences in local and regional climate. This study presented data showing that wind farms can produce local warming. Although this analysis involved a short period in a region with rapid growth of wind farms, its findings reasonably represent the local effects of wind farms. It draws attention to the need to better understand how wind farms may affect weather and climate.

Managing climate change in cities: Will climate action plans work? Stone B, Vargo J and Habeeb D (2012). *Landscape and Urban Planning*, 107(3): 263–271. http://dx.doi.org/10.1016/j.landurbplan.2012.05.014

UNITED STATES

Keywords: extreme events, warming, heat island, urban, rural, land use, regional climate, temperature, urban impacts

Background/Purpose: Recent analyses indicate that the mechanisms driving warming trends as well as the pace of warming at local to regional scales differ from those observed at the global scale. These findings highlight the need to examine climate management approaches that will likely be effective at the local scale. This study evaluated warming trends in large metropolitan regions of the United States relative to the planet as a whole, and evaluated the likely effectiveness of municipal and state level climate action plans in slowing the pace of warming. Because adaptation policies are beyond the scope of this bibliography, this summary focuses on the warming analysis.

Methods: Authors identified 50 of the most populous U.S. cities for which continuous climate data existed for urban and nearby rural weather stations between1961 and 2010. Weather station data taken from the Global Historical Climatology Network were adjusted for variables like change in station location. Changes in land cover within the cities were assessed using the National Land Cover Dataset.

Results: The warming rate for urban areas was 0.43^{o}F per decade, compared to 0.29^{o}F per decade for rural areas. The warming rural temperatures may be presumed to be largely due to the global greenhouse gas effect, assuming that the rural weather stations are not impacted by urbanization. At any point in time, urban weather stations were found to be warmer than the nearby rural station, suggesting amplification of trends from the urban heat island effect. The intensity of the “heat island” effect (i.e., localized warming for urban areas) varied, not increasing in 14 of the 50 cities studied. An important variable identified was the pace at which land cover is changing near the cities. The analysis suggests that urban temperatures are rising at double the rate of the planet as a whole.

Conclusions: Urban areas are regions of more intense warming than rural areas. The findings suggest land use as a significant and measurable driver of climate change, operating through a physical mechanism independent of greenhouse gas emissions. The pace of warming at regional to local scales can be slowed through a reversal of land cover change. Hence, a reduction of the urban heat island effect can more effectively slow ongoing warming trends in cities than emission reductions alone.

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.

Frequently the centerpiece of climate change messages to the public, temperature trends need to be based on rigorously collected data, and transparent and well documented analyses that account for the natural variability of the climate system.

Is the climate warming or cooling? Easterling DR and Wehner MF (2009). *Geophysical Research Letters*, 36: L08706. http://dx.doi.org/10.1029/2009GL037810

GLOBAL

Keywords: temperature

Background/Purpose: A number of sources have reported that the climate is no longer warming and instead has been cooling since 1998. Depending upon the time period chosen, annual global land-ocean surface air temperature trends could be positive or negative. Due to natural climate variability, it is possible for periods of cooling to be superimposed on the longer-term, human-influenced warming trend. These short-term fluctuations do not represent meaningful, long-term temperature trends.

Methods: The analysis used an observational dataset of globally averaged surface air temperatures for the period 1901-2008, along with model simulations (from the Coupled Model Intercomparison Project 3 database). The authors fit trends to running 10-year periods of the temperature time series for the observed record and three simulations, and analyzed the probability distribution functions of decadal trends for each of the four sets of time series.

Results: The analysis showed periods of no trend or even cooling, which occurred even in simulations without volcanic eruptions or solar variability (factors that would have

resulted in widespread cooling over a period of years). It is presumed that these periods are entirely due to natural internal variability. The analysis also showed roughly equal chances of a positive or negative decadal trend over the entire global surface air temperature time series. Simulations using observed natural and anthropogenic forcing showed a shift to more positive trends, but still a significant chance of a negative trend; the observed record showed a very similar distribution. It is reasonable to expect similar sustained multi-year periods of cooling embedded within the longer term warming to occur due to the natural variability of the climate system.

Conclusion: Periods of no trend or cooling of the globally averaged surface air temperature are found in the last 34 years of the observed record, as well as in model simulations of the 20th and 21st century with increasing greenhouse gases. Even in the presence of longer-term warming, decadal periods of cooling are expected due to natural variability.

Global surface temperature change. Hansen J, Reudy R, Sato M and Lo K (2010). *Reviews of Geophysics*, 48: RG4004. http://dx.doi.org/10.1029/2010RG000345

GLOBAL

Keywords: warming, GISS, sea surface temperature, climate dice, ocean conditions, urban impacts, rural, temperature

Background/Purpose: NASA's Goddard Institute for Space Studies (GISS) is among several groups that conduct analyses global surface temperature change. Although such analyses use the same input data, they employ different ways of addressing incomplete spatial and temporal data and non-climatic influences. First published in 1981, the GISS analysis provides an estimate of global temperature change for comparison with expected global climate change due to known or suspected climate forming mechanisms, both natural and human-induced. The analysis is published on the GISS web site, and updated monthly. In this paper, the authors present an update of the GISS global surface temperature analyses, compare results with those from alternative analyses, and discuss the challenges in communicating global warming trends to the public.

Methods: The current GISS analysis utilizes land-based temperature measurements from selected meteorological station measurements and Antarctic research stations, along with ocean surface temperature measurements (ship-based for 1880-1981 and from satellites for 1982 to present). Temperature trends of urban and peri-urban stations are adjusted for non-climatic factors using satellite-observed nightlights. Trends are presented as anomalies relative to the 1951-1980 base period.

Results: Successive decades from the 1970s to the 2000s warmed by 0.17^{o}C on average; the overall trend beginning in the late 1970s was 0.15-0.20^{o}C per decade. The 2000s was about 0.8^{o}C warmer than the beginning of the century (1880-1920). Two-thirds of the warming occurred since 1975, and warming over land was larger than

over oceans. Adjusting the data to account for urban effects resulted in an insignificant reduction of global temperature change. The use of different ocean data sets produced small enough differences that did not alter the conclusions about global temperature change.

The authors illustrate that a simple 12-month running mean of the anomalies as the best way to present global temperature data, for the following reasons: (1) it provides a powerful and intuitive visual presentation that facilitates communication with the public, and (2) it removes seasonal cycles and provides an improved measure of the strength and duration of El Niños, La Niñas and the response to volcanic eruptions.

The 12-month running mean global temperature in the GISS analysis has reached a new record in 2010. This is particularly notable because it coincides with the recent minimum solar irradiance having its maximum cooling effect. At the time of writing, analysis by both the GISS and the National Climatic Data Center (NCDC), showed 2005 as the warmest year; the UK Met Office Hadley Centre and the University of East Anglia Climate Research Unit (HadCRUT) analysis identified 1998 as the warmest. This inconsistency may raise questions in the media and the public. A likely explanation for the difference is the exclusion of much of the Arctic—where warming has been particularly large in the past decade—from the HadCRUT analysis; analyses by GISS and NCDC include estimated temperature anomalies for most of this region.

The authors discussed recent flaws and errors in data sets and analyses and the resulting changes made in procedures at GISS to minimize these in the future. Although these errors were all minor, temporary or both and did not compromise the integrity of the overall data product, they have been used by certain entities to cast doubt on the analyses and conclusions.

Finally, the authors acknowledge the challenges in communicating global warming to the public, a task that is made more difficult by the politicization of global warming and people's tendency to be focus on the latest local weather fluctuation.

Conclusions: Global temperature is rising as fast in the past decade as in the prior two decades, despite year-to-year fluctuations associated with the El Niño-La Niña cycle of tropical ocean temperature. Presenting data in multiple ways facilitates communication: the 12-month running mean is simple and reflects the magnitude and duration of effects due to volcanoes and cyclical variations; the 60-month mean minimizes variability due to the El Niño Southern Oscillation; and the 132-month running mean minimizes the effect of solar variability.

Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. Pierce DW, Das T, Cayan DR, Maurer EP, Miller NL, Bao Y, et al. (2012). *Climate Dynamics*, online publication. http://dx.doi.org/10.1007/s00382-012-1337-9 **CALIFORNIA**

Keywords: agriculture, atmosphere circulation, climate change; climate variability, flood, regional climate modeling; dynamical downscaling; snowpack, statistical downscaling, temperature

Background/Purpose: Warming and precipitation changes in California will directly impact crops and pests in the agricultural and wine-producing regions, and affect regional water resources and flood risk through changes in the snow line and snowpack. This paper presents probabilistic projections of temperature and precipitation change in California, which facilitates risk-based planning and a framework for taking adaptive steps in water resource management.

Methods: Sixteen global circulation models were used to develop probabilistic projections of temperature and precipitation changes over California by the 2060s. The global models were "downscaled" with two statistical techniques and three nested dynamical regional climate models. Downscaling climate data is a strategy for generating locally relevant data from Global Circulation Models (GCMs). This method requires several model runs to provide a distribution of projected outcomes. The GCMs also include simulations of natural climate variability in order to show the range of climate projections and how they compare to natural climate fluctuations.

Results: Looking at monthly averages, July temperatures shift so that the hottest July found in any simulation over the historical period (1985-1994) becomes a modestly cool July in the future period (2060-2069). Januarys as cold as any found in the historical period are still found in the 2060s, but the median and maximum monthly average temperatures increase notably. Winters show modestly wetter conditions in Northern California, while spring and autumn show less precipitation. Increasing precipitation is projected in the Southeastern part of the state.

Conclusions: These results have wide application to the needs of resource managers and other decision makers when adapting to forthcoming climate change in California.

I**mpacts of wind farms on land surface temperature.** Zhou L, Tian Y, Roy SB, Thorncroft C, Bosart LF and Hu Y (2012). *Nature Climate Change*, 2: 539-543. http://dx.doi.org/10.1038/nclimate1505 **UNITED STATES**

See summary under *Regional Climate Change*, page 41.

Precipitation

Precipitation is the general term for rainfall, snowfall and other forms of frozen or liquid water falling from clouds. A changing climate can directly influence precipitation amount, intensity, frequency and type. Large natural variability and strong geographic variations in these parameters are evident, 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 show 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 usually wet storms on the west coast of North America.

Extreme precipitation over the west coast of North America: Is there a trend?
Mass C, Skalenakis A and Warner M (2010). *Journal of Hydrometeorology*, 12(2): 310-318. http://dx.doi.org/10.1175/2010JHM1341.1 **NORTH AMERICA**

Keywords: atmosphere circulation, coastal impacts, extreme events, precipitation, fisheries, flooding, regional climate

Background/Purpose: Flooding following heavy precipitation is the most serious weather-related threat for the west coast of North America. Changes in precipitation extremes can arise from alterations in the moisture content of the air, which increases with increasing temperatures. The authors review the literature and data on heavy precipitation over the west coast, as well as flow data from unregulated Pacific Northwest rivers.

Methods: The authors analyzed precipitation records (from the U.S. Historical Climate Network and the Canadian Daily Climate Data) for a line of 19 regularly spaced coastal or near-coastal stations from southern California through British Columbia; 8 of these were located in California The extreme values of two-day precipitation totals were identified for each station for 1950 to 2009. The decadal distributions of the top 60, 40, and 20 two-day precipitation events were examined.

Data for maximum daily streamflow over the Pacific Northwest were also examined. Average daily streamflow data were obtained for 14 unregulated river gauges (three of which are in Northern California) from 1950 to 2009. The decadal variations of the top 60 and 20 daily discharges were analyzed.

Results: Over the 60-year period studied, no significant trends in extreme precipitation events were evident among the California stations, except for a large and highly significant decline at Eureka for the top 60 events. Although most of the trends were not significant, they appear to parallel the spatial pattern in maximum river discharge. Moving from south to north, extreme precipitation data show a small increasing trend over southern California, transitioning to a statistically significant decline over northern California and south-central coastal Oregon, an increasing trend over northern Oregon, then large, highly significant increases over the Washington Coast. A similar geographic pattern is observed in the coastal trends in extreme daily streamflow—that

is, increasing extreme streamflow over Washington and northern Oregon and declining trends for the rest of Oregon and Northern California.

The geographical patterns of trends in this study were not consistent with those projected over the next century. In addition, long-term simulations of West Coast precipitation trends have not duplicated the complex pattern shown by the observational record. These suggest that natural variability, not anthropogenic global warming, as the likely source of the spatial patterns.

Conclusions: Trends in heavy precipitation along the California coast are largely unchanged over the 60-year period of the study, except for Eureka, where a significant decline occurred. A consistent geographic pattern in the maximum daily discharge was also evident. The lack of agreement between the observed spatial patterns and simulated or projected changes indicate that the changes may be due to natural variability rather than human-influenced warming.

Regional precipitation trends: Distinguishing natural variability from anthropogenic forcing. Hoerling M, Eischeid J and Perlwitz J (2010). *Journal of Climate*, 23: 2131–2145. http://dx.doi.org/10.1175/2009JCLI3420.1 **GLOBAL**

See summary under *Climate Variability*, page 33.

Climate change, atmospheric rivers, and floods in California – A multimodel analysis of storm frequency and magnitude changes. Dettinger M (2011). *Journal of the American Water Resources Association*, 47(3). http://dx.doi.org/10.1111/j.1752-1688.2011.00546.x **CALIFORNIA**

Keywords: atmospheric rivers, climate variability/change; coastal impacts, extreme events, meteorology; atmospheric rivers; flooding (provided), precipitation/rain, storms

Background/Purpose: In many California rivers, major historical floods have been associated with the pineapple express or "atmospheric rivers" (AR) storms. Recent studies document the important role that ARs of concentrated near-surface water vapor above the Pacific Ocean play in the storms and floods in California. This paper summarizes a preliminary analysis of the 21st century future of atmospheric river storms from current climate models.

Methods: The investigator evaluated a 7-model ensemble of historical-climate and projected future climate simulations as a strategy for predicting precipitation-rich AR storms along the California coast. The modeling uses an A2 greenhouse-gas emissions scenario because it provides the strongest greenhouse forcing on climate and thus the clearest indications of directions of climate amidst natural variability.

Results: The multimodel analysis predicts more winters with exceptionally large numbers of AR storms in the 21st Century and fewer winters with exceptionally few such storms, so that changes in the frequency of "extreme" winters are more notable. ARs with higher-than-historical water vapor transport rates and storm temperatures are also projected to increase. Furthermore, the peak season within which most ARs occur is commonly projected to lengthen, extending the flood-hazard season.

Conclusions: This analysis predicts increased opportunities for both more frequent and more severe floods in California under projected climate changes. However, this model ensemble is relatively small and unlikely to reflect the full range of model uncertainties. In addition, the focus on a single emissions scenario does not address uncertainties regarding future emissions. These results remain preliminary and should be viewed as qualitative indicators of AR changes rather than as quantitative estimates of changed storm characteristics.

Atmospheric rivers, floods, and the water resources of California. Dettinger MD, Ralph FM, Das T, Neiman PJ and Cayan D (2011). *Water*, 3: 455-478. http://dx.doi.org/10.3390/w3020445 **CALIFORNIA**

Keywords: extreme events, precipitation; floods; water supply; California; atmospheric rivers, North Pacific Ocean, storms, water availability

Background/Purpose: California's largest storms are generally fueled by atmospheric rivers (ARs) and contribute 20-50 percent of the state's precipitation and streamflow. This article investigates some meteorological aspects of the connection between floods and water resources in California, with a particular focus on the dual role that AR storms play: (1) California's most dangerous storms and floods and (2) the basis for much of the State's water resources.

Methods: Precipitation totals from 1950-2008 are based on daily accumulated precipitation measurements from weather stations across the US, obtained by the National Climatic Data Center. Daily streamflow records analyzed were from the US Geological Survey Hydro-Climatic Data network. Gridded daily precipitation fields were used as historical inputs for a large-scale hydrologic model (Variable Infiltration Capacity) and simulated daily runoff outputs from the model were evaluated. For many of the analyses, historical occurrences of ARs were identified from twice-daily Special Sensor Microwave Imager imagery of water vapor in the atmosphere.

Results: California is shown to experience unusually large variations in annual precipitation and streamflow totals relative to the rest of the US, reflecting the unusually small average number of wet days per year needed to accumulate most of its annual precipitation totals. California receives some of the largest 3-day storm totals in the country. California's water resources and floods are shown to derive from the same storms, indicating the importance of integrated flood and water resources management.

Conclusions: Both water resources and floods in California are strongly dependent on the character and frequency of AR storms arriving from over the North Pacific Ocean. These storms may be key to determining and predicting changes of both California's water resources and flood regimes under projected global climate changes.

Reclamation, SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress, 2011. Alexander P, Brekke L, Davis G, Gangopadhyay S, Grantz K, Hennig C, et al. U.S. Department of the Interior, Policy and Administration, Bureau of Reclamation, Denver, Colorado (2011).http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf

WESTERN U.S.

Keywords: adaptation, agriculture, climate change, economic impacts, ecosystem impacts, extreme events, hydrology, water management supplies, precipitation, snowpack

Background/Purpose: The Bureau of Reclamation (Reclamation) is the largest supplier of water in the country and the second largest producer of hydroelectric power in the western U.S. It relies upon assumptions of present and future water supplies in its planning and operations. This report to Congress fulfills a requirement in federal law (Section 9503 of the SECURE Water Act). This law authorizes Reclamation to continually evaluate and report on the risks and impacts from a changing climate and to identify appropriate adaptation and mitigation strategies utilizing the best available science in conjunction with stakeholders.

This first report discusses, among other things, projected climate change over the western U.S. and its implications for snowpack, runoff amount and runoff timing; specified information on each major Reclamation basin identified in the SECURE Water Act; and basin-specific findings integrated into a west-wide perspective on projected climate and hydrologic changes. California basins included are the Klamath, Truckee, Sacramento, San Joaquin, and Colorado basins.

Methods: Much of this report is based on synthesizing available literature and summarizing key findings from peer-reviewed studies. Findings from an original assessment of climate change implications for snowpack and natural hydrology across the major Reclamation river basins are also presented.

Results: Key findings include the following:

- Much of the western U.S. has warmed by about 2^{o}F during the 20th century.
- There has been a shift towards more rain and less snow during the cool season, leading to increased cool season runoff and reduced snowpack accumulation in some areas in the western U.S. Warming and the associated loss of snowpack are projected to persist over much of the area, although geographic contrasts are expected (e.g., snowpack may increase in high altitude and high latitude areas in the 21st century).

- Precipitation levels have not changed, future projections suggest that the northwestern and north-central portions of the United States may gradually become wetter, while the southwestern and south-central portions (including the San Joaquin and Truckee basins) gradually may become drier. There is significant variability and uncertainty with precipitation projections.
- Runoff projections are more complex, and geographic differences are expected. Projected increasing precipitation in the northern tier of the western U.S. may serve to neutralize warming-related decreases in warm season runoff. By contrast, projected decreasing precipitation in the southern tier may amplify warming-related decreases in warm season runoff.

Conclusions: Annual and seasonal natural runoff are projected to be altered under climate change in ways that differ geographically. These changes alone, however, cannot provide the basis for water management impacts. The ability to use storage resources to adapt to future hydrologic variability and changes in runoff seasonality is an important consideration in assessing potential water management impacts at a local level.

Wind

Along with temperature and precipitation, wind measurements are commonly used to characterize the local climate. Wind is the movement of air from an area of high pressure to an area of low pressure. Global wind patterns arise from differences in the net solar radiation at the Earth's surface, and are also influenced by the Earth's rotation. On a local scale, differences in the rate of heating and cooling of land versus bodies of water greatly affect wind formation. Changes in wind patterns have been reported. The references summarized below discuss changes in the frequency and magnitude of Santa Ana winds, strong seasonal winds that blow through the Southern California mountain passes. The human influence on patterns of Santa Ana winds is also addressed.

Anthropogenic Reduction of Santa Ana Winds. Hughes M, Hall A and Kim J. California Energy Commission (2009). Publication number: CEC-500-2009-015-D. http://www.energy.ca.gov/2009publications/CEC-500-2009-015/CEC-500-2009-015-D.PDF **CALIFORNIA**

Keywords: desert, ecosystem impacts, fires, marine impacts, Santa Ana winds, wildfires, Southern California, regional climate, sea surface temperature, wildfire, wind

Summary: The Santa Ana (SA) winds are strong winds from the desert which blow on dry, hot days in Southern California. While they are widely recognized for increasing wildfire risk, they can also impact coastal ocean ecosystems off Southern California and Baja California due to their effects on lowering sea surface temperatures and increasing biological activity. There have been very few studies on the variability of these winds on timescales longer than a few months. This study investigates the intensity and

frequency of SA winds in response to anthropogenic climate change and examines the mechanisms driving the formation of SA winds.

A high-resolution reconstruction of Southern California's climate from 1959 to 2002 was used to identify SA wind events. To identify the local and synoptic (large scale, encompassing horizontal distances of 1,000 kilometers or more) atmospheric conditions associated with the winds, a "SA index" was created, representing the strength of the offshore wind at the exit of the largest gap in Southern California's topography. A separate analysis using simulations for the late 20th century (1971-1981) and mid-21st century (2045-2055) periods was conducted to quantify the anthropogenic climate change signal.

The number of Santa Ana days per winter season declined gradually over the 44-year period, resulting in nearly one-third fewer events per year between 1991 and 2001 compared to between 1959 and 1969; the intensity of the events also declined. Similarly, the number of Santa Ana days per year is projected to decline by nearly 20 percent in the mid-21st century compared to the late 20th century. The authors also concluded that large-scale, synoptic conditions only modestly explained the variability in the SA index. Another mechanism at play is the localized pressure gradient associated with a large difference in temperature between the cold desert surface and the warm ocean air. The simulations showed that this temperature difference declined with increased anthropogenic greenhouse gas levels, whereas synoptic conditions did not change. The frequency and magnitude of SA winds are projected to continue to decline due to increased levels of anthropogenic greenhouse gases. This reduction could have ecological implications—such as reduced wildfires, improved marine ecosystem conditions and better air quality—that need to be further investigated.

Local and synoptic mechanisms causing Southern California's Santa Ana winds, Hughes M and Hall A (2010). *Climate Dynamics*, 34(6): 847-857. http://dx.doi.org/10.1007/s00382-009-0650-4 **CALIFORNIA**

Keywords: Santa Ana winds, regional climate, desert

Background/Purpose: Numerous studies have identified mechanisms causing strong terrain-intensified winds when large-scale ("synoptic") conditions are favorable. These studies provide a plausible explanation for the formation of Santa Ana (SA) winds. However, the findings of other studies have suggested that another, more local mechanism might also play a role. This study investigates the contributions of these two plausible mechanisms.

Methods: Data from the North American Regional Reanalysis were used for the synoptic or large-scale perspective. A 12-year, 6-km resolution regional climate simulation of Southern California allowed the identification of events and a local perspective. A "Santa Ana index" (SA index) was developed by averaging the offshore wind strength through the largest gap in the Southern California topography. A metric

called a “Santa Ana day” was used to quantify a day with a SA index greater than 5 meters per second.

To examine the influence of the two different mechanisms on SA wind formation, the study analyzed the relationship between (a) synoptic conditions (days with high geopotential height anomalies) and Santa Ana days; and (b) the magnitude of the SA index and a pressure gradient due to a difference between very cold desert surface temperatures relative to air temperatures over the ocean.

Results: The SA index showed strong seasonality consistent with previous measures of SA wind occurrence—a peak in December and no strong offshore winds from April to early September. The analysis found strong variations in the SA index not related to the large-scale pressure gradient; when this gradient is unusually high, there is nearly a 50 percent chance of having weak or no SA winds. This indicates that this synoptic mechanism is not the primary driver of offshore surface wind strength. Instead, the study found that a pressure gradient caused by a strong desert-ocean temperature difference to be the more important mechanism.

Conclusions: Local thermodynamic processes arising from the difference in temperature between the desert and the ocean accounts for a large proportion of SA winds. This mechanism probably explains the seasonal cycle of SA events: December is the month when the desert surface is coldest relative to the air over the ocean. The desert temperature will probably increase more quickly than the air over the ocean in response to increases in greenhouse gases. As a result, SA frequency and intensity will potentially be reduced in the coming decades. The seasonality of SA winds, which is strongly constrained by this temperature gradient, could also be altered in a changing climate.

Human-induced changes in wind, temperature and relative humidity during Santa Ana events. Hughes M, Hall A and Kim J (2011). *Climatic Change*, 109(Suppl 1): 119-132. http://dx.doi.org/10.1007/s10584-011-0300-9 **CALIFORNIA**

Keywords: regional climate, Santa Ana winds, downslope winds, fire, greenhouse gases, ocean conditions, temperature, upper-ocean heat content, wind

Background/Purpose: This study investigates changes in the frequency and intensity of Santa Ana events, as well as in relative humidity and temperature—two meteorological variables relevant to fire conditions—in response to anthropogenic influences. Santa Ana winds are known to play a role in spreading wildfire, and a decrease in the relative humidity and an increase in temperature are known to favor fire.

Methods: Regional climate for the late-20th century and mid-21st century periods is calculated from downscaled model simulations spanning two time periods: 1971-1981 and 2045-2055. The carbon dioxide (CO_2) concentrations in the simulations were fixed at 330 parts per million by volume (ppmv) and 430 ppmv during the late 20th century

and mid-21st century periods, respectively. As with earlier studies conducted by the primary author, a Santa Ana (SA) index was used to quantify wind occurrence and characteristics.

Results: The number of Santa Ana days per season is reduced by nearly 20 percent in the mid-21st century compared to the late 20th century. The only sustained and systematic difference between the simulations for these two periods is the level of CO_2. Hence the difference in climate is likely due to anthropogenic CO_2–induced changes. A reduction in SA winds could lead to reduced wildfire in Southern California. The study also found that, during SA events, relative humidity is reduced and temperature increases—changes that would favor fire development.

Results from Hughes and Hall (2010) (see summary, above) were briefly reviewed in this paper. These results helped clarify the mechanism behind the weakening of SA winds during the mid-21st century, namely a reduction in the temperature difference between cold wintertime air in the desert and the warm air over the adjacent ocean.

Conclusions: The number of Santa Ana days is projected to be approximately 20 fewer in the mid-21st century compared to the late 20th century—an effect that is likely due to the anthropogenic increase in CO_2 concentrations. A decrease in relative humidity and an increase in temperature were also found to occur during SA events. The effects of these changes on wildfire behavior require further investigation.

I**mpacts of wind farms on land surface temperature.** Zhou L, Tian Y, Roy SB, Thorncroft C, Bosart LF and Hu Y (2012). *Nature Climate Change*, 2: 539-543. http://dx.doi.org/10.1038/nclimate1505 **UNITED STATES**

See summary under *Regional Climate Change*, page 41.

Extreme events

An extreme climate event is one that has appeared 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 if not impossible. 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.

An examination of climate change on extreme heat events and climate–mortality relationships in large U.S. Cities. Greene S, Kalkstein LS, Mills DM and Samenow J (2011). *Weather, Climate, and Society*, 3(4): 281-292. http://dx.doi.org/10.1175/WCAS-D-11-00055.1 **UNITED STATES**

See summary under *Impacts on Humans*, page 86.

Explaining extreme events of 2011 from a climate perspective. Peterson TC, Stott PA and Herring S (2012). *Bulletin of the American Meteorological Society*, 93(7): 1041-1067. http://dx.doi.org/10.1175/BAMS-D-12-00021.1 **GLOBAL**

See summary under *Authoritative Reports*, page 18.

Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. IPCC, Cambridge University Press, Cambridge, UK, and New York (2012). Field CB, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, et al. (Eds.).http://ipcc-wg2.gov/SREX/report/ **GLOBAL**

See summary under *Authoritative Reports*, page 19.

Framing the way to relate climate extremes to climate change. Trenberth K (2012). *Climatic Change*, 115(2): 283-290. http://dx.doi.org/10.1007/s10584-012-0441-5 **GLOBAL**

Keywords: climate variability, extreme events, warming, natural variability, storms, wind

Background/Purpose: Questions about the human influence on climate inevitably arise following an extreme event. However, because natural weather-related variability is large, human influences are difficult to perceive and detect. This commentary uses examples of recent extreme events to examine the role of human-induced global warming on extreme weather.

Methods: The author calculated changes in energy flow through the climate system due to increased levels of carbon dioxide, along with changes in water vapor concentrations in the atmosphere, to illustrate the role of human influence on extreme weather. He explained how both natural phenomena and human-induced warming contributed to recent extreme events.

Results: Sea surface temperatures have risen by 0.5-0.6^{o}C since the 1950s, leading to 4 percent more water vapor in the atmosphere over oceans since the 1970s. This has likely led to a 5-10 percent effect on precipitation and storms, contributing to more intense precipitation events. Instabilities can magnify these effects further, although

changes in wind shear and atmospheric stability as a consequence of the enhanced vertical motion may have reverse effects elsewhere. For major droughts that last a month or longer, cumulative effects become important; the absence of moisture creates higher temperatures, promoting heat waves and wildfires.

Conclusion: Human-induced changes in the composition of the atmosphere provide a warmer and moister environment for most weather events, magnifying the outcomes that would have resulted solely due to natural variability. No events are "caused by climate change" but climate change contributes to such events.

Perception of climate change. Hansen J, Sato M and Ruedy R (2012). *Proceedings of the National Academy of Sciences*, 109(37): E2415-E2423.
http://dx.doi.org/10.1073/pnas.1205276109 **GLOBAL**

Keywords: climate anomalies, extreme events, heat waves, temperature

Background/Purpose: The natural variability of local climate is perhaps the greatest barrier to public recognition of the human influence on climate change—a prerequisite for effective actions to mitigate greenhouse gas emissions. Questions are often raised about whether extreme events (such as the high profile heat waves in Texas and Oklahoma in the summer of 2011) are related to the ongoing global warming trend, or simply a result of natural variability. This study examines observational data to assess whether the frequency of unusually warm seasons has increased, making such extreme events more likely.

Methods: The authors used observational data (from the Goddard Institute for Space Studies (GISS) surface air temperature analysis); no climate models were used. The distribution of anomalies in seasonal mean surface air temperatures was analyzed to characterize variability and how it is changing. Anomalies were determined relative to a fixed 30-year base period, 1951-1980—a period of relatively stable global temperature, the earliest base period with good global coverage of meteorological stations, and a period more representative of the Holocene than later periods (plant and animal life are adapted to temperatures during the Holocene). Variability is represented in units of the standard deviation.

Results: Temperature anomalies in the past three decades have shifted (by more than one standard deviation) toward higher values, especially during the summer. This indicates that temperatures relative to the 1950-1980 base period have become warmer in each successive decade. The distribution has also broadened (the range of values has increased), particularly at the high temperature tail of the distribution. More notably, extreme summertime temperatures have become more frequent: Summertime anomalies at least three standard deviations greater than the base period mean, which were practically absent in the base period (occurring only over a few tenths of one percent of the global land area), occurred over about 10 percent of global land area in recent years. The increased anomalies provide greater confidence for concluding that

extreme events such as summer heat in the Moscow region in 2010 and in Texas in 2011 were a consequence of global warming.

Conclusion: The chance of unusually warm seasons (referred to by the authors as "climate dice") has become more likely in the past 30 years coincident with rapid global warming. Further, a new category of summertime extremely hot outliers (more than three standard deviations warmer than the 1951-1980 base period) has emerged. These changes can significantly impact the water cycle, resulting in drought in certain areas and heavy rainfall and floods in others. Natural ecosystems, adapted to the Holocene climate, may suffer adverse effects from the rapid warming.

A decade of weather extremes. Coumou D and Rahmstorf S (2012). *Nature Climate Change*, 2: 491–496 http://dx.doi.org/10.1038/nclimate1452 **GLOBAL**

Keywords: cyclones, detection (signal vs. noise), drought, extreme events, heat wave, precipitation, climate models, attribution, storms

Background/Purpose: The large number of recent extreme weather events around the world has triggered interest both inside and outside the science community as to whether they are related to climate change. This review focuses on the unprecedented extremes of the past decade that set new meteorological records, because these often have the greatest impacts on societies and their uniqueness simplifies statistical analysis.

Methods: The authors studied worldwide record-breaking meteorological events between 2000 and 2011. Climate models that predict climate responses to different driving forces (e.g., natural vs. anthropogenic) are reviewed for purposes of determining whether extreme events can be attributed to climate change.

Results: The past decade as a whole has experienced an unprecedented number of extreme events. Several recent studies indicate that heat waves would not have occurred without warming from climate change. In 2003, Europe experienced its hottest summer in 500 years and modeling showed that the risk of a heat wave this intense has at least doubled as a result of human influence on the climate. A record number of rainfall extremes occurred in the past decade, some of which can be attributed to climate change. In 2011, rigorous modeling studies implicated human influence on climate change as a driver of some of the recent rainfall extremes. The available evidence correlating storms to climate change is less conclusive than the evidence for heat waves and rainfall. Energy dissipation of North Atlantic hurricanes correlates well with increasing ocean temperatures, but this trend is not so clear elsewhere.

Conclusion: Statistical analysis, climate modeling, and physical reasoning indicate that heat waves and rainfall extremes are increasing with a warming climate. Human activity contributes to the climate change which is causing these extremes. Future research should focus on a better understanding of the processes behind the observed extreme

events. In addition, longer and improved data sets will better clarify associations between certain weather extremes (e.g., hurricanes) and climate change.

California Climate Extremes Workshop Report. Pierce, DW (Ed). Scripps Institution of Oceanography (2011).
http://sio.ucsd.edu/extreme climate/CA climate extremes report SIO Dec2011.pdf

CALIFORNIA

Keywords: air pollution, coastal impacts, community health, droughts, economic impacts, ecosystem impacts, energy, extreme events, farm workers, floods, infrastructure, sea level rise, storms, heat waves, fires, energy, economy, public health, precipitation/rain, temperature, transmission

This report summarizes the main findings of a workshop organized to address extreme events in California with a focus on climate change. Leading climate scientists from the physical, biological, social, and economic sciences presented findings and discussed impacts of climate extremes on California.

The following subject areas with cross-cutting climate change impacts were discussed:

Water:
Water is a common element to many extreme impacts, with effects occurring from floods, droughts and rising sea level. Possible declines in surface or groundwater is a concern for Central Valley farmers. More flooding due to declining winter snowpack and storms driven by "atmospheric rivers" threaten aquatic ecosystems, agriculture, transportation and energy infrastructure and have enormous economic impacts.

Heat waves:
Heat waves are expected to become more intense and frequent, especially along the coast. More humid nighttime heat waves and accompanying higher ozone production may result in increased cardiovascular disease, asthma attacks, emergency room visits and other public health impacts. Certain crops are sensitive to temperature extremes and can experience a steep decline once threshold temperatures are passed. Heat waves drive peak power use and the extra increase in energy demand on the hottest days is likely to grow significantly.

Wildfire and energy:
As summers become hotter and drier while winter snowfall melts earlier, seasons with many large wildfires are likely to increase. Air pollution from wildfires affects human health and can have detrimental effects on ecosystems. Fires can be started by power lines and wildfires can destroy power lines, thus affecting energy transmission.

Impacts of Climate Change on Physical Systems

Physical systems include the cryosphere (snow, ice and frozen ground), freshwater systems, and the ocean and coastal systems. 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 Nino/La Nina Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), or to both. Many of these observed changes are the direct result of rising temperatures.

Ocean circulation and patterns of variability

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 regions.

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.

State of the California Current (2009/2010 to 2011/2012), California Cooperative Ocean Fisheries Investigation Reports.
http://www.calcofi.org/publications/ccreports/reportslist.html

WESTERN U.S.

Keywords: adaptation, birds, California Current/California Current Ecosystem, climate variability, ecosystem impacts, El Niño, copepods, fish, La Niña, marine impacts, North Pacific Gyre Oscillation, North Pacific Ocean, ocean conditions, Pacific Decadal Oscillation (PDO), plankton, rockfish, salmon, seabird, upwelling, productivity

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) publishes the *State of the California Current* as part of its annual CalCOFI Report. CalCOFI is a unique partnership of the California Department of Fish and Wildlife, the National Oceanic and Atmospheric Administration Fisheries Service, and Scripps Institution of Oceanography. Established in 1949 to study the ecological aspects of the sardine population collapse off California, CalCOFI's efforts focus on the study of the marine

environment off the coast of California, the management of its living resources, and monitoring the indicators of El Niño and climate change.

The California Current moves southward along the coast off southern British Columbia to southern Baja California. It transports relatively cool, low salinity, nutrient-rich waters from sub-Arctic regions to the California coast. The *State of the California Current* reviews oceanographic conditions and ecosystem responses in the California Current System, from Baja California, Mexico to Oregon. Each report covers a one-year period that spans from spring of the beginning year through the spring of the following year. Observations included are those collected and analyzed by a diverse range of government, academic and private research programs. Recent observations are reviewed in the context of historical patterns as a means of identifying changes ostensibly related to recent climatic conditions.

State of the California Current 2009–2010: Regional variation persists through transition from La Niña to El Niño (and back?). Bjorkstedt E, Goericke R, McClatchie S, Weber E, Watson W, Lo N, et al. California Cooperative Oceanic Fisheries Investigations Reports (2010). 51:39-61. http://calcofi.org/publications/calcofireports/v51/Vol51_CACurrent_pg39-69.pdf

Summary: During the spring 2009 to spring 2010 period, a transition occurred from the cool La Niña conditions to a short-lived, relatively weak El Niño event. Upwelling was weaker than normal, contributing to warming over much of the California Current System (CCS) during the summer of 2009. (Upwelling is the wind-driven movement of deep, cool, and CO2- and nutrient-rich ocean water to the surface, replacing the warmer, usually nutrient-depleted surface water.) With the decline of La Niña, southern California conditions returned to near normal, while substantial warming remained in the northern CCS, with intense downwelling during winter 2009-2010. In early 2010, El Niño diminished rapidly, and upwelling off central and southern California resumed unusually early and strongly, while recovery from El Niño appeared to be less robust in the northern CCS. The period was marked by a continuation of the recent pattern of strong regional variability across the CCS.

State of the California Current 2010–2011: Regionally variable responses to a strong (but fleeting?) La Niña. Bjorkstedt E, Goericke R, McClatchie S, Weber E, Watson W, Lo N, et al. (2011), California Cooperative Oceanic Fisheries Investigations Reports (2011). 52:36-68 http://calcofi.org/publications/calcofireports/v52/Vol_52_36-68.StateofCurrent.pdf

Summary: The 2009-2010 El Niño dissipated rapidly in early spring 2010, but the transition to anomalously cool conditions followed somewhat later. The onset of anomalously strong upwelling throughout the CCS began in the summer of 2010, along with the development of unusually—in some cases record—cool conditions throughout the CCS. Regional contrasts were apparent during the period from the 2009-2010 El Niño through the transition to La Niña conditions in 2010-2011: the effects off

southern California were modest, while the northern California Current experienced more dramatic short-term changes. Ecosystem responses likewise varied. Off central and southern California, enhanced productivity was evident from rockfish recruitment, seabird abundance and reproductive success, and a resurgence of crustacean zooplankton following a period dominated by gelatinous zooplankton. Off northern California and Oregon, however, the return to La Niña conditions did not produce the same shift in the zooplankton populations, contributing to low at-sea survival of juvenile salmon. Tropical conditions in 2011 were ENSO-neutral and forecast to remain so into the fall and possibly into early 2012.

State of the California Current 2011-2012: Ecosystems Respond to Local Forcing as La Niña Wavers and Wanes. Bjorkstedt EP et al. (2012), Bjorkstedt EP, Goericke R, McClatchie S, Weber E, Watson W, Lo N, et al. California Cooperative Oceanic Fisheries Investigations Reports (2012). 52:41-76. http://calcofi.org/publications/calcofireports/v53/Vol_53_StateofCurrents_41-76.pdf

Summary: The CCS experienced La Niña conditions that dissipated through the spring and summer, resurged in fall and winter, and finally a transition towards ENSO-neutral conditions in spring 2012. The resurgence of La Niña was uneven, as reflected by variable responses in broad climate indices (such as the Pacific Decadal Oscillation), and by latitudinal variability in the timing, strength and duration of upwelling. Compared to 2010, ecosystem productivity declined in 2011 at varying magnitudes among taxa.

The pattern of regional variability throughout the CCS continued, as southern regions exhibited a mild response to climate forcing (tending towards climatological means) while northern regions showed greater effects of delayed or weaker than normal upwelling. Long-term observations off southern California show declines in dissolved oxygen and increases in nutrient concentrations in waters below the mixed layer (the layer between the ocean surface and a depth usually ranging between 25 and 200 meters, where the density is about the same as at the surface); these trends are consistent with recent prediction of the effects of global warming on the characteristics of upwelling source waters in the CCS.

Central Pacific El Niño and decadal climate change in the North Pacific Ocean. Di Lorenzo E, Cobb KM, Furtado JC, Schneider N, Anderson BT, Bracco A, et al. (2010). *Nature Geoscience*, 3(11): 762-765. http://dx.doi.org/10.1038/ngeo984 **WESTERN U.S.**

Keywords: El Niño Modoki; North Pacific Gyre Oscillation; ocean circulation; marine impacts; North Pacific Gyre Oscillation; North Pacific Ocean; ocean circulation; sea surface temperature, sea level pressure

Background/Purpose: The North Pacific Gyre Oscillation (NPGO) is a climate pattern associated with decadal variability of ocean circulation. It is characterized by sea surface temperature anomalies that resemble the central Pacific warming El Niño

pattern (CPW, also known as El Niño Modoki), a phenomenon associated with interannual variability. The NPGO explains low-frequency fluctuations of upper ocean salinity and nutrients in the central and eastern North Pacific, which are associated with ecosystem impacts. The origin of this low-frequency variability and its sensitivity to greenhouse gas-induced changes are unknown. This study examines the role of sea surface temperature anomalies associated with central Pacific El Niño in extra-tropical atmospheric circulation changes that in turn drive the decadal fluctuations of the NPGO.

Methods: The authors analyzed correlations between NPGO variance and sea level pressure anomalies over the Hawaiian region (SLP_{HI}), and between SLP_{HI} and tropical Pacific sea surface temperature (SST) anomalies using a statistical model and an atmospheric general circulation model coupled to an ocean model, respectively. Observational data consisted of monthly anomalies of sea level pressure from the National Centers for Environmental Protection Reanalysis II, and sea surface temperature data from the National Oceanic and Atmospheric Administration Reanalysis.

Results: The Hawaiian SLP variability explains a significant fraction of the low-frequency variability of the NPGO. Low-frequency variations of the atmospheric SLP_{HI} are, in turn, driven by changes in central tropical Pacific SSTs, as indicated by the results of the coupled model simulations. The location of the maximum positive correlations in the central tropical Pacific is consistent with the defining characteristic of the SST anomaly pattern associated with the CPW or El Niño Modoki.

Conclusions: The study results suggest that the low-frequency character of the NPGO originates from ocean-atmosphere interactions associated with the Central Pacific El Niño. NPGO variability has intensified in the late 20th century, explaining certain climate and ecosystem indices across the North Pacific Basin. This variability may increase further, as Central Pacific El Niño events are projected to become more frequent in the future. Hence the NPGO may play a more significant role in shaping Pacific climate and marine ecosystems.

Ocean temperatures

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}C. 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).[3]

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

Changes in the sea surface temperature threshold for tropical convection. Johnson NC and Xie S-P (2010). *Nature Geoscience*, 3(12): 842-845. http://dx.doi.org/10.1038/ngeo1008 **GLOBAL**

Keywords: cyclones, atmosphere, ocean conditions, precipitation/rain, sea surface temperature

Background/Purpose: Atmospheric convection in the form of tropical cyclones is known to occur above a threshold for sea surface temperatures (SSTs) of 26–28^{o}C or 78.8-82.4^{o}F. This threshold reflects the strong effect of local SSTs throughout the tropical oceans on atmospheric instability. Modeling studies suggest that this threshold may be rising in a warming climate; however, some observational data for the past few decades suggest otherwise. If the threshold does not rise, it is likely that cyclones may occur more frequently in the future with increased ocean warming. This study examines the correspondence in the variability of and long-term trends in tropical mean SSTs and the SST threshold for convection over 30 years.

Methods: Authors used both observational data on SST and on rainfall for the past 30 years and state of the art global climate models. Two sets of estimates of the SST threshold for convection were derived based on the rainfall data and examined for covariability with SST. In addition, the authors analyzed the correlation between tropical mean SST and SST threshold values from simulations using ten global climate models. Finally, the results of climate model simulations for two 20-year periods, 2001-2020 and 2081-2100, of rainfall rate as a function of SST and the frequency distribution of SST were examined.

Results: There was significant correspondence between tropical mean SST and the convective threshold. Both parameters show an upward trend of about 0.1^{o}C/decade. Similarly strong correspondence was observed in the simulations produced by the ten climate models on all timescales. The projected changes in rainfall rate and SST frequency distributions for 2001-2020 and 2081-2100 showed remarkable similarity, indicating that these are not expected to change with a warming climate.

Conclusions: The tropical SST threshold for convection is rising—and will continue to rise—at the same rate as the increase in tropical SSTs. If this is the case, hurricanes and other precipitation events will require warmer ocean surfaces for initiation in the future.

Robust warming of the global upper ocean. Lyman JM, Good SA, Gouretski VV, Ishii M, Johnson GC, Palmer MD, et al. (2010). *Nature*, 465(7296): 334-337. http://dx.doi.org/10.1038/nature09043 **GLOBAL**

Keywords: bias correction, sea surface temperature, ocean warming, upper-ocean heat content

Background/Purpose: Studies indicate that the world's oceans are warming due to greenhouse gas emissions from human activity. Most of the Earth's total energy uptake in recent decades has occurred in the upper ocean—such temporal changes are often presented as curves showing upper-ocean heat content anomalies (OHCA). OHCA curves are derived using different methods, and show different patterns of interannual variability. The underlying uncertainties in these patterns are unclear. This study examines sources of uncertainty among estimates of OHCA, and derives a composite of several OHCA curves to examine the global ocean warming trend.

Methods: OHCA values were calculated from data from the U.S. Argo Global Data Assembly Center and from the World Ocean Database 2005 for the period 1993 to 2008. Expendable bathythermograph (XBT) data make up the majority of the measurements of upper ocean heat content from 1967 to 2002. XBT data, which were primarily used to estimate ocean sound speed for submarine warfare, have been shown to have partly correctable temporal and spatial biases. Between 2000 and 2005, temperature measurements transitioned to high-quality conductivity-temperature-depth (CTD) data with the deployment of the Argo system. Argo also dramatically increased sampling in the Southern Oceans. The authors estimated the uncertainty associated with: bias correction of the XBT data (by comparing these with higher-accuracy data, mainly from Argo); the mapping methodology; the effects of irregular or sparse geographic sampling; and the use of different climatologies (i.e. the time period against which each year's record was compared to derive the magnitude of the anomaly). The authors also created a composite of several bias-corrected OHCA curves to examine the warming trend for the period covered.

Results: Although interannual variability differed among the OHCA curves, they all show significant warming of the global upper ocean over the 16-year period from 1993 to 2008, at generally similar warming rates. A composite of several OHCA curves using different XBT bias corrections likewise yielded a statistically significant linear warming trend for the period studied. The curves all flatten out after 2003 (with some variability in the year leveling occurs). The reason for this is unclear, although it coincided with the time the Argo system first achieving near-global coverage. From 1995 to 2004, uncertainty due to XBT correction dominated: increasing from 1994 to 1999, then decreasing after 2000 as the Argo system reached maturity, thus decreasing the relative contribution of XBT data to the OHCA estimates.

Conclusions: The greatest source of uncertainty in the OHCA curves was bias from ship-based XBT data. This uncertainty decreased with the full deployment of a system of high-quality conductivity-temperature-depth instruments on a near-global system of autonomous Argo floats. Despite these uncertainties, there has been robust warming of the global upper ocean for 1993-2008.

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135 years of global ocean warming between the Challenger expedition and the Argo Programme. Roemmich D, John Gould W and Gilson J (2012). *Nature Climate Change*, 2(6): 425-428. http://dx.doi.org/10.1038/nclimate1461 **GLOBAL**

Keywords: Challenger, Argo, ocean conditions, ocean warming, sea surface temperature, ocean conditions

Background/Purpose: The first globe-circling study of the oceans occurred in 1871-1876 with the voyage of *HMS Challenger*, which acquired 300 deep-ocean temperature profiles. Data from this voyage provides a basis for evaluating ocean temperature trends. This study is the first global-scale comparison of the 135 years of data between the *Challenger* voyage and the modern-day Argo programme (2004-2010). Argo's global system of free-drifting floats collect more than 100,000 temperature and salinity profiles per year at ten-day intervals spaced every 3^{o} of latitude and longitude, to depths of up to 1,980 meters (m).

Methods: Seasonally adjusted differences between Argo and *Challenger* temperature measurements were calculated. A 135-year interval of data between the *Challenger* (1872-1876) and Argo (2004-2010) were compared.

Results: Comparison of the *Challenger* and Argo temperature data showed spatial mean warming at the surface of 0.59 ^{o}C ± 0.12 between the two monitoring periods. This increase is consistent with previous global sea surface warming estimates. Below the surface, the mean warming was 0.39 ^{o}C ± 0.18 at 366 m (200 fathoms) and 0.12 ^{o}C ± 0.07 at 914 m (500 fathoms). The 0.33 ^{o}C ± 0.14 average temperature difference from 0 to 700 m is double the globally observed value over the past 50 years. The Atlantic Ocean warmed faster than the Pacific Ocean.

Conclusion: Data from the *Challenger* provided a valuable baseline of 19th century ocean temperatures. The *Challenger* record showed that upper ocean is substantially warmer today than during the 1870s, and that this warming is global in extent. Comparisons with other temperature records indicate that the warming occurred on the centennial timescale rather than in recent decades. This warming has implications for global sea level rise, as well as changes in evaporation rates and hence precipitation.

Human-induced global ocean warming on multidecadal timescales. Gleckler PJ, Santer BD, Domingues CM, Pierce DW, Barnett TP, Church JA, et al. (2012). *Nature Climate Change*, 2(7): 524-529. http://dx.doi.org/10.1038/nclimate1553 **GLOBAL**

Keywords: attribution, anthropogenic, ocean warming, temperature, upper-ocean heat content, ocean conditions

Background/Purpose: Observational records have shown large-scale increases in upper-ocean temperatures. These changes have been demonstrated in previous studies to be consistent with anthropogenic influences rather than natural variability.

Such studies relied on a single observational data set and one or two models. Furthermore, improved estimates of ocean temperature that correct for systematic instrumental biases have recently become available. In this study, the authors examine the causes of ocean warming using improved observational estimates and results from multimodel simulations.

Methods: Three data sets providing estimates of volume average temperature anomalies for the upper 700 meters of the global oceans were examined, along with bias-corrected estimates of two of these datasets. Separate estimates were also derived using a mapping technique to "infill" data where and when measurements are not available. These estimates were compared against results from model simulations of 20th century temperatures, both with and without external influences (specifically anthropogenic greenhouse gases and volcanic eruptions). Linear trends for observed and simulated datasets for the global oceans and each of the six ocean basins (North Atlantic, South Atlantic, North Pacific, South Pacific, North Indian, and South Indian oceans) were also compared. The aim is to search for time-increasing correspondence between the model-predicted ocean-warming fingerprint and the observational data sets, and then determine whether such correspondence could be due to natural variability alone. Finally, "signal-to-noise" ratios were calculated. A description of the highly technical derivation of the signal and noise estimates is beyond the scope of this summary. Simply put, "signal" refers to the pattern of response (or "fingerprint") to human-induced changes in greenhouse gases and other factors, and "noise" refers to natural variability.

Results: The bias-corrected data sets showed increases in upper ocean temperature anomalies ranging from 0.022 to 0.028 ^{o}C per decade. Temperature trends using data sets that included "infilled" values for data-sparse ocean regions showed lower variability than data sets that did not ("subsampled" data sets). Linear trends over 1960-1999 in observed and simulated temperature anomalies showed that the Atlantic has warmed more than the Pacific. Simulated trends that incorporate volcanic eruptions are more consistent with the observational data, compared to simulations that did not—which, in most cases, were larger than observed trends. The estimated "signal-to-noise" ratios showed a pronounced increase as the number of years increased, largely due to the corresponding decrease in the magnitude of the noise with time. This indicates an increasing human influence on ocean temperature anomalies.

Conclusions: Results from this study provide evidence for the anthropogenic influence on upper-ocean warming. These findings are based on a robust analysis using multiple bias-corrected observational data sets, infilled and subsampled data, and model simulations.

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. 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.

Dynamical suppression of sea level rise along the Pacific coast of North America: Indications for imminent acceleration. Bromirski PD, Miller AJ, Flick RE and Auad G (2011). *Journal of Geophysical Research*, 116: C07005.
http://dx.doi.org/10.1029/2010JC006759 **WESTERN U.S.**

Keywords: coastal impacts, ocean circulation, erosion, flood, ocean conditions, Pacific Decadal Oscillation, wind stress curl, sea level rise, sea level height, storms

Background/Purpose: Global mean sea level has risen by an estimated 1 to 2 millimeters (mm)/year over the 20th century, increasing at a faster rate (to about 3 mm/year) since the early 1990's. The U.S. West Coast has generally shown similar rates of increase over much of the 20th century. Since 1980, however, sea level rise in the region has remained stationary. This study investigates the reasons for this difference.

Methods: Observational data analyzed consisted of long tide gauge records and satellite altimetry data. The satellite altimetry measurements were used to investigate the relationship of sea level variability along the eastern boundary of the North Pacific basin with sea level variability across the basin, as well as their associations with models of climate variability. Ocean model simulations were used to examine the relative importance of wind stress and heat anomalies in driving regional sea level (RSL) trends. The relationship between spatial changes in wind and coastal sea level variability was also investigated.

Results: The observational and satellite altimetry data both show similar sea level height (SLH) variability and trends over the same time period, including the recent flattening of RSL rise along the Pacific coast that is significantly lower than the global trend. A similar plateau in the rate of RSL rise along the Pacific coast during 1900-1930 was evident from tide gauge records.

The patterns of SLH variability were found to be related to broad-scale ocean circulation patterns, reflecting responses to a combination of surface warming and changes in wind stress patterns—key factors that affect circulation. Model simulations indicate that persistent wind stress patterns are the dominant factor affecting sea levels along the Pacific Coast of North America. A dramatic change in wind stress patterns occurred in this region after the mid-1970's shift in the Pacific Decadal Oscillation (PDO) from cold to warm phase. The warm phase is characterized by increased wind stress and upward movement of cold water or "upwelling" toward the surface along the West Coast.

Upwelling tends to depress coastal sea levels. Hence, the upward trends in coastal wind stress since 1980 and the increased upwelling associated with it would suppress RSL rise. A recent drop in wind stress to levels not observed since before the mid-1970's may signal a resumption of sea level rise.

Conclusions: Since roughly 1980, the predominant wind stress associated with the shift in the PDO along the west coast served to mitigate the rising trend in mean sea level rise, suppressing regional RSL below the global rate. If the recently observed change in wind stress patterns persists—indicative of a shift in the PDO--then RSL along the west coast may resume, approaching or exceeding the global rate of mean sea level rise.

The impact of the 2009-10 El Niño Modoki on U.S. West Coast beaches. Barnard PL, Allan J, Hansen JE, Kaminsky GM, Ruggiero P and Doria A (2011). *Geophysical Research Letters*, 38(13): L13604. http://dx.doi.org/10.1029/2011GL047707

WEST COAST, CALIFORNIA

Keywords: sea level; erosion; El Niño; coastal impact; extreme events; flood; sea surface temperature; ocean conditions; storms; wave energy; waves

Background/Purpose: Along the U.S. West Coast, El Niños can influence both ocean water levels and the predominant storm tracks. Classic El Niños are characterized by a maximum warm sea surface temperature (SST) anomaly in the eastern Pacific. Recently, a second type of El Niño has been documented. Known as El Niño Modoki , it occurs when the maximum warm sea surface temperature anomaly is focused in the central equatorial Pacific Ocean. This paper describes the broad coastal impacts of the 2009-10 El Niño Modoki in the context of past coastal behavior, including comparisons with the1997-98 classic El Niño.

Methods: The authors analyzed coastal change observations—specifically changes in shoreline position and winter shoreline retreat—collected as part of five beach monitoring programs that spanned 5 to 13 years. Study sites included three in California (Southern, Central and Northern), one in Oregon, and one in Washington. In addition, the authors evaluated wave and water level conditions, specifically wave energy, wave direction, and mean winter water levels relative to long-term seasonal mean values to provide a better understanding of observed beach changes during the 2009-10 El Niño Modoki.

Results: The hydrodynamic and beach morphology data evaluated showed that:

- 2009-2010 was the only winter since the El Niño winter in 1997-98 in which wave energy throughout California was about 20 percent above the mean.
- The 2009-10 El Niño Modoki was characterized by an anomaly in winter mean wave direction, second in magnitude only to 1997-98 event; winter wave approach shifted southerly, except in Southern California.

- During the 2009-10 El Niño Modoki, the winter mean water level anomaly exceeded the mean at all locations, and was collectively the second highest positive anomaly since the early 1990s, although dwarfed by the 1997-98 El Niño.
- The shoreline retreated 23 percent more than the average winter; mean winter retreat was exceeded at all study sites except for Oregon.
- The 2009-10 El Niño winter produced the most receded shoreline position and greatest winter shoreline retreat in the Southern California survey record. It forced the shoreline position to its most eroded state in Central California since observations commenced, and led to severe erosion in Northern California that caused considerable infrastructure damage.

Compared to classic El Niños, lower sea surface temperature anomalies are associated with El Niño Modoki. Recent El Niño Modokis are characterized by a distinct south-north gradient of decreasing anomalies for wave energy and water levels. Hence, the anomalously high sea levels and wave energy associated with classic El Niños may be tempered on the west coast during El Niño Modokis.

Conclusions: Coastal erosion during the 2009-10 El Niño Modoki was substantial along California beaches. This phenomenon was marked by warm sea surface temperature anomaly focused in the central equatorial Pacific; the persistence of the anomaly results in longer periods of elevated wave energy but lower coastal water levels. If the intensity of El Niño Modokis continues to increase, as has occurred in recent decades, severe impacts on coastal beaches such as those observed in 2009-10 are likely. The ocean and atmospheric dynamics associated with El Niño Modokis need to be monitored and better understood.

Estimating the potential economic impacts of climate change on Southern California beaches. Pendleton L, King P, Mohn C, Webster DG, Vaughn R and Adams P. (2011). Climatic Change 109(Suppl 1):S277-S298. http://dx.doi.org/10.1007/s10584-011-0309-0 **CALIFORNIA**

Keywords: climate change, economic impacts, beaches, sea level rise, erosion, flood, socioeconomic factors,storms

Background/Purpose: California's beaches are vulnerable to the impacts of sea level rise. Sea level rise can narrow beaches and affect erosion and accretion when severe storms combine with higher high tides. This study investigated the potential physical and economic effects of permanent beach loss in southern California caused by a projected sea level rise, and of erosion and accretion from a single, stormy year.

Methods: Beach width changes at 51 Southern California beaches, from County Line Beach in Ventura County to San Onofre State Park in San Diego County, were projected using previously estimated beach slope values. Sediment budgets (the volume of sand deposited or removed) were estimated using a model based on wave-climate conditions of the 1982/1983 El Niño year. A model was used to estimate the

effects of a 1-meter sea level rise on beach attendance, beach expenditures, and the non-market value of going to the beaches. Simple estimates of the costs of physically "renourishing" beaches with new sand were also developed.

Results: Assuming that permanent inundation occurs gradually, a minimum 1-meter sea level rise is expected to reduce the average widths of all beaches in Southern California by 2100. The projected loss is uneven across beaches, ranging from a reduction of 6 to 16 meters, with an average of approximately 9 meters. The effects on beach width and beach use of a single extremely stormy year were found to be on the same order as the effects of 100 years of sea level rise.

The effect of climate-driven beach change differs for users based on their preferred beach activity (i.e., biking, sand-based, or water-based). Overall, increased sea level reduces economic value of beaches. Some beaches experience increased attendance while others experience reduced attendance. The economic impacts of permanent inundation and erosion are unevenly distributed across southern California. Beach visits in Los Angeles and Orange counties could decrease by more than half a million visits annually by 2100.

Conclusions: Even in the face of sea level change, beach going is likely to remain a significant recreational asset to southern California. However, sea level rise can significantly affect economies relying on beach attendance. The estimated economic loss for the region is substantial ($40 to $63 million annually), and spread unevenly. A single extremely stormy year can have a temporary, but substantial economic impact similar to the average annual impacts from a full meter of sea level rise. A major concern for future beach going activity and the beach-related economy relates to wave-driven erosion and accretion, where further research is needed.

The protective role of coastal marshes: A systematic review and meta-analysis.
Shepard CC, Crain CM and Beck MW (2011). *PLoS One*, 6(11): e27374.
http://dx.doi.org/10.1371%2Fjournal.pone.0027374 **GLOBAL**

Keywords: adaptation, biomass, marshes, coastal, waves, coastal impacts, flood, shoreline, vegetation, marine impacts, mitigation, sea level

Background/Purpose: Studies suggest that salt marshes may protect coastal communities from extreme weather events and sea level rise related to climate change. Such studies were based on a small number of historical reports and the consistency and extent to which marshes protect communities was not investigated. This paper reviews the current evidence for the processes of wave attenuation, shoreline stabilization and floodwater attenuation to determine if and under what conditions salt marshes offer these coastal protection services.

Methods: The authors searched the literature related to salt marshes and coastal protection and conducted meta-analyses on papers which had sufficient data for quantitative analysis.

Results: Combined across all studies, salt marsh vegetation weakened waves and stabilized the shoreline. Vegetation density, biomass production, and marsh size were positively correlated with both wave weakening and shoreline stabilization. Although the authors were not able to find studies quantitating floodwater attenuation within salt marshes, several studies noted how wetland alteration negatively impacted water quantity regulation along the coast.

Conclusions: Coastal marshes may be beneficial for climate change adaptation, especially as extreme coastal weather and sea level rise become more pronounced. These results provide support for using approaches that will incorporate natural features and processes into hazard mitigation and climate change adaptation.

Evaluating tidal marsh sustainability in the face of sea-level rise: A hybrid modeling approach applied to San Francisco Bay. Stralberg D, Brennan M, Callaway JC, Wood JK, Schile LM, Jongsomjit D, et al. (2011). *PLoS ONE*, 6(11): e27388. http://dx.doi.org/10.1371/journal.pone.0027388 **CALIFORNIA**

Keywords: coastal impacts, ecosystem impacts, flood, marine impacts, marshes, sea level

Background/Purpose: Tidal marshes are dynamic ecosystems which support a diverse group of species and help protect the environment through processes like flood mitigation. These ecosystems are expected to be threatened by sea level rise (SLR) over the next century. Managers seek guidance on whether marshes will be resilient under a range of potential future conditions and on prioritizing marsh restoration and conservation activities. This paper used a modeling approach to explore the sustainability of tidal marshes over the next 100 years, using San Francisco Bay as a case study.

Methods: A hybrid method was developed that involves a realistic, mechanistic treatment of marsh accretion (vertical accumulation of sediment and organic material) dynamics and incorporates spatial variation across an estuary. Accretion models were run for 70 combinations of starting elevation, mineral sediment, organic matter, and SLR assumptions. Results were applied spatially to evaluate eight Bay-wide climate change scenarios.

Results: When model runs were combined across subregions with different estimated suspended sediment concentrations (SSC) and organic material values, Bay-wide projections of mid marsh habitat area varied substantially, depending primarily on SLR and SSC assumptions. Across all scenarios evaluated, however, the models projected

a shift in the mix of intertidal habitats, with a loss of high marsh and gains in low marsh and mudflats within the study area.

Conclusions: The results give bleak predictions for long-term natural tide marsh sustainability under a high-SLR scenario. To minimize marsh loss, they recommend conserving adjacent uplands for marsh migration, redistributing dredged sediment to raise elevations, and concentrating restoration efforts in sediment-rich areas. The authors developed a web-based decision support tool (www.prbo.org/sfbayslr).

Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Resource Council (2012). Committee on Sea Level Rise in California, Oregon, and Washington, Board on Earth Sciences and Resources, Ocean Studies Board, Division on Earth and Life Studies.
http://www.nap.edu/openbook.php?record_id=13389 **WESTERN U.S.**

See summary under *Authoritative Reports*, page 14.

The Impacts of Sea Level Rise on the San Francisco Bay. Heberger M, Cooley H, Herrera P, Gleick PH and Moore E (2012). California Energy Commission (2012). Publication number: CEC-500-2012-014.
http://www.energy.ca.gov/2012publications/CEC-500-2012-014/CEC-500-2012-014.pdf
CALIFORNIA

Keywords: sea level rise, coastal impacts, San Francisco Bay, vulnerability, low-income population, communities of color, infrastructure, environmental justice, erosion, flooding, wetlands

Summary: Sea level has risen nearly eight inches over the past century along the California coast. An earlier analysis projected increases ranging from 1.0 to 1.4 meters (m) along the California coast by the year 2100. This study estimated the impacts of these projected increases on the population, infrastructure, ecosystems and property at risk along San Francisco Bay's 1,000-mile shoreline. Sea level rise will cause more frequent and more damaging floods, and increase the size of the coastal floodplain. A 1.0 m sea level rise is estimated to put 220,000 people at risk of a 100-year flood event and a replacement cost of $49 billion for damaged property. A 1.4 m rise in sea level increases the estimated impacts to 270,000 people and $62 billion in replacement costs. Further analysis of key characteristics that increase a population's vulnerability to the adverse impacts of flood events revealed large numbers of low-income people and communities of color that may be especially vulnerable. Wetlands and some critical infrastructure, such as roads, hospitals, schools, emergency facilities, wastewater treatment plants and power plants will also be vulnerable.

Impacts of Predicted Sea-Level Rise and Extreme Storm Events on the Transportation Infrastructure in the San Francisco Bay Region. Biging GS, Radke JD and Lee JH. (*University of California, Berkeley*).California Energy Commission (2012). Publication number: CEC-500-2012-040.
http://www.energy.ca.gov/2012publications/CEC-500-2012-040/CEC-500-2012-040.pdf
CALIFORNIA

Keywords: sea level rise, flooding, inundation, extreme storms, peak water levels, transportation infrastructure, accessibility, storms

Summary: The San Francisco Bay Area's transportation infrastructure consists of 620 miles of freeways; 800 miles of state highways; 19,000 centerline miles of local roadways; 600 miles of track for both passengers and freight; three international airports; and four major ports. This study first summarized the literature concerning the impacts of climate change on transportation infrastructure in general, then focused on assessing the vulnerability of the Bay Area's transportation infrastructure to the effects of inundation based on a projected 1.4-meter sea level rise in tandem with a 100-year flood event.

The authors created new high-resolution models of ground elevation and of surface elevation for roads, bridges buildings and other infrastructure, and an updated geographic information system (GIS) for the greater Bay area. These were used to project areas of inundation, including length of roads and rails and areas at airports and ports at risk of inundation. Finally, the authors measured the vulnerability of the road network under potential inundation scenarios using a metric representing loss of accessibility, as follows: (a) accessibility of first responders to households in their area of responsibility; (b) changes in travel time between intersections ("nodes") of the major regional transportation system; and (c) changes in travel time to the hinterland from major highway intersections. The cross-Bay links disrupt the greatest volumes of traffic and prove to be critical components of the regional network.

Finally, the authors measured the vulnerability of the road network under potential inundation scenarios using a metric representing loss of accessibility. Impacts on first responders, on regional commute, and on access into the hinterland were examined. Among their findings were: (a) with a 100-year storm event, the greater Bay region will lose access to 16 first responder fire stations (with no sea level rise) and to 36 (with a 1.4-m sea level rise); (b) with regard to regional commute travel times, east-to-west movement is estimated to be 3 to 11 times longer than normal, and north-to-south movement up to 3 times longer; and (c) access into the hinterland in the North Bay is projected to be devastated by inundation.

Glaciers and snowpack

Glaciers are one of the most visible indicators of climate change. With few exceptions, alpine glaciers—including those in the central and southern Sierra Nevada in

California—have been receding globally in response to a warming climate over the past century.

Similarly, the accumulation of snow at high elevations can be affected by warming temperature. 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. Mountain snowpack has been declining in the Western U.S., partly due to human-induced warming. The influence of natural variability, specifically the intra-annual Pacific-North American pattern, on the snowpack trends was recently examined.

Influence of the PNA on declining mountain snowpack in the Western United States. Abatzoglou JT (2011*). International Journal of Climatology*, 31(8): 1135-1142. http://dx.doi.org/10.1002/joc.2137 **WESTERN U.S.**

Keywords: climate variability, hydrology, snow, snowmelt, snowpack, freezing level, Western United States

Background/Purpose: The widespread decrease in mountain snowpack across the Western U.S. has been shown to be consistent with human-induced warming in prior attribution studies. The observed decreases across much of the Cascades, Northern Rockies and Sierra Nevada, however, have been greater than model predictions based solely on human influence. Changes in the Pacific-North American (PNA, an atmospheric circulation pattern that varies on intramonthly timescales) over the last half century are hypothesized to have accelerated losses in snowpack. To investigate the factors that may account for this discrepancy, this study examines the influence of the PNA pattern on trends in both the percent of precipitation falling as snow and in snowmelt during the late winter—factors affecting snowpack.

Methods: Metrics analyzed were interpolated from or derived from models using daily free-air temperature data and daily gridded precipitation data from 1958 to 2005. The daily PNA index was calculated, and an adjusted index derived to determine the temperature-driven trend independent of the PNA. Trends in freezing level elevation (the elevation at which the air temperature is at or below freezing), the fraction of accumulated precipitation that falls as snow (SFE/P), and positive degree days (PDD, the sum of values above freezing in late winter, i.e., January through March) were calculated using the observed and adjusted PNA index. The study covered the western tier of the continental U.S. that encapsulated the Cascades, Sierra Nevada, Northern Rockies, and Wasatch Range.

Results: Over the last half century, the PNA has undergone a phase shift toward positive values, which are generally associated with anomalously high freezing levels. Trends in SFE/P, the fraction of accumulated precipitation falling as snow, decreased across the study region with nearly a 10:1 ratio of decreasing trends to increasing trends; the median trend is -1.4 percent per decade. With the PNA adjusted to remove

its influence on daily freezing levels, the decreases in SFE/P were substantially reduced in magnitude. This suggests that changes in the PNA have strongly contributed to decreases in snow accumulation efficiency. Likewise, PNA was also shown to influence trends in snowmelt: observations show positive trends in PDD (indicating warming and increased snowmelt) that were greater than calculated trends using the adjusted PNA index.

Conclusions: The declining mountain snowpack in the Western U.S. was shown to be influenced by late winter changes in the PNA; the influence of anthropogenic warming had been previously demonstrated. The changes in PNA influenced both snowfall accumulation and snowmelt, and were shown to have accelerated the mountain snowpack decline over the last half century.

Quantifying 20th century glacier change in the Sierra Nevada, California. Basagic HJ and Fountain AG (2011). *Arctic, Antarctic, and Alpine Research,* 43(3): 317-330. http://dx.doi.org/10.1657/1938-4246-43.3.317 **CALIFORNIA**

Keywords: Sierra Nevada, glaciers, regional climate, retreating, area, regional climate

Background/Purpose: Alpine glaciers serve as indicators of climate change, providing proxy records of past climates given the scarcity of historic climate records in alpine regions. These glaciers have generally been receding globally over the 20th century in response to a warming climate—a change that affects alpine hydrology and global sea level rise. In addition to compiling a glacier inventory, this study of glaciers in Sierra Nevada, California, quantifies the magnitude and rate of change in glacier extent and examines the climate drivers.

Methods: Changes in glacier extent were assessed based on a photographic record starting in the late 1880s. Glacier extents were derived from vertical aerial and ground-based photographs, and measured with a global positioning system. Sufficient data to define the glacier extent for two time periods at least 100 years apart were available for 14 glaciers. Seasonal air temperatures and precipitation data from the Parameter-elevation Regressions on Independent Slopes Model or PRISM were analyzed to determine their influence on glacier change. The influence of local topography was analyzed using four variables: elevation, slope, aspect and headwall height (the elevation difference of the peak or ridge above the glacier and the glacier boundary based on the topographic maps).

Results: Between 1903 and 2004, the change in area for the 14 glaciers examined ranged from -21 to -78 percent, with an average of -55 percent. Loss of glacier area was found to be significantly correlated with summer and winter air temperatures. The changes in area occurred in four phases:

- Period I, from 1903 to about 1920, glacier area was constant, and winter/spring/summer temperatures were as much as -1^{o}C below the long-term averages and spring precipitation was above average;

- Period II, from 1920 through the 1960s, glaciers retreated rapidly as temperatures warmed about 0.5^{o}C above average and spring precipitation decreased to the long-term average; midway through this period, temperatures oscillated by 0.5^{o}C cooler or warmer than average and spring precipitation decreased;
- Period III, between the 1970s and early 1980s, glaciers stopped retreating and in some cases started to advance (increase in area), when temperatures were cool and spring precipitation was above normal;
- Period IV, in the late 1980s, glaciers again began to retreat as temperatures warmed by at least 0.5^{o}C, with the rate of retreat increasing by the late 1990s when winter and spring temperatures were the warmest on record.

The relatively uniform timing of area changes in the study glaciers is a response to regional climate. The variations in the magnitude of individual glacier changes are likely due to local topographic differences that affect mass accumulation and melting. Specifically, glaciers with tall headwall cliffs showed smaller losses in area.

Conclusions: The loss of glacier area over the past century in the Sierra Nevada was found to be associated with changes in the regional climate, particularly summer and winter air temperatures and spring precipitation. The magnitude and the timing of the loss appear consistent with what have been reported in the Western U.S. and globally. If the Sierra Nevada glaciers continue to shrink at the current (1972–2004) rates, the investigators project that most will be gone in 50–250 years.

Reclamation, SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress, 2011. Alexander P, Brekke L, Davis G, Gangopadhyay S, Grantz K, Hennig C, et al. U.S. Department of the Interior, Policy and Administration, Bureau of Reclamation, Denver, Colorado (2011).http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf

WESTERN U.S. (includes CALIFORNIA)

See summary under *Changes in Climate*, page 50.

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 stresses exerted by non-climate factors (such as habitat fragmentation and pollution) on ecosystem health. Individual species responses can have larger implications, as they may disrupt predator-prey and other ecological relationships, alter community composition, and interfere with ecosystem functioning.

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 from heat-related mortality and morbidity. Other projected climate related health impacts include increases in vector-borne disease transmission; decreased food quality and security; increased death, disease and injury from storms, floods and fires; reduced water quality and availability; and increased morbidity and mortality associated with air pollution.

Research shows that future climate scenarios will disproportionately affect those who are socially and economically disadvantaged[4]. 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. In a 2010 Cal/EPA report: "Indicators of Climate Change in California: Environmental Justice Impacts", the following four indicators are presented: disparities in air conditioner ownership and ability to cope with heat; farmworker exposure to extreme heat; exposure to urban heat for low-income residents; and vulnerability to wildfires for the rural poor. (see http://www.oehha.ca.gov/multimedia/epic/pdf/ClimateChangeEJ123110.pdf)

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[4] 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

Heat-related morbidity and mortality

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 also has focused on factors affecting vulnerability to the health impacts of climate change and indicators representing these factors that be used in vulnerability assessments.

Environmental health indicators of climate change for the United States: Findings from the State Environmental Health Indicator Collaborative. English PB, Sinclair AH, Ross Z, Anderson H, Boothe V, Davis C, et al. (2009*). Environmental Health Perspectives*, 117(11): 1673-1681. http://dx.doi.org/10.1289/ehp.0900708

UNITED STATES

Keywords: air quality, elderly, energy, environmental justice, heat island, infants/children, mitigation, precipitation (rain), public health, wildfire

Background/Purpose: It is projected that over the next few decades substantial increases in temperature and other weather changes will occur that will have large impacts on public health. To estimate impacts of climate change on human health and develop adaptation strategies, *indicators* of vulnerability and preparedness along with accurate surveillance data on climate-sensitive health outcomes are needed. This paper develops environmental health indicators for inputs into human health vulnerability assessments that can be used for climate-related public health preventative actions.

Methods: The investigators conducted a review of the scientific literature to identify outcomes and actions related to climate change. Data sources included governmental and nongovernmental agencies and the published literature. Sources were identified and assessed for completeness, usability, and accuracy. Priority was then given to identifying longitudinal data sets that were applicable at the state and community level.

Results: A list of surveillance indicators was developed for health practitioners and policy makers that include: climate-sensitive health outcomes (e.g., mortality, respiratory disease) and environmental (e.g., ozone levels, heat alerts, wildfire frequency) and vulnerability indicators (e.g., elderly, children, coastal populations). Other indicators include mitigation (e.g., use of renewable energy, number of vehicle miles traveled), adaptation (e.g., access to cooling centers, heat island mitigation plans), and policy indicators of climate change (e.g., number of cities participating in climate change initiatives).

Conclusions: Although data exist for many of the environmental and health measures identified in this study, more evaluation of their sensitivity and usefulness is needed. It

will be necessary to increase data quality and availability and to develop new surveillance databases, especially for climate-sensitive illnesses.

Socioeconomic indicators of heat-related health risk supplemented with remotely sensed data. Johnson D, Wilson J and Luber G (2009). *International Journal of Health Geographics*, 8: 57. http://dx.doi.org/10.1186/1476-072X-8-57

UNITED STATES

Keywords: community health, elderly, infants/children, heat island, heat wave, public health, socioeconomic factors, urban impacts

Background/Purpose: Currently, areas of a community with populations vulnerable to extreme heat events are identified by mapping sociodemographic variables. Physical environmental variables (e.g., urban heat island effect) that may contribute to increased risk from extreme heat events are not accounted for. The authors evaluated a possible method to improve spatial delineation of risk from extreme heat events in urban environments.

Methods: Five models were evaluated on their performance in predicting heat-related mortality using census tract-specific data for Philadelphia, PA. Different variables were incorporated into the models, as follows: Model 1, only sociodemographic counts and total population; Model 2, only thermal data (remotely sensed land surface temperature); Model 3, thermal data, sociodemographic count and total population; Model 4, only socioeconomic rate and population density; and Model 5, thermal data, sociodemographic rate and population density. The sociodemographic variables used are known to be risk factors affecting vulnerability to extreme heat. They describe race, age (elderly and children), education (less than high school) and poverty. The results of the models were compared against mortality data from an extreme heat event that occurred in Philadelphia during the summer of 1993.

Results: The model that incorporated remotely sensed land surface temperature and sociodemographic variables yielded the best predictions of heat-related mortality, compared to models using only remotely sensed data or only sociodemographic rates. The model using remotely sensed data alone predicted mortality better than that using only sociodemographic rates.

Conclusions: Using both thermal remote sensing data and sociodemographic data can provide a more spatially specific assessment of risk from extreme heat in urban areas. The results from a model that incorporates both data sets can better inform planning and intervention needs.

Mapping community determinants of heat vulnerability. Reid CE, O'Neill MS, Gronlund CJ, Brines SJ, Brown DG, Diez-Roux AV, et al. (2009). *Environmental Health Perspectives*, 117(11): 1730-1736. http://dx.doi.org/10.1289/ehp.0900683

UNITED STATES

Keywords: air conditioning, community health, elderly, environmental justice, heat wave, vegetation, public health;

Background/Purpose: Substantial evidence has linked extreme heat events to increased deaths and illness. Using epidemiological studies that identify specific population characteristics that mark vulnerability to heat waves, the investigators mapped vulnerability to heat across the United States for purposes of identifying areas for intervention and further research. The goal was to create a *cumulative heat vulnerability index* for nationwide comparison.

Methods: The authors mapped and analyzed 10 vulnerability factors for heat-related death and illness across the U.S: six demographic characteristics (age, poverty, education, living alone, race, and ethnicity); two household air conditioning variables; vegetation cover; and diabetes prevalence. Data came from the U.S. Census Bureau, satellite pictures (vegetation cover) and a national survey of diabetes prevalence. Values of increasing vulnerability were assigned to 39,794 census tracts and cumulative heat vulnerability index values were generated.

Results: Four of the 10 factors explained more than 75 percent of total variance: social/environmental vulnerability (combined education/poverty/race/green space), social isolation, air conditioning prevalence, and proportion elderly/diabetes. These four factors were used to generate the cumulative heat vulnerability index. The Northeast and Pacific Coast had the highest vulnerability, while the Southeast had the lowest vulnerability. Inner cities had the highest vulnerability in urban areas. Eight of the thirteen most vulnerable census tracts were in the San Francisco Bay Area (San Francisco County and Alameda County), and one was in Los Angeles County.

Conclusions: The methods used here provide a template for generating local and regional heat vulnerability maps. In conjunction with health outcome data, the vulnerability indices can be used for targeting interventions in the most vulnerable populations.

The effect of temperature on hospital admissions in nine California counties. Green RS, Basu R, Malig B, Broadwin R, Kim JJ and Ostro B (2010). *International Journal of Public Health*, 55(2): 113-121. http://dx.doi.org/10.1007/s00038-009-0076-0

CALIFORNIA

Keywords: cardiovascular diseases; hospitalizations, elderly, temperature, heat stress, respiratory tract diseases, public health

Background/Purpose: Studies worldwide report relationships between increased ambient temperature and mortality; however, few studies have looked at heat-related morbidity. This study examined heat-related illnesses in California, where temperature and humidity are generally mild, but where pollution levels tend to be higher than in other areas of the United States.

Methods: Daily hospital admissions data were obtained for nine counties from the Office of Statewide Health Planning and Development from May 1999 through September 2005. Health outcomes examined included heart disease, stroke, respiratory diseases, asthma, heat stroke and diabetes. Weather data were obtained from the California Irrigation Management Information System and the US EPA to determine mean daily apparent temperature (incorporates temperature and humidity). The analysis was limited to the months of May through September. An epidemiological statistical method (time-stratified case-crossover design) compared the exposure in the case period when events occurred with exposures in nearby control periods to examine how differences in exposure might explain the differences in the daily number of cases. Possible confounding effects of ozone and particulate matter ($PM_{2.5}$) were evaluated.

Results: Diseases in several categories were related to increased same-day apparent temperature. A 10^{o}F increase in mean apparent temperature was associated with a 3.5% increase in ischemic stroke for patients 65 years or older, 2.0% increase in all respiratory diseases, 3.7% increase in pneumonia, 10.8% increase in dehydration, 3.1% increase in diabetes, and 7.4% increase in acute renal failure. No association was found between apparent temperature and cardiovascular diseases. Controlling for ozone and $PM_{2.5}$ reduced the effects of temperature on respiratory diseases.

Conclusions: Even without extremes in apparent temperature, an association was observed between temperature and hospital admissions. The authors stress the importance of limiting heat exposure and preventing illness by using air conditioning and other mitigation efforts.

High ambient temperature and the risk of preterm delivery. Basu R, Malig B and Ostro B (2010). *American Journal of Epidemiology*, 172(10): 1108-1117. http://dx.doi.org/10.1093/aje/kwq170 **CALIFORNIA**

Keywords: air pollution, infants/children, pregnancy outcome, premature birth, temperature, public health

Background/Purpose: With temperatures expected to increase due to climate change, the authors find it essential to study the health outcomes of elevated temperature in vulnerable populations, such as expectant mothers. A preliminary study in New York reported an association between increased heat-humidity and preterm labor. This study looked at the possible association between elevated ambient temperature and preterm delivery in California.

Methods: California's Office of Vital Records provided birth outcome data for 16 California counties. The births took place between May and September in the years 1999 to 2006. Length of gestation was taken from birth certificate data, with preterm delivery defined as births from 20 to 36 gestational weeks. Daily mean, maximum and minimum temperatures and relative humidity for May through September were provided by the California Irrigation Management Information System and the US EPA Air Quality System. Air pollution monitoring data (particulate matter, sulfur dioxide, carbon monoxide, nitrogen dioxide) from California Air Resources Board statewide monitors was evaluated to look for possible associations with birth outcomes. An epidemiological statistical method (case-crossover design) was used to examine short-term exposures with acute outcomes.

Results: High ambient temperature was significantly associated with preterm birth for all mothers. An 8.6% increase in preterm delivery was associated with a 10^{o}F (5.6^{o}C) increase in weekly averages of apparent temperature (temperature that incorporates humidity). Maternal racial/ethnic group, age, education, and sex of the infant did not affect the results. Stronger correlations were apparent among younger mothers, blacks, and Asians. Temperature-related preterm deliveries were independent of exposure to air pollutants.

Conclusions: There is a significant correlation between apparent temperature and preterm delivery during the warm season. The authors discuss limitations to the study and the need for more large-scale studies that consider biologic acclimatization and susceptible subgroups.

The effects of temperature and use of air conditioning on hospitalizations. Ostro B, Rauch S, Green R, Malig B and Basu R (2010). *American Journal of Epidemiology*, 172(9): 1053-1061. http://dx.doi.org/10.1093/aje/kwq231 **CALIFORNIA**

Keywords: air conditioning; cardiovascular diseases; hospitalization; extreme events; respiratory tract diseases; temperature; mitigation; public health; heat stress

Background/Purpose: Extreme heat events have been associated with mortality. Less clear are the specific impacts of high temperature on morbidity and the effectiveness of mitigation strategies such as use of air conditioners (ACs). This study investigated apparent temperature (a measure of temperature and humidity) and hospital admissions (see *Greene et al*, *2010* above) and whether air conditioning ownership and usage mitigated this association.

Methods: The authors assessed temperature and hospital admissions data in California from 1999 to 2005 (see *Greene et al., 2010*). AC ownership and usage was obtained from the 2004 California Residential Appliance Saturation Survey, sponsored by the California Energy Commission. Approximately 22,000 responses were used from 53 out of 58 counties. The relationship between AC ownership and socioeconomic status was assessed by using a survey of household income and US Census data. An

epidemiological statistical method (time-stratified case-crossover design) was used where temperature on the date of hospitalization (case) is compared with temperatures on several control days occurring on the same day of the week within the same month and year. Since the control days are selected within the same month as the hospitalization, seasonal or long-term effects are minimized.

Results: Significant associations were observed between increased apparent temperature and risk of hospitalization for several outcomes, including cardiovascular disease, ischemic stroke, respiratory disease, heat stroke, diabetes and acute renal failure. Ownership and usage of ACs significantly reduced the effects of temperature on adverse health outcomes. There was no evidence that income confounded the relationship between temperature and hospitalization in California.

Conclusions: This study may be a first to use localized measures of temperature exposure, AC prevalence and use, and family income in an evaluation of heat-related hospitalizations. The results demonstrate the important effects of temperature on public health and the importance of intervention (in this case AC use) in reducing heat-related illness.

High ambient temperature and mortality in California: Exploring the roles of age, disease, and mortality displacement. Basu R and Malig B (2011). *Environmental Research*, 111(8): 1286-1292. http://dx.doi.org/10.1016/j.envres.2011.09.006

CALIFORNIA

Keywords: air pollution; temperature, infants/children, heat stress; public health, respiratory tract diseases, temperature related mortality

Background/Purpose: The elderly, infants and children, and individuals with pre-existing health conditions have been shown to be particularly sensitive to the adverse health effects of high temperatures. Few researchers have addressed mortality displacement, a forward temporal shift in the rate of mortality in a population, usually attributed to heat and other environmental phenomena. (In other words, already frail individuals may have died sooner as a result of the exposure.) If mortality displacement is the primary driver of the observed effects, then mostly individuals with little life expectancy would be impacted. If mortality displacement is not a significant factor, then heat exposure would represent a greater loss of life among the general population. This study examined the mean daily apparent temperature (a metric that reflects a combination of air temperature, relative humidity, and wind speed) and mortality in California counties during the warm season from 1999-2006 to ascertain which specific causes of mortality are associated with temperature and to identify age and subgroup populations at increased risk. The potential effect of mortality displacement was also investigated, along with the confounding effects of air pollution, air conditioning, and geographic location.

Methods: Meteorological data were obtained from three different monitoring networks: the California Irrigation and Management Information System, the US Environmental Protection Agency Air Quality System, and the National Climatic Data Center. The meteorological data was used to calculate mean daily apparent temperature and temperature extremes above the 90th percentile. Data on air pollutants from the California Air Resources Board were used to evaluate the potential confounding effects of CO, O_3, NO_2, and $PM_{2.5}$. Data on daily mortality for the 13 most populous counties in California came from the California Department of Health Services, Health Data and Statistics Branch. Deaths from all causes were studied, excluding accidents, homicides, and suicides. Air conditioner prevalence was studied as an effect modifier and estimated from data supplied by the 2004 California Residential Appliance Saturation Survey, a utility survey sponsored by the California Energy Commission.

Results: Non-accidental mortality was associated with heat exposure in the same day and up to a maximum of three days after exposure (excess risk= 4.3% per 5.6 °C increase in apparent temperature). Similar risks were found for mortality from cardiovascular diseases and respiratory diseases, and among children (0-18 years old), adults and the elderly (>50 years old). These associations were still found after adjustment by air pollutants, indicating no confounding effects from exposure to air pollutants. Similar results were found in an evaluation of temperatures above the 90th percentile, although the effect estimate was nearly doubled, suggesting non-linearity for the higher exposure ranges. Since no significant effects were observed in the following days, there was no evidence of mortality displacement. There appears to be regional differences in responses to heat exposure. A greater impact occurred for northern California and among coastal areas, where people experience smaller temperature ranges and thus may be less acclimated to higher temperatures. People living in northern California and coastal areas are also less likely to have air conditioners in their homes due to the milder climates, making them more vulnerable to heat extremes.

Conclusions: The effect of temperature on mortality is most pronounced on the same day and up to three days following the initial exposure. The findings indicate that mortality displacement does not appear to play a role in the observed effects, indicating a wide impact of heat exposure on the general public. A rapid response is thus needed to prevent heat-related deaths among vulnerable populations.

Ambient temperature and morbidity: A review of epidemiological evidence. Ye X, Wolff R, Yu W, Vaneckova P, Pan X and Tong S (2011). *Environmental Health Perspectives*, 120(1). http://dx.doi.org/10.1289%2Fehp.1003198 **GLOBAL**

Keywords: air pollution, elderly, extreme events, heat stress, heat wave, hospitalizations, infants/children, morbidity, public health, temperature, respiratory tract diseases

Background/Purpose: The effect of increasing ambient temperature on morbidity is recognized as a significant public health issue. This paper reviews current

epidemiological evidence concerning the relationship between ambient temperature and morbidity. It identifies knowledge gaps in the field and recommends future research directions.

Methods: The PubMed electronic database was searched for studies before 30 June 2010 that examine the relationship between ambient temperature and morbidity. Forty relevant studies, mostly conducted in the United States and Europe during the last decade, were identified in peer-reviewed journals. Of these, 24 examined the relationship between ambient temperature and morbidity, 15 investigated the short-term effects of heat wave on morbidity, and 1 assessed both temperature and heat wave effects. Selection criteria included studies that used original data and appropriate effect estimates (statistical methods); used ambient or a composite temperature measure; and where outcome included a noncommunicable disease (e.g., cardiovascular, respiratory diseases). Descriptive and time-series studies (epidemiology methods) were the two main research designs used to investigate the temperature–morbidity relationship.

Results: Measurements of temperature exposure and health outcomes used in these studies differed widely. The majority of studies reported a significant relationship between ambient temperature (both hot and cold) and total or cause-specific morbidities. Despite variation among specific diseases, increased overall morbidity has been consistently associated with heat waves. Some studies examined temporal patterns (lag structure) of the association between exposure to temperature over previous days and health risk on a particular day. The lag effect of hot temperature on morbidity was shorter (several days) compared with that of cold temperature (up to a few weeks). The temperature–morbidity relationship may be confounded or modified by sociodemographic factors (e.g., susceptible groups such as children, the elderly and certain ethnic groups) and air pollution. In addition, domestic (e.g., use of air conditioning) and local adaptation (e.g., cooling centers) factors could influence the direction and magnitude of the effects of ambient temperature.

Conclusions: There is a significant short-term effect of ambient temperature on total and cause-specific morbidities. However, further research is needed to determine appropriate measures of exposure; consider a diverse range of morbidities; estimate delayed temperature effects; and understand the possible interactive effects of air pollutants and temperature on morbidity.

Heat waves and cause-specific mortality at all ages. Basagaña X, Sartini C, Barrera-Gómez J, Dadvand P, Cunillera J, Ostro B, et al. (2011). *Epidemiology*, 22(6): 765-772. http://dx.doi.org/10.1097/EDE.0b013e31823031c5 **GLOBAL**

Keywords : extreme events, heat wave, infants, public health, cardiovascular, respiratory, heat, mortality, temperature related mortality

Background: A number of studies report increases in mortality during periods of extreme heat between the years 1970-2008. However, there is a lack of knowledge

about the specific causes of death, especially in infants. Analysis of heat-related mortality is of interest for the following reasons: 1) knowledge of how heat may affect persons who are already sick from other causes will help improve preparedness of the health system during heat waves; 2) identifying specific causes of death can help avoid misclassifying deaths as due to other causes; and 3) identifying health outcomes truly affected by heat that might not yet be suspected as heat-susceptible.

Methods: The study includes all deaths in the Catalonia region of Spain during the warm season (May 15-October 15) for the years 1983–2006 (503,389 deaths). Mortality data was obtained from the Mortality Registry of Catalonia and included date of death, main cause, age and sex. Maximum daily temperatures and humidity data were obtained for 66 weather stations throughout Catalonia. Extremely hot days were defined as days with maximum temperature above the 95th percentile. Total mortality was grouped into 66 causes of death; infant mortality was grouped into 8 causes of death. The authors used an epidemiological statistical method (time-stratified case-crossover design) to evaluate the association between the occurrence of extremely hot days and mortality.

Results: Mortality increases were as large as 19 percent when 3 consecutive hot days occurred. Extreme heat was linked to 1.6 percent of all deaths in the warm seasons; about 40 percent of the heat-related deaths did not occur during heat-waves but on isolated hot days. Increased causes of death included cardiovascular and respiratory diseases, mental and nervous system disorders, infectious and digestive system diseases, diabetes, and some external causes such as suicide. The heat effect on mortality was concentrated among the elderly, with higher risks after 60 years of age. Infants displayed adverse health effects from heat on the same day, for conditions originating in the perinatal period (within one month after birth). For the perinatal cases, cardiovascular, respiratory, digestive system, and hemorrhagic and hematologic disorders were the causes of death.

Conclusions: Heat contributes to an increase in mortality from multiple diseases and disorders, with infants being most vulnerable during the perinatal period.

An examination of climate change on extreme heat events and climate–mortality relationships in large U.S. Cities. Greene S, Kalkstein LS, Mills DM and Samenow J (2011). *Weather, Climate, and Society*, 3(4): 281-292. http://dx.doi.org/10.1175/WCAS-D-11-00055.1 **UNITED STATES**

Keywords: atmosphere circulation, ocean circulation, extreme events, mortality, heat stress, public health, temperature related mortality

Background/Purpose: Extreme heat events (EHEs) are a leading cause of weather-related deaths in the United States. Studies evaluating climate change impacts on future EHE trends conclude that many regions can anticipate more frequent and severe heat events. This study quantifies potential future climate change impacts on heat-

related mortality in 40 large U.S. cities, including San Jose, Los Angeles, San Diego and San Francisco, California.

Methods: Mortality data from the National Center for Health Statistics were obtained from June through August during 1975–95 for the 40 cities. The "spatial synoptic classification method" was used to categorize representative daily weather conditions in each city. Each day was assigned to one of six airmass categories (e.g., dry tropical, moist polar) which was then used to identify weather situations likely to increase the incidence of adverse health effects. A mortality algorithm was developed that relates the variation in standardized mortality on all EHE days within a city to meteorological and environmental variables. The synoptic classification was combined with downscaled future climate projections for the years 2020-2029; 2045-2055; and 2090-2099 from an atmosphere-ocean circulation model to produce daily calendars for each decade. The EHE-attributable mortality impact was then calculated for the future decades for each city using the mortality algorithm. Potential changes in the demographic patterns of the cities were not considered.

Results: A fairly consistent increase in the number of EHE days across locations was projected over time. By the end of the twenty-first century, every city will experience an increase in the average number of summertime EHE days compared to 1975–95. The average number of EHE-attributable deaths was projected to more than double from the value in the 2020–29 period compared to the results in 2090–99. The most pronounced increases are projected to occur in the eastern U.S.

Conclusions: Overall, the results show extreme heat events represent a source of increased health risk and impacts for many cities across the United States. Already vulnerable cities in the east and Midwest will bear a significant amount of the large mortality increases if the weather warms as the models indicate. Continuing to improve advances in EHE notification and response will have a significant impact in reducing EHE-related mortality.

Mapping Climate Change Exposures, Vulnerabilities, and Adaptation to Public Health Risks in the San Francisco Bay and Fresno Regions. Jerrett M, Su J, Reid C, Jesdale B, Hinojosa A, Shonkoff S, Seto E, Morello-Frosch R (UC Berkeley) (2012). California Energy Commission. http://www.energy.ca.gov/2012publications/CEC-500-2012-041/CEC-500-2012-041.pdf **CALIFORNIA**

Keywords: adaptation, air pollution, heat stress; environmental justice; public health, rural

Summary: In California, climate change and mitigation policies aimed to lessen its effects may exert a disproportionate burden on lower socioeconomic status communities. In this paper, a conceptual framework was used for mapping climate change exposures, susceptibilities to these exposures, and adaptive capacity related to human health. This framework was used to perform a vulnerability assessment for the

San Francisco and Fresno areas for purposes of assessing where climate change adaptation efforts are most needed.

The authors identified, modeled and mapped environmental, social and health factors that are closely related to climate change and vulnerability. They quantified the cumulative impacts of four high-priority indicators to construct four sets of *cumulative environmental hazard inequality indices* (CEHII) at the regional level. These indicators are (1) *heat stress,* using absolute and relative temperature exceedance; (2) *air pollution,* using NO_2, PM2.5, and diesel PM concentrations; (3) *social and health vulnerability,* using preterm birth and low birth weight, elderly over 65 living alone, and lack of car ownership; and (4) *adaptive capacities*, using less impervious surface, high tree canopy coverage, and high air conditioning ownership. These results were then projected to the census tract level and indices were compared against two disparity (i.e., social vulnerability) metrics – census tract-level racial-ethnic composition (percentage of non-whites) and socioeconomic position (income less than 200 percent of the federal poverty level).

An *environmental justice screening method* (EJSM) tool was used to examine the relative rank of cumulative impacts and social vulnerability within metropolitan regions and to identify environmental justice areas. Using the same indicators to construct the CEHII, the EJSM tool calculates scores ranging from 1 to 5 for census tracts and locates areas that are more vulnerable to climate change impacts.

Adaptive capacity represented the greatest inequality in both the San Francisco and Fresno regions. In both areas, there was minimal inequality related to heat stress; diesel particulate matter showed the greatest inequality for air pollution exposures; and tree canopy shading showed the most inequality as an adaptive capacity variable. Social and health vulnerability had the second largest cumulative inequality in both regions, with lack of car ownership as the major contributor. Downtown urban areas for both Fresno County and the San Francisco Bay Area showed cumulatively higher vulnerability than more outlying areas, with the exception of the rural western portion of Fresno County. The use of the CEHII and the environmental justice screening method provides a useful approach for highlighting areas of greatest vulnerability for targeting adaptation planning.

Inequalities in cumulative environmental burdens among three urbanized counties in California. Su JG, Jerrett M, Morello-Frosch R, Jesdale BM and Kyle AD (2012). *Environment International*, 40(0): 79-87.
http://www.sciencedirect.com/science/article/pii/S0160412011002601

CALIFORNIA

Keywords: air pollution, community health, environmental justice, extreme events, heat stress, heat vulnerability (humans); public health; socioeconomic factors; temperature; vulnerability

Background/Purpose: Low-income communities and people of color are disproportionately affected by environmental and health burdens in their communities. In this study, the authors used a cumulative environmental hazard inequality index (CEHII) to assess inequalities within and among three urban counties in California: Alameda, San Diego, and Los Angeles. The authors had previously used CEHII to assess inequalities in air pollution exposures by racial-ethnic composition and by poverty status. In this study, the CEHII was used to assess inequalities in exposures to heat stress.

Methods: The authors assessed inequalities in exposures to both single and multiple environmental hazards in the three counties. The environmental hazards consisted of three air pollutants, namely diesel particulate matter (diesel PM), nitrogen dioxide (NO_2) and fine particulate matter (PM2.5), and two metrics for summer heat stress, i.e., absolute heat stress (calculated using apparent temperatures exceedances above 40^oC) and relative summer heat stress (temperature exceedances above the 1971-2000 historical normal maximum temperature for each monitoring station). Two population metrics were used to examine inequities: racial-ethnic composition based on the 2000 US Census (defined as the percentage of non-whites in the population); and the proportion of the population with an income less than 200% of the federal poverty level. The authors modified a metric (the "concentration index" developed for the World Bank to estimate health inequalities across regions and groups in a population) to quantify inequalities from a specific environmental burden (i.e., the individual environmental hazards listed above). To measure inequalities from multiple burdens, the authors calculated the CEHII by assuming fully multiplicative burdens; two indices were examined: one for the cumulative environmental burdens from the three air pollutants, and the other from the three air pollutants and heat stress.

Results: Distance to coast, elevation, and latitude explained about 75% of the variance in absolute heat stress. Relative heat stress was generally higher in places closer to coastal areas and in low-elevation regions.

Los Angeles County census tracts had the highest non-white population (99.6%) and the lowest non-white population (0%). The greatest maximum and mean NO_2 concentrations and the highest mean concentrations of diesel PM and $PM_{2.5}$ were also found in this county. It had the greatest maximum absolute temperature exceedances (7.44^oC per day) and the lowest mean relative temperature exceedances (1.14^oC per day). San Diego County had the greatest mean absolute temperature exceedances (5.18^oC per day), the greatest minimum absolute temperature exceedances (4.46^oC per day), and the greatest maximum (3.64^oC per day) relative temperature exceedances. Alameda County had the lowest maximum (2.97^oC per day) and mean (0.38^oC per day) absolute temperature exceedances, and the greatest mean relative temperature exceedances (1.57^oC per day).

Of the three air pollutants considered, diesel PM showed the greatest inequality, followed by NO_2 and PM2.5. Inequalities from cumulative exposure to air pollution exceeded inequalities from exposure to single pollutants within and between the

counties. Except for relative heat stress in San Diego, inequalities for absolute and relative heat stresses inequalities were small. Hence, the addition of heat stress did not substantially influence the spatial pattern of inequality.

Conclusions: In general, the results from this study correspond with previous studies showing communities of color bear greater environmental burdens than mainly white and affluent communities. This study showed that inequalities from multiple environmental hazards were generally significantly different and greater than single hazard inequalities. This finding demonstrates the importance of taking into account the cumulative burdens in assessing inequalities of a region for policy-making.

Summer temperature variability and long-term survival among elderly people with chronic disease. Zanobetti A, O'Neill MS, Gronlund CJ and Schwartz JD (2012). *Proceedings of the National Academy of Sciences*, 109(17): 6608-6613. http://dx.doi.org/10.1073/pnas.1113070109 **UNITED STATES**

Keywords: air pollution, elderly, hospitalizations, climate variability, temperature-related mortality, public health,

Background/Purpose: Time series studies show that hot temperatures may contribute to increases in deaths and illness on a short-term time scale (days to weeks after the exposure). There is strong evidence that people adapt to usual temperatures but are more likely to become ill when summertime temperatures are variable, which is expected to occur with climate change. This multi-city study examined whether year-to-year variations in summertime temperature variability around its long-term trends within a city are associated with year-to-year variations in survival of city-specific population groups. The elderly and people with chronic diseases were chosen as study groups since they are more susceptible to the acute effects of temperature.

Methods: Medicare data (1985–2006) were used to identify 4 cohorts of hospitalized people over age 65 with chronic obstructive pulmonary disease, diabetes, congestive heart failure, and myocardial infarction in 135 US cities with diverse geographic and climatic features. A single weather station was selected for each city based on the proximity of the station to the city's population center and the availability of data for 1985–2006. Daily mean temperature data were obtained from each station. For each year, a variable for the standard deviation (SD) of mean daily summertime (June–August) temperature in each city was created. Yearly summer temperature variance was linked to the hospitalized individuals during follow-up in each city and was treated as a time-varying exposure. Other variables considered included population density, proportion of the population below the poverty level, race, and percentage of land in green surface. Multi-staged statistical analyses (beyond the scope of this summary) were used to estimate the chronic effects on mortality of long-term exposure to summertime SD and the results were pooled across cities.

Results: Higher temperature SD in the warm season was significantly associated with shorter survival time in older subjects discharged following an admission for the four diseases. Associations were stronger for individuals over age 75. The temperature SD had a weaker association with survival time in the cities with a higher proportion of green surface and a stronger association in cities with a higher proportion of nonwhite residents. California cities were included in this study and had higher than average temperature SD.

Conclusions: Long-term increases in temperature variability may increase the risk of mortality, especially in elderly patients who already have underlying diseases.

The effect of high ambient temperature on emergency room visits in California. Basu R, Pearson D, Malig B, Broadwin R and Green R (2012). *Epidemiology*, 23(6): 813-820. http://dx.doi.org/10.1097/EDE.0b013e31826b7f97 **CALIFORNIA**

Keywords: air pollution, temperature, public health, emergency room visits, morbidity, cardiovascular diseases

Background/Purpose: The association between elevated temperature and mortality has been studied globally. To fully characterize the health effects of heat exposure, morbidity must also be considered since death constitutes only a portion of acute health effects. Much of the evidence showing the association between heat waves and morbidity has been studies of hospital admissions. In order to measure more immediate, acute effects from exposure to extreme heat, the authors evaluated daily temperature and emergency room (ER) visits in California.

Methods: Mean daily apparent temperature (incorporates temperature and humidity) and hospital admissions for several diseases were analyzed in nine California counties from May to September for the years 1999 to 2005. The California Irrigation Management Information System and the US EPA provided weather data for 16 climate zones. The California Air Resources Board provided daily 1-hour maximum concentrations for ozone, carbon monoxide, particulate matter and other pollutants. ER visit data was obtained from the California Office of Statewide Health Planning and Development. More than 1.2 million ER visits were included in the data. The analyses considered effects by disease subgroup, race/ethnic group, age group, and potential confounding from air pollutants (ozone and particulate matter). The investigators used regression models combined in meta-analyses to estimate overall effects.

Results: A 10-degree Fahrenheit increase in same-day mean apparent temperature was positively associated with ischemic heart disease, ischemic stroke, diabetes, intestinal infection, dehydration, acute renal failure, and heat illness. Same-day apparent temperature was negatively associated with aneurysm, hemorrhagic stroke, and hypertension. Adjusting for air pollutants did not significantly change any of the outcomes. Risks varied by age and by racial or ethnic group.

Conclusions: This study adds to the growing body of information on increased temperature and morbidity and is the first to focus on ER visits during both heat-wave and non-heat-wave periods. It revealed the importance of understanding the specific mechanisms of heat-related morbidity and the need to focus on cause-specific diseases to better understand how heat affects health.

Evaluation of a heat vulnerability index on abnormally hot days: An environmental public health tracking study. Reid CE, Mann JK, Alfasso R, English PB, King GC, Lincoln RA, et al. (2012). *Environmental Health Perspectives*, 120(5): 715-720. http://dx.doi.org/10.1289/ehp.1103766 **UNITED STATES**

Keywords: extreme events, heat vulnerability (humans), hospitalizations, morbidity, public health, respiratory tract diseases, temperature related mortality, heat stress

Background/Purpose: Extreme heat has been associated with increased morbidity and mortality. Recent studies show that heat-related health risks are not evenly distributed throughout the population with some groups being more vulnerable. A heat vulnerability index (HVI) has been developed previously that geographically locates populations with increased vulnerability to heat in U.S. metropolitan areas. The HVI incorporates factors such as poverty, race, education, social isolation, air conditioning prevalence, and pre-existing health conditions. This study compared associations between the HVI and daily rates of morbidity and mortality on abnormally hot days and normal days in five states, including California. The purpose of this comparison is to determine whether areas with higher HVI experienced higher morbidity and mortality rates on abnormally hot days.

Methods: The investigators modeled (Poisson regression) the interaction of HVI and deviant days (days whose deviation of maximum temperature from the 30-year normal maximum temperature is at or above the 95th percentile) on hospitalization and mortality counts in the years 2000 to 2007. Illnesses requiring hospitalization included electrolyte imbalance, cardiovascular diseases, cerebrovascular disease, respiratory illness, acute renal failure and heat-related illness. The analysis included 1,205 zip codes in California, 392 in Massachusetts, 20 in New Mexico, 119 in Oregon, and 212 in Washington. Daily ozone data was obtained from the nearest air quality monitor within the zip code.

Results: Overall, on both normal and deviant days, HVI was associated with higher hospitalization and mortality rates in all the states. In California, correlations were significantly stronger on deviant days for heat-related illness, acute renal failure, electrolyte imbalance, and nephritis. California had the highest daily mean counts of hospitalizations for each outcome.

Conclusion: The results suggest that the HVI can be used to identify areas with increased risks of adverse health outcomes in general and that it may identify areas at increased risk of heat-related illness on abnormally hot days. HVI was consistently

associated with most health outcomes, independent of heat exposure (i.e. on both abnormally hot and normal days). This suggests that HVI can be used as an indicator of overall health vulnerability, as well as vulnerability to heat-related outcomes on abnormally hot days. Further research should assess whether the HVI indicates increased health risks in association with different heat exposure metrics (e.g., other temperature thresholds, such as the 99th percentile of temperature) and whether the HVI should be adjusted for different regions in the country.

Social Vulnerability to Climate Change in California. Cooley H, Moore M and Allen L (Pacific Institute) (2012). California Energy Commission.
http://www.energy.ca.gov/2012publications/CEC-500-2012-013/CEC-500-2012-013.pdf
CALIFORNIA

Keywords: agriculture, air conditioning, air pollution, coastal impacts, economic impacts, wildfire, extreme events energy, environmental justice, flood, infants/children, public health, sea level

Summary: Although much research has emerged on the physical effects of climate change, less attention has been given to effects on human communities. Impacts on human populations are influenced by conditions that determine the event's impact and how well communities prepare, respond, and recover to a climate-driven event. The authors used downscaled climate model outputs to determine the distribution of climate change's potential impacts throughout California. To understand how communities will be affected, *social vulnerability* (i.e., how susceptible a population is to a hazard and its ability to prepare for and respond to this hazard) was evaluated. A "climate vulnerability index" was developed to indicate regional social vulnerability for populations. This index combines 19 indicators into an overall climate score, taking into account factors such as air conditioner ownership, percentage of tree cover and workers in outdoor occupations. Maps are presented to show where social vulnerability to climate change is greatest and where climate-related hazards are projected to be severe. The most significant risk from climate change occurs where there is a large population exposed to a climate-related hazard and where social vulnerability is greatest.

Public health intervention

Programs to prevent or reduce heat-related illnesses and deaths have been established in various localities. The effectiveness of these programs has been the subject of recent papers.

Effectiveness of public health interventions in reducing morbidity and mortality during heat episodes: A structured review. Bassil KL and Cole DC (2010). *International Journal of Environmental Research and Public Health*, 7(3): 991-1001.
http://dx.doi.org/10.3390/ijerph7030991 **GLOBAL**

Keywords: elderly, extreme events; heat stress; morbidity; public health; temperature, temperature related mortality

Background/Purpose: In response to concerns about the health effects of hot weather, public health interventions have been implemented. This review assesses interventions which attempt to reduce morbidity and/or mortality resulting from heat exposure.

Methods: The authors analyzed the literature on public health interventions implemented worldwide during heat waves. Fourteen papers spanning the years 1997-2009 were chosen. Studies took place in the U.S., Canada, U.K., France, Czech Republic and Portugal. Statistical methods used by the papers included cross-sectional surveys, regression analyses and an economic analysis.

Results: Most respondents in studies investigating public risk perceptions were aware when an extreme heat episode occurred. However, respondents did not always change their practices, primarily because they did not identify themselves as vulnerable and did not know appropriate intervention measures. Studies of health outcomes related to heat episodes indicated positive outcomes from public health intervention in reducing morbidity and mortality.

Conclusions: There is currently limited work on public intervention outcomes. The available data suggests that public interventions are positively affecting communities. Still, there is concern about whether the most vulnerable groups (e.g., the elderly and homeless) are adequately being cared for during heat episodes.

An evaluation of the progress in reducing heat-related human mortality in major U.S. cities. Kalkstein L, Greene S, Mills DM and Samenow J (2010). *Natural Hazards*, 56(1): 113-129. http://dx.doi.org/10.1007/s11069-010-9552-3 **UNITED STATES**

Keywords: extreme events, mortality; heat stress; public health; temperature, temperature related mortality

Background/Purpose: This study estimates excess mortality from extreme heat events (EHE) for forty major U.S. cities during two time periods: 1975–1995 and 1975–2004. A goal of this study was to determine the progress made in reducing mortality attributed to EHE since 1995, a year which spurred interest and implementation in notification of extreme heat events. Another goal was to evaluate the mortality data in EHE days in terms of climate trends and adaptation efforts.

Methods: The authors developed two time series using the meteorological and mortality data. The first series (1975-1995) represents the “control” period before the widespread increase in extreme heat event awareness. The second series (1975-2004) was compared to the earlier period to estimate the direction and nature of EHE-attributable excess mortality that has occurred since 1995.

Meteorological data were obtained for each city for the period 1948-2007 from the National Climatic Data Center. The daily count of all-cause deaths from June 1 through August 31 for the years 1975–2004 was obtained for each city from the National Center for Health Statistics. For each study day, differences in the observed daily mortality from the daily standardized summertime average for that year were calculated. EHE days were identified as those days classified with weather types whose mean daily-standardized mortality difference is statistically greater than 0.

Step-wise regressions were utilized to estimate city-specific mortality algorithms, which accounts for the impact of the duration, severity, and timing of extreme heat events. The authors employed the mortality algorithms to calculate excess mortality attributable to EHE. Excess mortality results were expressed both as lives lost and associated mortality rates (excess deaths per 100,000 residents) using 2000 Census population estimates.

Results: There was a reduction in mortality from EHE since 1996. Adjusting for changes in the average number of extreme heat event days per year in each period does not affect this result. However, this adjustment affects measurements of the cities' ability to reduce the mortality. The reductions are hypothesized to be partly attributable to improvements in adaptation and mitigation efforts.

Conclusions: This analysis revealed that most of the US cities studied have experienced reductions in EHE-related excess mortality between 1996 and 2004. The authors hypothesize that these reductions are due to improvements in EHE forecasting and recognition combined with an increased commitment of resources to EHE education, notification and response measures.

Other impacts

In addition to its direct impacts on human health, increasing temperatures can alter the fate, transport, and toxicity of environmental contaminants. These can, in turn, lead to adverse effects on human and ecosystem health.

The toxicology of climate change: Environmental contaminants in a warming world. Noyes PD, McElwee MK, Miller HD, Clark BW, Van Tiem LA, Walcott KC, et al. (2009). *Environment International*, 35(6): 971-986.
http://dx.doi.org/10.1016/j.envint.2009.02.006 **GLOBAL**

Keywords: air pollution, food webs, toxicology, pesticides, precipitation (rain), public health, salinity, snowmelt, storms, temperature

Background/Purpose: Scientists have studied and reported on predictions of pollutant behavior under different climate change scenarios. However, less work has been undertaken to evaluate the toxicological consequences of altered pollutant distribution

patterns. This review article examines how climate change can impact the environmental distribution and toxicity of chemical pollutants and how this might impact future human and ecosystem health.

Methods: The authors studied original research articles, reviews, and government and intergovernmental reports. The review focused on interactions of chemical pollutants with environmental parameters, temperature, precipitation, and salinity, as altered by climate change. Three broad classes of chemicals were targeted: air pollutants (ozone and particulate matter, or PM); persistent organic pollutants (POPs) such as organochlorine pesticides; and other classes of pesticides.

Results: The following highlights a few of the many chemical and biological processes potentially impacted by future climate change: Increased temperature can raise the toxicity of contaminants and elevate ozone concentrations in the atmosphere. Warming can also increase chemical degradation. Changes in climate coupled with air pollutant exposures, especially in areas that are urbanized, polluted and subject to reduced precipitation, may impair public health. Increased POPs may occur as a result of climate-related alterations on food webs, ice and snowmelt, and organic carbon cycling. Warming may also harm pollutant-exposed wildlife. For example, increased water temperatures can transform chemical pollutants into more toxic compounds. Such effects would be most deleterious for species living at the edge of their tolerance range with little potential for acclimation. Precipitation decreases can enhance volatilization of certain pesticides and may worsen air pollution in urban areas. Increased precipitation, on the other hand, can enhance surface deposition of POPs and run-off of pesticides. Increased intensity and frequency of storms can cause more chemical contamination in surface waters and surrounding watersheds. Salinity changes can affect aquatic species and alter the chemical properties of toxic compounds.

Conclusion: There is a growing body of evidence that climate change will have broad negative effects on the toxicity and distribution of environmental contaminants. The vulnerability of humans and wildlife to climate-sensitive chemical exposures, in the context of other stressors that are being altered with climate change, requires more rigorous investigation.

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 responses listed above. Papers grouped based on whether they discuss terrestrial or aquatic impacts (a few papers cover both).

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. Movement towards the poles or higher latitudes, or to higher elevations are most commonly observed.

Range shifts: Terrestrial

Birds track their Grinnellian niche through a century of climate change. Tingley MW, Monahan WB, Beissinger SR and Moritz C (2009). *Proceedings of the National Academy of Sciences*, 106(Supplement 2): 19637-19643.
http://dx.doi.org/10.1073/pnas.0901562106 **CALIFORNIA**

Keywords: birds; climatic niche; geographic range; elevational gradient; range shifts; occupancy dynamics; temperature

Background/Purpose: In the face of environmental change, birds can adapt by either evolving new physiological tolerances or by moving to areas which support their current physiological tolerances. The process by which species follow limiting environmental boundaries through geographical space to remain in a favorable climatic space is called *niche tracking*. The set of climatic conditions in which species can occur is also known as the Grinnellian niche. "Niche centroids" provide measures of the distributional center of favorable climatic conditions. The authors tested for evidence of niche tracking in 53 bird species in California's Sierra Nevada Mountains. The authors also tested whether environmental gradients tracked by a species can be predicted *a priori* based on climatological factors that have set historical distributions.

Methods: Avian site occupancy data came from historical surveys (1911–1929) and contemporary resurveys (2003–2008) of 82 sites along four elevational transects throughout the Sierra Nevada. Species observations originated from the Grinnell Resurvey Project. Historical specimen data were obtained from museum collections accessed through ORNIS (http://olla.berkeley.edu/orniset). Monthly mean minimum

temperature, mean temperature and total precipitation were obtained from the PRISM model. The average historical temperature and precipitation observed across an entire species' range, bound by occurrences of historical data (1860-1940), determined the centroid of its climatic niche. These climate variables were used to develop testable hypotheses of species' niche sensitivity to breeding season temperature versus precipitation. Multi-season occupancy models were generated to examine site-specific occupancy dynamics as a predictive driver for niche tracking throughout a range.

Results: Niche tracking was the major response to climate change in this study. Of the 53 species studied, 91% tracked either temperature or precipitation over time and 26% tracked both temperature and precipitation. Species tracked precipitation to wetter conditions. Warmer or cooler conditions were tracked depending on the species. Analysis of niche sensitivity significantly predicted the temperature and precipitation locations tracked by species. Climate sensitivities were significantly associated with observed niche tracking for both temperature and precipitation. Both the niche sensitivity predictions and tracked environmental factors were significantly related to the average elevation occupied by a species.

Conclusions: The climatic niche can be a strong driver of responses to climate change for avian species. The highly individualistic responses of species to past and present climate change may be explained by differing species-specific sensitivities to climate parameters and the direction of climate change relative to the climatic niche. Occupancy models which consider climate niches may help forecast where and how to conserve species in response to climate change.

The role of climate, habitat, and species co-occurrence as drivers of change in small mammal distributions over the past century. Rubidge EM, Monahan WB, Parra JL, Cameron SE and Brashares JS (2010). *Global Change Biology*, 17(2): 696-708. http://dx.doi.org/10.1111/j.1365-2486.2010.02297.x **CALIFORNIA**

Keywords: chipmunks, range shifts, small mammals, species loss, vegetation

Background/Purpose: Correlative models based on observed species-environment relationships are often used to predict the effect of climate change on species' distributions. Critics argue that the models are difficult to validate across time, so their predictive accuracy is untested. Another criticism is that the models exclude important biological factors such as species interactions. The authors addressed some of these criticisms by evaluating data from a study by Moritz et al. (2008) that suggests warming is the main driver of small mammal distribution shifts observed in Yosemite National Park.

Methods: This study further investigated environmental drivers of the observed range shifts in the Moritz study by using different models. The models incorporate possible drivers of the distributional shifts to predict current distributions, one of which is climate. Historical (1900–1940) climate, vegetation, and species occurrence data were used to

develop distribution models. Projections from these models were made on the current (1980-2007) environment. These projections were tested against modern field resurveys of each species.

Results: Climate was the dominant predictor explaining the species distribution. However, climate was not consistently an adequate predictor of the distributional change observed in all three species. For two species, climate alone or climate and vegetation models were good at predicting the distributional shifts. For the third species, the stability of distribution was not predicted by the modeling.

Conclusions: The authors demonstrate that correlative distribution models may be used to understand species' potential responses to changes in the environment. Here it appears that some chipmunk species in Yosemite have responded to climate change through distributional shifts. However, in some situations the predictive performance of models may be limited.

Climate-induced range contraction drives genetic erosion in an alpine mammal. Rubidge EM, Patton JL, Lim M, Burton AC, Brashares JS and Moritz C (2012). *Nature Climate Change*, 2(4): 285-288. http://dx.doi.org/10.1038/nclimate1415 **CALIFORNIA**

Keywords: biodiversity , ecosystem impacts, genetic erosion, alpine chipmunk, range shifts, small mammals, species loss

Background/Purpose: Biologists have ample evidence that climate change is impacting the distribution of species and thus threatens biodiversity. Evidence suggests that climate change can reduce genetic diversity over time. However, few studies have directly tested for genetic consequences of climate-induced range contraction, despite the importance of such diversity to population persistence. In this study, the authors compared changes in genetic diversity over the same period in two chipmunk populations in Yosemite National Park (YNP)—one that has responded to climate warming by contracting its elevational range, and another that has maintained a stable elevational range.

Methods: The authors compared modern and historical specimen data for the alpine chipmunk (*Tamias alpinus*) and the lodgepole chipmunk (*T. speciosus*) and quantified population genetics. The alpine chipmunk has retracted its elevational range upwards over the past century; the lodgepole chipmunk has remained stable. Museum skins used in this study were collected by Joseph Grinnell and colleagues from 1915 to 1916 and housed in the mammal collection at the University of California, Berkeley. For the modern data set, resurvey teams trapped animals at original sites between 2003 and 2008. DNA was extracted and sequenced in the historical and modern specimens and genetic diversity was compared by statistical analysis.

Results: Genetic diversity declined in the alpine chipmunk population. The range contraction observed in this species has resulted in increased genetic subdivision over

the past century. The authors did not detect significant genetic changes over the same time period in the lodgepole chipmunk.

Conclusions: These results strongly support the hypothesis that a climate-driven range contraction has decreased genetic diversity and increased local isolation for alpine chipmunk populations in YNP. As the climate continues to warm, this species is likely to further retract its elevational range, experience further genetic erosion and population fragmentation, and thus become more vulnerable to extinction.

Identifying Vulnerable Species and Adaptation Strategies in the Southern Sierra of California Using Historical Resurveys. Santos, MJ, Moritz M, and Thorne JH (University of California, Berkeley, and University of California, Davis) (2012) California Energy Commission Publication number CEC-500-2012-025.
http://www.energy.ca.gov/2012publications/CEC-500-2012-025/CEC-500-2012-025.pdf

CALIFORNIA

Keywords: adaptation, range shifts, small mammals, vegetation

Summary: Some species change their geographic range over time as a response to changing conditions that characterize their ecological niche. Small mammal species in the Sierra Nevada have both expanded and contracted their elevational ranges. This study explores whether shifts are linked to changes in habitat distribution and how the shifts affect predictions of future small mammal distribution. A series of analyses was developed with the goal of assessing the direct and indirect effects of climate, via vegetation change, on small mammal distribution dynamics. The study quantified vegetation and climate changes in a study area over the last 80 years. Data sets used were VTM (Vegetation Type Mapping), CalVeg (US Forest Service remotely sensed vegetation map), PRISM (downscaled climate data produced in the *Climate Vulnerability and Adaptation Study for California*) and GRP (Grinnell Resurvey Project small mammal data). Habitat Suitability Index values from California Department of Fish and Game were used to assess whether species were present in their most suitable habitat.

Species that expanded their elevational distribution range followed suitable habitats, and their niche broadened over time. However, species whose elevation range has contracted did not track suitable habitats, and their niche remained constant. Climate and vegetation models suggested that species respond faster to climate change than to vegetation change.

The direction and magnitude of species *sensitivity* to climate and vegetation changes affect the variation of species distribution. Sensitivity is defined as “the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.” Understanding life history traits, habitat preferences and temporal dynamics can help identify which species may positively and negatively respond, or not respond, to climate and vegetation changes.

Anthropogenic refugia ameliorate the severe climate-related decline of a montane mammal along its trailing edge. Morelli TL, Smith AB, Kastely CR, Mastroserio I, Moritz C and Beissinger SR (2012). *Proceedings of the Royal Society B: Biological Sciences*, online publication. http://dx.doi.org/10.1098/rspb.2012.1301 **CALIFORNIA**

Keywords: adaptation, extreme events, flood, ground squirrels, species loss, precipitation/rain, range shifts, small mammals

Background/Purpose: Populations can respond to climate change through migration, adaptation, or local extinction. Mountainous areas can harbor species that find it difficult to successfully migrate or adapt to climate change. Such animals have strict habitat and dietary needs and are sensitive to warming, snow loss, flooding and severe weather. Climate change may especially threaten populations at their equatorial or lower margins—their lower adaptive capacity and reduced fitness may make trailing edge populations more likely to go extinct. The authors studied the dispersion of a California ground-dwelling mammal found in mid- to high elevations in California's Sierra Nevada and Cascade mountains. They predicted that climate change will have led to extirpations (local extinctions) at sites experiencing greater increases in temperature and/or changes in precipitation. They also examined whether human-mediated increases in food and water availability (referred to as "anthropogenic refugia") supported population abundance.

Methods: The Museum of Vertebrate Zoology (University of California at Berkeley) provided historical records of the Belding's ground squirrel (*Urocitellus beldingi*) from 1902 to 1966. This time period was considered to predate many of the influences of climate change in California. The investigators surveyed 74 sites where the squirrels were historically observed and/or trapped. Resurveys in or near the Sierra Nevada and southern Cascades were done in July and August of 2010 and 2011. Surveys in northern California where the squirrels enter and awake from hibernation were conducted in May. Detection from resurveys at the 74 sites was analyzed by occupancy modeling (using the program PRESENCE). Climate data were obtained from a meteorological modeling program (Parameter-elevation Regressions on Independent Slopes Model or PRISM) that bases its predictions on observed weather measurements. Species distribution was determined through modeling.

Results: The resurvey found squirrels present at only 43 of the 74 historical sites. No squirrels were present in 47 historically unoccupied sites, suggesting no colonization. Interestingly, these results correlate with previously observed range shifts of Belding's ground squirrels in Yosemite National Park. The probability of site evacuation was related to hot and cold weather extremes, and wet precipitation extremes. Human modification through food or water supplementation strengthened the squirrel population. Squirrel persistence at warmer lower elevations was enhanced when sites were correlated with human modification. Excluding human modified sites, the squirrel habitat range shrunk by 255 meters. Modeling projections indicate that climate change

will continue to reduce the squirrel population, leading to a loss of 72% to 99% of the population.

Conclusion: There has been a dramatic loss of the Belding's ground squirrels without evidence of colonization. Such a disappearance in less than a century is significant and may have profound consequences. Other species affected by ground squirrel population changes include raptors and carnivores, which partly rely on squirrels for food. This study shows how not all California species are successfully adapting to the current climate change and how mountain species loss is already evident.

The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Tingley MW, Koo MS, Moritz C, Rush AC and Beissinger SR (2012). *Global Change Biology*, 18(11): 3279-3290. http://dx.doi.org/10.1111/j.1365-2486.2012.02784.x **CALIFORNIA**

Keywords: elevational range shift, birds, Sierra Nevada, California, occupancy models, precipitation, species distribution, temperature

Background/Purpose: Studies show strong evidence for 20th century temperature-driven range shifts in distributions for birds and other montane species in western North America. However, there is substantial heterogeneity in species' responses (e.g., upslope versus downslope shift versus no shift), demonstrating the complexities underlying how birds will respond to future climate change. This study quantifies the impacts of temperature and precipitation changes over the last century on the elevational ranges of bird species breed in the Sierra Nevada Mountains.

Methods: Bird observations were collected along three broad elevational transects (Lassen, Yosemite, and Southern Sierra) as part of the Grinnell Resurvey Project. Systematic surveys were originally done in 1924-1928 for Lassen, 1915-1919 for Yosemite, and 1911 for Southern Sierra, by Joseph Grinnell et al. Resurveys for Lassen occurred in 2006-2007, for Yosemite in 2003-2008, and for Southern Sierra in 2008-2009. Trends in average annual temperature and precipitation for the survey locations were determined from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). Generalized linear mixed models (GLMM) were used to analyze environmental factors related to range change and how well individual species' traits explained whether or not the species moved. Environmental factors studied include range limit (upper or lower), survey region (Lassen, Yosemite, or Southern Sierra), temperature, precipitation, and regional population trend for species in the second half of the 20th century. The studied traits of individual species include migratory status, mean mass of breeding adult, territory type, mean home range size of breeding individuals, mean clutch size of females, and diet breadth.

Results: Over the past century, rising temperature pushed species upslope while increased precipitation pulled them downslope, resulting in heterogeneous range shifts within species and among regions. While 84% of species shifted their elevational

distribution, only 51% of upper or lower range boundary shifts were upslope. By comparison, 82% of range shifts were in a direction predicted by changes in either temperature or precipitation. Species were significantly more likely to shift elevational ranges if they had small clutch sizes, defended all-purpose territories, and were year-round residents.

Conclusions: This study strengthens the evidence for elevational shifts in breeding distributions of birds in the western US. It illustrates the complex interplay between species-specific and region-specific factors that influence patterns of breeding range change over time. The study found heterogeneous responses resulting from the combined effects of temperature (pushing species upslope) and precipitation (pulling them downslope); variation among species in their relative sensitivity to temperature and precipitation; spatial variation in recent climate change; and differing propensities to shift depending on species traits. Future projections of increasing temperature and highly variable precipitation create a strong potential for heterogeneous responses by species at range margins.

Systemic range shift lags among a pollinator species assemblage following rapid climate change. Bedford FE, Whittaker RJ and Kerr JT (2012). *Botany*, 90(7): 587-597. http://dx.doi.org/10.1139/b2012-052 **CANADA**

Keywords: butterflies, migration, range shifts, warming, pollination/pollinators, seasonality, temperature

Background/Purpose: Climate change is driving geographical range shifts among many species. Insects are particularly sensitive to changes in climate, yet are not well represented in the climate change literature. Few studies describe observed distributional changes relative to historically documented niche position for an entire pollinator taxon or over broad regions, or describe spatially coherent patterns for such changes. The authors investigated climate-related range shifts among well-sampled butterfly populations in Canada, specifically addressing two questions: (1) do observations of butterfly species indicate northern distributional shifts over the past several decades of substantial climate change; and (2) how well are species tracking their climatic niches?

Methods: Data on butterfly species locations were obtained from the Canadian National Collection of Butterflies. The authors analyzed observations of 81 species and measured their range shifts in two periods: 1960-1975 (which precedes most major recent climate changes) and 1990-2005 (period of accelerated global climate change). Measurements of species dispersal were obtained on the basis of national surveys of expert opinion; mobility scores ranged from 0 (sedentary) to 10 (extremely mobile). Wingspan values (from a published study) were also included as another index of mobility. The datasets from the two study periods were compared using graphical interpretation and statistical techniques.

Climate data were derived from weather station observations across Canada. Four climatic variables known to correlate with butterfly distributions were used: minimum annual temperature; maximum annual temperature; annual precipitation totals; and precipitation seasonality. Statistical analyses were carried out to determine whether climatic conditions have changed between the two time periods.

Results: The authors found a weak latitudinal trend toward increased warming of minimum annual temperatures at species' historical range margins; no trends were found with regard to the other climate variables. There was a strong latitudinal gradient in how successfully the margins of each butterfly species range track increasing minimum annual temperatures between time periods. Butterfly range shifts lag far behind expectations across northern Canada, where climate change has occurred at a faster rate than in southern regions. The overall trend is for range margins of species in northern Canada to shift far less than necessary to track rapidly rising minimum annual temperatures. By contrast, species in southern Canada, where temperatures have risen more slowly, have tracked warming temperatures readily despite widespread, intensive land uses.

Mobility scores and wingspan were not found to be related to changes over time in latitudinal position at the species' range margins.

Conclusion: The authors had expected the leading edge of the butterfly species ranges to expand to track shifting climatic conditions, particularly in the northern areas which have been relatively free of human-created dispersal barriers. Instead, they found lags in geographic range shifts, indicating that these species have not tracked climatic conditions closely. Even for the most mobile species, and without human activity preventing dispersal, these pollinators are not migrating as much as would be expected to adapt to climate change. The inability of species to shift geographically with sufficient speed in response to climate change has been predicted as a factor increasing a species' extinction risk. This study's findings may have implications for long-term conservation, particularly given the potential impacts on the ecosystem services provided by butterflies (e.g., pollination).

Range shifts: Aquatic

Impacts associated with the recent range shift of the aeolid nudibranch *Phidiana hiltoni* (Mollusca, Opisthobranchia) in California. Goddard JR, Gosliner T and Pearse J (2011). *Marine Biology*, 158(5): 1095-1109. http://dx.doi.org/10.1007/s00227-011-1633-7 **CALIFORNIA**

Keywords: California Current/ California Current Ecosystem; coastal impacts; nudibranch; range shift; Pacific Decadal Oscillation (PDO); ecological impact; marine impacts; sea surface temperature

Background/Purpose: Northward range shifts driven by global climate change have been observed in many marine species. Ecological impacts, however, have been documented in only a few of these shifts. The sea slug *Phidiana hiltoni* is reported to have begun spreading northward in 1977 from Monterey Bay (coinciding with the shift in the Pacific Decadal Oscillation (PDO) from a cool to warm phase). By 1992, it had reached Duxbury Reef, 110 kilometers to the north. This paper examines the climate-related range expansion of this nudibranch along the California coast and examines the species' potential role in the decline of vulnerable nudibranch prey species observed at the northern edge of its new range.

Methods: The range expansion of *P. hiltoni* is based on historical surveys and personal observations from the 1950s to present day. Its diet was examined using fecal samples and laboratory feeding trials. The abundance of other nudibranches at the reef was evaluated before and after the arrival of *P. hiltoni.*

Results: In the wild, *P. hiltoni* preyed largely on hydroids and appeared to prey on nudibranches. In the laboratory, *P. hiltoni* attacked most of the dendronotid and aeolid nudibranchs presented to it. Since the arrival of *P. hiltoni* at Duxbury Reef, the number of nudibranchs vulnerable to attack by *P. hiltoni* declined an average of two-thirds. There was no change in the non-vulnerable species and no change in either group at two other sites where *P. hiltoni* was significantly less abundant.

Conclusions: The northward expansion of *P. hiltoni* appears to have caused the decline in prey species at Duxbury Reef, likely through a combination of direct predation and competition for prey. Further research may show that the observed range shift of *P. hiltoni* may constitute one of the first documented effects of global warming on the nudibranches of the region. A brief larval period and cyclonic re-circulation in the lee of Point Reyes may drive self-recruitment of *P. hiltoni* at Duxbury Reef and hinder further northward spread.

Range shifts: Aquatic and terrestrial

Rapid range shifts of species associated with high levels of climate warming. Chen I-C, Hill JK, Ohlemüller R, Roy DB and Thomas CD (2011). *Science*, 333: 1024 – 1026. http://dx.doi.org/10.1126/science.1206432 **GLOBAL**

Keywords: biodiversity, birds, fish, migration, range shifts

Background/Purpose: Climate change may threaten biodiversity around the world. Many species from different geographies are migrating to higher latitudes and elevations. This study investigated the link between the world-wide phenomenon of range shifts and warming.

Methods: The authors conducted a meta-analysis of available studies of range shifts for a wide range of species around the world. Plants, mammals, birds, insects, and fish

were all included in the analysis. Both latitudinal (North America, Europe and Chile) and elevational (Europe, North America, Malaysia, and Marion Island) range shifts were investigated: 764 species (23 taxonomic groups) were studied for latitudinal shifts and 1367 species (31 taxonomic groups) were studied for elevational shifts.

Results: Latitudinal shifts are occurring at a median rate of about 11 miles/decade and elevational shifts are occurring at a median rate of about 12 yards/decade. Rates are substantially greater than reported in a previous meta-analysis. Shifts were greatest in areas with the most warming. Places with the greatest latitudinal shifts and warming were the United Kingdom, Finland, and Portugal. Places with the greatest elevational shifts and warming were Yosemite National Park (California), Green Mountains (Vermont), and Western Europe (including additional studies in Spain and Switzerland). Individual species within taxonomic groups vary greatly in their range shifts.

Conclusions: Rates of latitudinal and elevational shifts appear to increase with the level of warming. Average rates of latitudinal distribution change match those expected on the basis of average temperature change. However, there is significant variation within taxonomic groups. Species traits and environmental factors like habitat loss may affect range shifts for each species. More detailed physiological, ecological, and environmental data are needed to provide specific prognoses for individual species.

The pace of shifting climate in marine and terrestrial ecosystems. Burrows MT, Schoeman DS, Buckley LB, Moore P, Poloczanska ES, Brander KM, et al. (2011). *Science*, 334: 652-655. http://dx.doi.org/10.1126/science.1210288 **GLOBAL**

Keywords: seasonal shift, warming, biodiversity, ocean, land; coastal impacts; ecosystem impacts; marine impacts; migration; precipitation/rain; range shifts; seasonal shift; temperature

Background/Purpose: The shifting of biogeographic ranges and altered phenology are means by which species cope with a warming climate. Considerable variation in species responses to warming temperatures has been reported across the globe. This is not surprising since patterns of climate change are dynamic and highly heterogeneous. Organisms are expected to track changes in temperature over space and time (or seasons) to maintain their thermal niches. This paper presents two measures that describe changes in the thermal environment across the land and ocean and how they may be useful predictors of ecosystem health and biodiversity.

Methods: The investigators calculated two metrics: the *velocity of climate change* and the *shifts in seasonal timing of temperature*. The velocity of climate change represents the speed and direction of movement of temperature (geographic shifts of isotherms over time). Global surface temperatures from 1960-2009 were used to calculate the two measures. The velocity of climate change (in km/year) was calculated as the ratio of the long-term temperature trend (in ^{o}C/year) to the two-dimensional spatial gradient in

temperature (in ^{o}C/km, over a 3^{o}-by-3^{o} grid), oriented along the spatial gradient. The seasonal climate shift (days/decade) was calculated as the ratio of the long-term temperature trend (^{o}C/year) to the seasonal rate of change in temperature (^{o}C/day). Seasonal shifts for spring and fall are presented globally using April and October temperatures.

Results: Globally, the median velocity of isotherms (which combines spatial gradients with rates of long-term temperature change) across the ocean is 79 percent of that on land (21.7 km/decade compared to 27.3 km/decade). At latitudes where both land and ocean are present, velocities in the ocean are similar to those on land (27.5 km/decade and 27.4 km/decade, respectively). The much flatter thermal landscape in the ocean tends to increase velocities and therefore offsets the effect of greater warming on land to bring the velocities for the two environments closer together. In areas with the least land mass (the sub-Arctic and within 15^{o} of the equator), the velocity of climate change is two to seven times faster in the ocean than on land. Areas of high climate change velocity extend across broader areas in the ocean than on land—where the velocity tends to be very patchy. This may partially explain the 1.5 to 5 times faster average range shifts reported in the ocean than on land (based on a few taxa mainly in temperate regions).

Although warming is faster on land, change in seasonal timing is generally greater in the ocean because of smaller seasonal thermal variation. Seasonal timing of spring temperatures shifted 30-40% faster in the ocean than on land: spring ocean temperatures arrived earlier by 2.08 days/decade in the Northern Hemisphere and 2.52 days/decade in the Southern Hemisphere, compared to an earlier arrival by 1.46 and 2.15 days/decade, respectively, on land.

Considerable geographical heterogeneity exists in rates of velocity of climate change and magnitude of seasonal shift, and their consequences depend on biophysical attributes of regions. Hence, biological responses will vary, as sub-regional and habitat-specific patterns in temperature may run counter to the simple expectation of poleward range shift and shifts toward earlier spring and later fall.

Conclusions: The global distribution of the velocity and seasonal shift of climate change over the past 50 years can help generate predictions that can be compared with observed biological changes. Geographical variation in the velocity of climate change may explain much of the reported variation among range shifts of individual species. Maps of the velocity of climate change and seasonal shift show the areas where the threat to biodiversity from organisms' need to rapidly track thermal conditions by shifting distributions and retiming seasonal thermal events may be greatest.

Body size changes

Morphology can provide insight into the ability of species to respond to a changing environment. Changes in body size, a key physiological trait, in response to a warmer or increasingly variable climate have been reported. These changes may reflect both

direct (e.g., temperature or precipitation outside the range of a species' physiological limits) and indirect (e.g., increased food availability) effects of climate change.

Body size changes: Terrestrial

Size increase in high elevation ground squirrels over the last century. Eastman LM, Morelli TL, Rowe KC, Conroy CJ and Moritz C (2012). *Global Change Biology*, 18(5): 1499-1508. http://dx.doi.org/10.1111/j.1365-2486.2012.02644.x

CALIFORNIA

Keywords: body size, *Callospermophilus lateralis,* , ground squirrels, *Otospermophilus beecheyi,* Sierra Nevada, *Urocitellus beldingi*, small mammals

Background/Purpose: Studies show that nutrition and food availability strongly affect body size in rodents. Evidence suggests that recent warming could lead to a positive trend in body size due to increased food availability resulting from earlier "green-up" and a longer growing season. However, the expected direction is selection for decreased body size under chronic warming. This study examines how two high elevation contracting squirrel species in the Sierra Nevada and one lower elevation, stable species have responded morphologically to climate change over the last century.

Methods: Museum specimens of the two high elevation squirrels, Belding's ground squirrel (*Urocitellus beldingi*) and the golden-mantled ground squirrel (*Callospermophilus lateralis*), and one lower elevation species, the California ground squirrel (*Otospermophilus beecheyi*), were measured. Skull length, a trait correlated with body size, and maxillary toothrow length (MTRL), a predictor of skull shape, were measured. Specimens for each species were available from two time periods (1902-1950 and 2000-2008). Statistical analyses were conducted to test for differences in skull length and MTRL between the historical and modern species.

Results: An increase in skull length in the high elevation species was found. These obligate hibernators did not change in shape. Both species have contracted their lower elevation ranges, and the increase in skull length may be a reflection of the environmental changes (warming, earlier snowmelt, more precipitation as rain instead of snow) that have led to longer feeding seasons and potentially more available resources. The low elevation species showed no significant change in either body size or shape over the last century. This species, which has shown no significant range shift, appears to not be responding to environmental changes. No significant changes in MTRL were found in any of the species.

Food availability has been identified as the most influential environmental factor contributing to body size (for which skull length is a proxy). A change in MTRL would reflect a genetic adaptation to changes in the quality of a species' diet.

Conclusions: This study's findings support previous research showing that resource quality and availability drive body size changes in mammals. The authors hypothesize that the increased body size is due to a direct effect on the physiological limits of the species, rather than nutritional constraints. The authors note that the changes in skull length may represent short-term responses that may not be sufficient for maintaining viability in the face of long-term climate change. A genetic response is needed for the long-term persistence of a population experiencing environmental shifts.

Avian body size changes and climate change: warming or increasing variability?
Goodman RE, Lebuhn G, Seavy NE, Gardali T and Bluso-Demers JD (2012). *Global Change Biology*, 18(1): 63-73**.** http://dx.doi.org/10.1111/j.1365-2486.2011.02538.x

CALIFORNIA

Keywords: birds, Bergmann's Rule, body mass, climatic variability, ecogeographic rules, ecotypic variation, energy reserves, migration, morphology, wing length, temperature

Background/Purpose: Birds and other wildlife are responding in a variety of ways to climate change, including changes in body size. Bergmann's rule is a long established ecogeographical pattern which states that body size is positively associated with latitude and can be used to predict how avian body size will change in response to climate warming. However, predictions about how body size will change are dependent on one of several mechanistic explanations behind the rule. For example, severe weather events can exert significant selection pressure on bird body size, favoring heavier body mass. Global climate shifts may be affecting body size through changes in food availability. This study investigates change in avian body size in California to provide insight into the possible mechanisms underlying Bergmann's rule. The authors also examined whether birds may be increasing in size as a possible response to climate variability or food availability changes.

Methods: Two data sets (Point Reyes Bird Observatory Conservation Science's Palomarin Field Station and San Francisco Bay Bird Observatory's Coyote Creek Field Station) were selected to examine morphological changes in ecologically diverse bird species. The dataset from the Palomarin Field Station was from 1971 through 2010 and the Coyote Creek Field Station was from 1983 through 2009. Birds captured and handled were followed with standardized protocols. Each bird was identified based on species, age, and sex, and numbered with a federal metal band. The unflattened wing length was measured to the nearest millimeter. Breeding range (local or northern) and migration distance (long distance or short distance) were classified for each species. Linear mixed-models were used to estimate temporal trends in body size and wing length. Statistical analyses were performed separately for the Palomarin and Coyote Creek datasets.

Results: Except for a few seasonal data points, wing length increased significantly across all species in both datasets at a rate of 0.024-0.084% per year. Significant body

mass increases were generally observed in spring and summer at both stations. Overall it was concluded that changes in body mass were more variable than changes in wing length.

Conclusion: This study showed evidence for increasing body size across a wide range of bird species in central California. Wing length has increased in a wide variety of species over the last few decades. Body mass changes were also observed, although they were less significant. These results contrast from those found in earlier studies in Israel, England and Pennsylvania (study periods ranging between 1950 and 2003) that reported decreased avian body size and used Bergmann's rule to support these shifts. However, in addition to warming temperatures, the consequences of climate change include changes in precipitation, extreme weather events and climate variability. Such changes can affect primary productivity and food availability and may potentially explain why this study found increasing body sizes. The authors note that the climate patterns and plant ecosystems in central California may show stronger increases in productivity in response to climate change, explaining why bird body sizes are increasing.

Body size changes: Aquatic

Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems. Cheung WWL, Sarmiento JL, Dunne J, Frolicher TL, Lam VWY, Deng Palomares ML, et al. (2012). *Nature Climate Change*, online publication. http://dx.doi.org/10.1038/nclimate1691 **GLOBAL**

Keywords: ecosystem impacts, fish, marine species, physiology, ecosystem

Background/Purpose: Changes in temperature, oxygen content and other ocean properties affect marine organisms, especially ectotherms (cold-blooded animals such as fish). Studies report the most common responses are changes in species distribution, phenology and productivity. Scientists hypothesize that warming and reduced oxygen may also reduce body size of marine fish. The authors model the integrated climate-related biological responses of marine fishes due to changes in distribution, abundance and body size.

Methods: The modeling examined biological responses of over 600 species of marine fish. The analysis considered the relationship between the organism and its environment, as well as species dispersal, distribution, and population dynamics. Two earth system models (NOAA's GFDL ESM2.1 and IPSL-CM4-LOOP) were used to predict (using the SRES A2 (high) greenhouse gas emissions scenario) physical and chemical ocean conditions (sea bottom temperature and dissolved oxygen) that influence fish body weight. The changes in average maximum body weight for individual fish in a population and for fish assemblage from the year 2000 to 2050 were calculated.

Results: Assemblage-averaged maximum body weight may shrink by 14–24 percent globally from 2000 to 2050 in a warmer and less oxygenated ocean projected under a high greenhouse gas emissions scenario. Changes in distribution and abundance—that is, distribution shifts along with the increased abundance of smaller bodied species and decreased abundance of larger-bodied species—accounted for about half of the projected shrinkage. The remainder was due to changes in physiology. Tropical and intermediate latitudinal areas are expected to be heavily impacted, with average body weight reductions of more than 20% by 2050. Out of the 20% assemblage-level shrinkages, about 10% is explained by increased oxygen demand and reduced oxygen supply. The model projects a poleward shift of fish communities, which will also contribute to the shrinkage of body weight.

Conclusions: This study demonstrates that ocean warming will impact the metabolic rates of ocean fishes. The physiological response to oxygen-limited water is expected to cause a reduction in individual- and assemblage-level body size. Other human impacts, such as overfishing and pollution, are likely to contribute to this problem. The predicted changes in fish may have large implications for ecosystem functions, trophic interactions, and fisheries.

Migration time

Biological processes are generally regulated by 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 the timing of life cycle events (also known as phenology) such as bird migration, butterfly emergence, 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.

Migration time: Terrestrial

Climate-associated phenological advances in bee pollinators and bee-pollinated plants. Bartomeus I, Ascher JS, Wagner D, Danforth BN, Colla S, Kornbluth S, et al. (2011). *Proceedings of the National Academy of Sciences*, 108(51). http://dx.doi.org/10.1073/pnas.1115559108 **UNITED STATES**

Keywords: bees, pollination, flowering, warming

Background/Purpose: Temperature can disrupt the timing of periodic animal and plant life cycle events. Mutualistic interactions such as pollination may be especially vulnerable because of the potential for life cycle mismatching if the species involved do not respond similarly to changes in temperature. This paper investigated climate-

related shifts in the timing of wild bee pollinators and compared these shifts to studies of bee-pollinated plants over the same time period.

Methods: Ten wild bee species widely distributed across northeastern North America were studied. The species chosen emerge early in spring and are thus considered good indicators of response to climate change. The investigators used data from the contemporary period (2000–2010) in conjunction with data from museum specimens dating back to the 1880s to examine a 130-year period. Monthly minimum and maximum temperature and precipitation corresponding to the year and location where the specimen was collected were gathered. They used the published literature on native bee-pollinated plants from northeastern North America to compare with rates of phenological advance between plants and bee pollinators.

Results: Over the past 130 years, the emergent timing of 10 bee species in northeastern North America has advanced on average of about 10 days. Most of this change occurred after 1970, paralleling observed climate warming trends. Changes in the timing of when bees are ready to pollinate happen at the same rate as time changes in plant flowering.

Conclusions: For the types of bees studied, bee emergence is keeping pace with shifts in host-plant flowering in northeastern North America. However, as rates of temperature warming increase, phenological mismatch could occur in the future.

Spatiotemporal Variation in Avian Migration Phenology: Citizen Science Reveals Effects of Climate Change. Hurlbert AH and Liang Z (2012). *PLoS ONE*, 7(2): e31662. http://dx.doi.org/10.1371%2Fjournal.pone.0031662 **NORTH AMERICA**

Keywords: birds, climatic niche, migration, warming, temperature

Background/Purpose: Throughout the US, strong warming trends in spring have led to earlier starts to the growing season and earlier onset of arrival, breeding and other life history events of migratory birds. Understanding the strength and magnitude of such responses varies across species. The ecological context of such responses will be important for identifying birds at most risk under future climate conditions. This study investigates the unexplained variation in the magnitude of the migratory changes across bird species and geographic regions.

Methods: Spring arrival dates for 18 common migratory birds in the US east of the Mississippi River and for two Canadian provinces for the years 2000-2010 were obtained from the online citizen science program *eBird* (http://www.birds.cornell.edu/citscitoolkit/projects/clo/eBird/). A real-time, online checklist program, *eBird* provides rich data sources for basic information on bird abundance and distribution at a variety of spatial and temporal scales. The database was used to explore variation in mean arrival dates across a geographic area. Data on climatic niche breadth, average abundance and population trend from 1966-2009

throughout eastern North America were evaluated from the Breeding Bird Survey (BBS). The BBS is a long-term, large-scale, international avian monitoring program initiated in 1966 to track the status and trends of North American bird populations. Historical temperature data were obtained from the PRISM Climate Group (which uses measurements of climatic factors to produce continuous grid estimates of monthly, yearly, and event-based climatic parameters). Statistical analyses incorporating species-specific variables (e.g., migration distance, niche breadth, abundance) were used to correlate bird arrival dates with mean minimum spring temperature.

Results: Across all species and geographic locations, for every ^{o}C of spring temperature warming, birds shifted arrival dates 0.8 days earlier. In some areas, certain species shifted as much as 3–6 days earlier per °C. Species whose arrival dates advanced the earliest are those that migrate more slowly, migrate for short distances and have broader climate niches. Species shifted arrival earlier at southern latitudes compared to northern latitudes for the same degree of warming.

Conclusions: This study highlights the variability in phenological responses to climate change across species and across space. The single most important predictor of the strength of the phenological response to temperature was the speed with which a species migrated northward. The investigators speculated that species advancing more slowly may be better able to assess local conditions en route and adjust their arrival time with favorable conditions at the breeding ground. These findings have implications for environmental management, such as the identification and preservation of avian species which cannot adapt as well to climate change.

Migration time: Aquatic

Genetic change for earlier migration timing in a pink salmon population. Kovach RP, Gharrett AJ and Tallmon DA (2012). *Proceedings of the Royal Society B: Biological Sciences*, online publication. http://dx.doi.org/10.1098/rspb.2012.1158

UNITED STATES

Keywords: microevolution, genetic change, salmon, circadian rhythms, migration timing

Background/Purpose: Evolutionary mechanisms allow populations to adapt to environmental changes. Phenotypic changes, such as animal size, in populations affected by climate change have been documented. This study focused on rapid genetic changes of a pink salmon population in Alaska with an earlier migration time. The timing of seasonal life-history events is often associated with local water temperatures. It has been hypothesized that quick evolutionary changes in migration timing would allow pink salmon to adjust to climate change.

Methods: 32 years of genetic data (17 complete generations) were assessed for genetic changes towards earlier migration timing. Phenotypic data on migration timing

and data from a marker locus, with experimentally altered allele frequencies, were also analyzed to determine whether there is a genetic basis for earlier migration timing in the pink salmon population.

Results: Average migration time occurs nearly two weeks earlier than it did 40 years ago. There appears to have been a directional selection for earlier migration timing. Directional selection is a type of selection that removes individuals from one end of a phenotypic distribution. There was a significant decrease in the late-migrating phenotype. From 1983 to 2011, there was an over threefold decrease in the genetic marker for late-migration timing. Circadian rhythm genes, which control the waking and sleeping cycle, did not show selective changes from 1993 to 2009.

Conclusions: Results from this study indicate rapid genetic evolution for earlier migration timing in this population of pink salmon. Migration timing is likely a complex phenomenon influenced by many genes. Because circadian rhythm genes did not show any evidence for selection, it is possible that these genes do not directly affect migration timing. It is also possible that selection occurred at circadian rhythm genes prior to 1993, the earliest date of genetic samples used in this study. In addition, although directional selection may have allowed the fish population to adapt to environmental change, it came at the cost of genetic diversity. This study helps elucidate the process of relatively quick evolution in response to climate-related environmental changes.

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 Nino/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.

Population abundance/ecological interactions: Terrestrial

Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. Bentz BJ (2010). *Bioscience*, 60(8): 602. http://dx.doi.org/10.1525/bio.2010.60.8.6 **NORTH AMERICA**

Keywords: cold tolerance, drought, ecosystem impacts, fires, forests, mountain pine beetle, bark beetles, seasonality, spruce beetle, temperature

Background/Purpose: Native bark beetles, which evolved with the coniferous forest ecosystems of western North America, are key agents of change in these systems. Beetle outbreaks raise tree mortality rates and can result in replacement by other tree species. In recent decades, billions of coniferous trees have been killed by bark beetles in forests ranging from Mexico to Alaska and recent outbreaks are among the largest and most severe in recorded history. This article assesses the current knowledge regarding effects of climate change on bark beetles that cause extensive conifer mortality in the western US and Canada.

Methods: The authors discuss potential direct and indirect impacts of climate change on host trees (e.g., vigor, age), and bark beetle community ecology and population dynamics. They explored the potential effects of a changing climate on bark beetle dynamics using two case studies. Population models and climate forecasts were used to examine the responses of two bark beetle species: spruce beetle and mountain pine beetle.

Results: Based on projected warming, increases in temperatures conducive to beetle population success were predicted for the two species of beetles. Significant temporal and spatial variability in temperature suitability is predicted, emphasizing the complexity in both the thermal habitat and temperature-based physiological processes of the insects.

Conclusions: Bark beetle response to climate change can be characterized by a high degree of complexity and uncertainty, as populations are influenced directly by shifts in temperature and indirectly through climatic effects on community associates and host trees. There is a need for a better understanding and more refined models that integrate indirect effects of climate change on host trees with bark beetle population success, as well as interactions among beetle outbreaks and other forest disturbances (e.g., wildfire, drought).

A climate change vulnerability assessment of California's at-risk birds. Gardali T, Seavy NE, DiGaudio RT and Comrack LA (2012). *PLoS One*, 7(3): e29507. http://www.ncbi.nlm.nih.gov/pubmed/22396726 **CALIFORNIA**

Keywords: adaptation, birds, migration, vulnerability, sea level, scoring methodology, conservation, viticulture

Background/Purpose: Scientists are seeking to modify existing conservation tools by integrating traditional conservation concerns (such as existing stressors and projected land-use change) with concerns associated with climate change. To support statewide climate change adaptation efforts, this paper describes a framework for assessing climate change vulnerability of California's at-risk birds and integrating it into the *Bird Species of Special Concern* (BSSC) list maintained by the California Department of Fish and Game.

Methods: The original BSSC list contains 238 bird taxa and has the following criteria: population and range size, population and range trend, population concentration, percent of range or population in California, and threats (e.g., habitat loss, pollution, disease). To evaluate climate change vulnerability, the authors expanded the BSSC list to include bird taxa that meet at least one of the following additional criteria: 1) "high" climate change vulnerability scores as defined by the U.S. national assessment (in *The State of the Birds 2010 Report on Climate Change* published by the U.S. Department of the Interior, http://www.stateofthebirds.org/stateofthebirds2010); 2) projected to have a 50% or higher decrease in their California range between 2060 and 2099 under the highest emissions scenario modeled by Audubon California; 3) potentially vulnerable to climate change based on expert opinion; and 4) listed as state or federally threatened or endangered or recently delisted. The expanded BSSC list has 358 nominated taxa. To quantify climate vulnerability, *sensitivity* (physiological tolerances, migratory status and dispersal ability) and *exposure* (changes in habitat suitability, in food availability and in extreme weather) were considered. Sensitivity and exposure were independently scored and multiplied to generate a climate change vulnerability index for each bird taxa. Scoring was based on information from published papers and the Birds of North America species accounts.

Results: Using the combined sensitivity and exposure scores, the 358 taxa in the expanded BSSC list were ranked, with 128 classified as vulnerable to climate change. Birds associated with wetlands had the largest representation relative to other habitat groups. Of 29 bird taxa listed as federally and/or state threatened and endangered in California, 21 (72%) are considered vulnerable to climate change. Integrating climate vulnerability and California's BSSC list resulted in the addition of five taxa and an increase in priority rank for 10.

Conclusions: This is a first attempt to quantify climate vulnerability into an existing list of at-risk species. The disproportionate representation of vulnerable taxa associated with wetlands is likely related to sea level rise and extreme climatic events; further, freshwater wetlands are predicted to decrease throughout the state. Limitations to this approach include not taking into account adaptive capacity of birds and other measures of uncertainty.

Population abundance/ecological interactions: Aquatic: Freshwater

Harmful filamentous cyanobacteria favoured by reduced water turnover with lake warming. Posch T, Koster O, Salcher MM and Pernthaler J (2012). *Nature Climate Change*, 2: 809-813.
http://dx.doi.org/10.1038/nclimate1581 **GLOBAL**

Keywords: Lake Zurich, cyanobacteria, nitrogen, warming, nutrients, plankton

Background/Purpose: Rising air temperatures and the resultant heating of water bodies increase the susceptibility of lakes to harmful algal blooms. Warming leads to stronger thermal stratification due to the temperature-dependent density difference between the upper and deep water zones and can upset the oxygen balance. This study investigated the cumulative effects of warming temperature and nutrient alteration on Lake Zurich in Switzerland.

Methods: Nutrient and temperature parameters at Lake Zurich were determined for 40 years (1972-2011). Data were collected by the Zurich Water Supply. The following parameters were determined monthly for 19 depths: total phosphorus, nitrogen ratios, dissolved oxygen and temperature. Monthly microscopic evaluations of fixed samples were used to determine total phytoplankton and the cyanobacteria *P. rubescens*.

Results: Harmful cyanobacterium *Planktothrix rubescens* became the dominant species in Lake Zurich during the past four decades. Phosphorous (P) levels decreased fivefold; however, nitrogen (N) levels did not diminish simultaneously, increasing N:P ratios. The increased N:P ratios favored the non-N2-fixing cyanobacterium.

Conclusions: This study documents a toxic cyanobacteria that seems to proliferate when lake warming works in parallel with altered nutrient levels. The absence of water turnover and increased water temperatures favor the seasonal growth of P. rubescens. The changed N:P ratio appears to be needed in order for P. rubescens to establish itself in Lake Zurich.

Population abundance/ecological interactions: Aquatic: Marine

Impacts of climate change on fisheries. Brander K (2010). *Journal of Marine Systems*, 79: 389-402. http://dx.doi.org/10.1016/j.jmarsys.2008.12.015 **GLOBAL**

Keywords: adaptation, copepods, fisheries, La Niña/El Niño, marine impacts, North Atlantic Oscillation, ocean conditions, temperature, wind

Background/Purpose: There is increasing concern over the impacts of climate change on fisheries production in addition to other pressures that fish populations already experience (e.g., habitat loss, pollution, introduced species). Climate change has direct and indirect impacts on fish stocks. Direct effects influence physiology and behavior

and alter growth, reproduction and distribution. Indirect effects act on the productivity, structure and composition of the marine ecosystem, which impacts prey availability. This paper assembled and analyzed evidence of effects of climate change on fisheries to show that climate affects the distribution, productivity and resilience of fish stocks. It presents an overview of climate effects in terms of scale, processes, methodology and geography. Although this summary focuses on current impacts, predictions of future impacts are also discussed.

Methods: The author reviewed over 100 peer-reviewed publications with a focus on the effects of climate on primary production. Selected publications were chosen to illustrate regional examples of how climate can influence fisheries.

Results: Some of the observations include:

- Although global aggregated marine primary production is not expected to change substantially over the next four or five decades, there is a strong basis for predicting changes at the regional level.
- Natural climate variability events, like El Niño, have been linked to primary production and location of suitable habitat for certain species like tuna.
- The reduction in winter sea-ice extent around the western Antarctic Peninsula has been a proposed factor in the decline of Antarctic krill.
- In the California Current System, zooplankton species characteristic of shelf waters have replaced southerly oceanic species and northern fish species (Pacific salmon, cod and rockfish) have increased, while the southern migratory fish such as pacific sardines, have declined.
- Global empirical studies using statistical modeling show correlations between fluctuations in recruitment, growth, and fisheries production and climatic factors.

Conclusions: Climate change impacts on marine biological production are ultimately the sum of processes acting on individual organisms - growth, reproduction, mortality, and behavior. Further research is needed to more clearly understand the complexities and interactions of these processes. The information presented in this review has implications for economic and social impacts, fisheries management, monitoring and research, and adaptation to climate change.

The impact of climate change on the world's marine ecosystems. Hoegh-Guldberg O and Bruno JF (2010). *Science*, 328(5985): 1523-1528.
http://dx.doi.org/10.1126/science.1189930 **GLOBAL**

Keywords: greenhouse gases, marine impacts, ocean acidification, species distribution

Background/Purpose: Our understanding of the effects of climate change on marine ecosystems is limited due to the complexity of the ocean and difficulties in taking measurements in marine environments. This article provides a comprehensive review of the reported impacts of anthropogenic climate change on marine ecosystems. The

authors explore how these impacts on marine ecosystems will present challenges and costs for societies worldwide.

Methods: The authors reviewed 60 scientific papers that discuss physical changes in our oceans (e.g., warming, declining oxygen concentrations, current dynamics) and climate change impacts on a wide range of marine ecosystem processes and services.

Results: Increasing concentrations of anthropogenic greenhouse gases have increased global average temperatures by about 0.2^{o}C per decade over the past 30 years. Much of this heat has been absorbed by the oceans, raising the average temperature of its upper layers by 0.6^{o}C over the past century. This increased heat content has driven other changes, including sea level rise, more intense storm systems, greater stratification of the water column and the resultant decrease in nutrient availability. In addition, the oceans have also absorbed about one-third of the carbon dioxide emissions, leading to acidification of the ocean's surface waters (a steady decrease of 0.02 pH units per decade over the past 30 years has been estimated). These alterations had adversely impacted ecosystems, for example leading to include decreased ocean productivity, reduced habitat complexity, shifting species distributions, altered predator-prey relationships and increased disease occurrences. Little is known about the potential for large-scale synergisms or antagonisms among the multiple anthropogenic stressors on the ocean. There is a growing risk that certain biological thresholds (e.g., temperature and acidity) will be exceeded, resulting in serious threats to ecosystems such as coral reefs.

Conclusions: Although there is considerable uncertainty about the spatial and temporal details, climate change is clearly and fundamentally altering ocean ecosystems. The rapid ecological shifts that are occurring in the world's oceans present major challenges for policy makers. Overall, reducing greenhouse gas emissions remains the priority as it will reduce the growing risk of pushing the earth into an unknown and highly dangerous state.

Climate controls on marine ecosystems and fish populations. Overland JE, Alheit J, Bakun A, Hurrell JW, Mackas DL and Miller AJ (2010). *Journal of Marine Systems*, 79: 305-315. http://dx.doi.org/10.1016/j.jmarsys.2008.12.009 **GLOBAL**

Keywords: North Atlantic Oscillation, marine impacts, ocean conditions, teleconnections

Background/Purpose: The current characterization of climate variability linking to predictions of decadal events remains incomplete. In part, this limitation is due to the difficulty in establishing a direct time series analysis between climate variability and patterns and cycles in ecosystems. This paper investigates reasons behind current climate variability in the Pacific and Atlantic Oceans and proposes a model which may aid in anticipating the impacts of climate variability on large biological populations and associated ecosystems.

Methods: The analysis of climate variability was based on a literature review. Specifically, variability of the North Atlantic Oscillation (NAO) and Pacific North American (PNA) atmospheric teleconnections (large spatial covariability) and subsequent climate patterns were investigated. The paper provides phase space diagrams, which are graphical representations used to reveal the behavior of a system, to characterize the Northern Hemisphere climate in any given year. The paper also assesses whether Intergovernmental Panel on Climate Change (IPCC) climate models can accurately represent the warming trend from anthropogenic contribution to future climate. In addition, it suggests a model that may help in understanding variability on decadal time scales by paying close attention to multi-year memory, internal feedbacks, and non-linearities.

Results: Although there was some correlation between the NAO and PNA patterns using the phase space diagrams, no consistent covariability between ocean basins was observed for the 20th century. Although the IPCC model may be able to predict a future trend for major ecosystem regions, the trend may be compounded by the continuing large, unpredictable interannual and decadal variability. An inherent weakness of the model proposed in this paper is its inability to predict the timing of variability events. Overall, it remains difficult to effectively predict the consequences of natural patterns of variability, as well as to distinguish between natural and anthropogenic climate change. However, by looking at oceanic response patterns, there may be features in oceanic ecosystems that may allow for some predictability of future ecosystem changes.

Conclusions: The warming trend across ocean surface layers combined with the unpredictable natural climate changes will severely affect ecosystems in a variety of ways. However, by furthering our understanding of ocean thermodynamics as well the temporal nature of climate forcing of ecosystems, we may be able to forecast responses to large decadal climate events, even if their timing is uncertain.

Global phytoplankton decline over the past century. Boyce DG, Lewis MR and Worm B (2010). *Nature*, 466(7306): 591-596.
http://dx.doi.org/10.1038/nature09268 **GLOBAL**

Keywords: biomass, sea surface temperature, marine impacts, ocean conditions, seasonality

Background/Purpose: Marine phytoplankton accounts for about half the planet's primary production, affecting marine organism diversity, ecosystem functioning and fishery yields. Satellite remote sensing analyses of phytoplankton concentrations since 1979 have suggested decadal-scale fluctuations related to climate forcing, but the length of this record is insufficient for discerning long-term trends. This study assesses phytoplankton biomass at local, regional and global scales since 1899.

Methods: Total chlorophyll pigment concentration was used as an indicator of plankton biomass. The National Oceanographic Data Center and the Worldwide Ocean Optics Database provided data on global concentrations. Chlorophyll concentration trends at local, regional and global levels were estimated (using generalized additive models). Local trends in chlorophyll pigment concentration were estimated by dividing the global ocean into 10^{o} by 10^{o} cells. Regional trends were estimated by dividing the global ocean into 10 regions: Arctic, North Atlantic, Equatorial Atlantic, South Atlantic, North Indian, South Indian, North Pacific, Equatorial Pacific, South Pacific, and Southern (i.e., the Antarctic area).

Results: At the local level, phytoplankton declines were observed in 59% (*n* = 214) of the cells containing sufficient data. At the regional level, phytoplankton has declined in eight out of ten ocean regions. Increases were observed in the North Indian and South Indian regions. The global annual rate of chlorophyll decline was approximated to be 1% relative to the global median chlorophyll concentration. There are interannual to decadal phytoplankton fluctuations that correlate with basin-scale climate indices. Long-term declining trends are associated with increasing sea surface temperatures.

Conclusions: Global phytoplankton concentration has declined over the past century and should be considered in future studies of marine physical and biological systems, including fisheries.

Global patterns and predictors of marine biodiversity across taxa. Tittensor DP, Mora C, Jetz W, Lotze HK, Ricard D, Berghe EV, et al. (2010). *Nature*, 466(7310): 1098-1101. http://dx.doi.org/10.1038/nature09329 **GLOBAL**

Keywords: coastal impacts, marine impacts, ocean conditions, species diversity, sea surface temperature, species distribution

Background/Purpose: Concerns about the effects of anthropogenic impacts on marine diversity have motivated scientists to identify environmental predictors of species richness in our oceans. The investigators examine how marine richness overlaps with recently mapped cumulative human impacts (e.g., exploitation, habitat destruction, climate change) across the world oceans.

Methods: To examine patterns of species richness, data were compiled on the global distribution of 11,567 species across 13 different taxonomic groups. The analysis was limited to taxa for which sufficient records were accessible to determine global distribution. Zooplankton, plants, invertebrates, fishes and mammals were included in the analysis. The analysis had a gap in deep-sea diversity as these data were scarce, and only had limited marine invertebrate data; the analysis did not consider microbes or viruses. Data were obtained from occurrence records for marine species in an Ocean Biogeographic Information System (www.iobis.org) and global maps of coastal species richness were projected onto grids. Environmental data (e.g., sea surface temperature, oxygen concentration) were compiled from published sources. Multivariate spatial

linear models were used to evaluate the support for six hypotheses that may explain observed diversity patterns through relating richness to mean environmental conditions per cell grid.

Results: Two major patterns emerged: coastal species showed maximum diversity in the western Pacific, whereas oceanic groups consistently peaked across broad mid-latitudinal bands in all oceans. Total species richness across taxa was mostly driven by fishes. Spatial regression analyses revealed sea surface temperature as the only environmental predictor highly related to diversity across all 13 taxa. Habitat availability and life-history factors (e.g., mobility, range size) were also important for coastal species. Areas of high species richness were disproportionately concentrated in regions with medium or higher human impacts.

Conclusions: The findings indicate a fundamental role of temperature or kinetic energy in structuring marine biodiversity. Changes in ocean temperature, in conjunction with other human impacts, may ultimately rearrange the global distribution of life in the ocean.

The California Current Integrated Ecosystem Assessment (IEA), Module II: Trends and Variability in Climate-Ecosystem State. Farallon Institute for Advanced Ecosystem Research (2010).
http://www.faralloninstitute.org/Publications/SydemanThompson2010IEAModuleIIReport.pdf **CALIFORNIA**

Keywords: birds, California Current Large Marine Ecosystem, El Niño/La Niña-Southern Oscillation (ENSO), sea level, fisheries, marine impacts, North Pacific Gyre Oscillation, ocean conditions, sea surface temperature, upwelling

Background/Purpose: The California Current Large Marine Ecosystem (CCLME) is a large, dynamic and spatially heterogeneous marine environment in the North Pacific Ocean off the west coast of North America, spanning from approximately the northern tip of Vancouver Island (British Columbia, Canada) to Punta Eugenia (Baja California, Mexico). Ecosystem observations in the CCLME have shown notable changes in recent years, during which physical changes—including ocean warming, changing winds and altered circulation—have also occurred. A synthesis of long-term change in both physical and biological attributes of the California Current had not previously been undertaken. This report examines the hypothesis that there are co-varying trends in physical and biological attributes of the California Current in a comprehensive ecosystem-wide manner.

Methods: An Integrated Ecosystem Assessment (IEA) is a scientific tool for ecosystem-based management of the oceans that assesses human pressures and environmental influences on the health of large marine ecosystems. This IEA module assesses marine climate-ecosystem relationships in the CCLME over the past 50 years. A special focus was placed on recent salmonid fisheries closures and seabird breeding

failures. Twenty-one time series of physical and biological conditions from various latitudes in the California Current were evaluated for trends in central tendency (mean monthly or annual values) and variability (variance) of monthly/annual parameter values. Physical and biological datasets were also examined for cross-correlations in parameters that are expected to change with global warming. In particular, the investigators evaluated whether changes in biological variables are related to change in temperature, sea level, and circulation.

Physical datasets included physical pressure variables—the upwelling index; multivariate ENSO index; North Pacific Gyre Oscillation index; and measures of North Pacific currents—and physical state variables—Pacific Decadal Oscillation Index; sea level; sea surface temperature. Biological datasets included variables representing lower trophic levels—chlorophyll; small plankton volume; northern copepod index; euphasiid biomass—and mid to upper trophic levels—Chinook fall escapement; Coho percent smolt-adult returns; Cassin's Auklet reproductive success; California sea lion pup production; rockfish abundance; herring spawning biomass; herring landings; juvenile rockfish index; hake pre-recruit abundance; and common murre mortality.

Results: There were increasing trends in the values of the North Pacific Gyre Oscillation (NPGO), Multivariate ENSO Index, and Upwelling Index, sea surface temperature (Monterey Bay) and sea level (San Francisco). Plankton abundance, and seabird, rockfish, and salmon productivity and/or survival declined in different regions of the CCLME. There has been increasing interdecadal variance in sea surface temperature, sea level, and certain biological parameters.

Sea level correlated strongly with all other physical variables for January through May, and thus appears to be an important indicator that integrates a variety of changes occurring in other physical environmental variables. Sea level did not, however, correlate with many of the biological variables, while the January-May NPGO did (correlating with 11 of 13 biological variables). While the reason for this is unclear, the authors hypothesize that the reason may be because the NPGO integrates both upwelling and transport mechanisms—multiple processes known to influence biological productivity in the CCLME.

Most of the positive relationships found between trophic level variables were expected, given the direct trophic links. The strong positive correlation between Chinook salmon fall escapement and the Coho salmon Oregon Production Index suggests that conditions affect salmon abundance in both regions in similar ways.

No significant relationships were found between physical variables and chlorophyll-a concentrations and between euphasiid biomass and herring and higher trophic level predators. This finding is surprising, given the well known relationships between chlorophyll-a and ocean conditions, and between euphasiids and many predators. The authors suggest that differences in location (spatial mismatch) between the variables may explain the lack of relationships.

Conclusions: The analyses showed substantial ecological change in the CCLME, spanning multiple trophic levels. Many of the biological changes—which are generally declines in abundance or productivity and in some cases increased variance—are related to physical conditions in a manner consistent with expectations under global warming. The CCLME is undergoing changes in temperature, sea level, and upwelling and such changes agree with those expected under anthropogenic global warming. Change in predator and prey populations can be attributed to physical marine climate signals. Specifically, the top predator species (salmon and auklet) appear sensitive to variation (particularly spatial availability) in the abundance of prey which, in turn, is highly dependent on climatic and oceanic conditions. It is clear that predator-prey relationships are key to understanding recent failures in salmon and auklet populations, and that marine climate variability is playing a role in driving predator-prey interactions.

Wintertime ocean conditions synchronize rockfish growth and seabird reproduction in the central California Current ecosystem. Black BA, Schroeder ID, Sydeman WJ, Bograd SJ and Lawson PW (2010). *Canadian Journal of Fisheries and Aquatic Sciences*, 67(7): 1149–1158. http://dx.doi.org/10.1139/F10-055 **CALIFORNIA**

Keywords: birds; California Current/California Current Ecosystem; El Niño/La Niña-Southern Oscillation (ENSO); marine impacts; ocean conditions; sea surface temperature; upwelling

Background/Purpose: In the California Current Ecosystem (CCE), regional changes in upwelling, stratification, and temperature have been linked to productivity and reproductive success in a wide range of species. Life history traits and growth patterns of certain species typically respond at annual time scales and integrate ecosystem variability. These biological measures can be used as indices of ecosystem response to climate forcing. This study explores the interrelationships among rockfish and sea bird time series in the CCE; examines shared patterns of variability in biological responses to generate multispecies indicators; and relates biological effects to climate data (using time series analyses), with emphasis on how wintertime ocean variability influences diverse measures of biological function.

Methods: Six biological time series were used: (1-2) egg lay dates for auklet and common murre; (3-4) breeding success for auklet and common murre, (5-6) otolith growth-increment chronology for splitnose rockfish and yelloweye rockfish. Exact dates of success or failure were used for the years1972 through 1994. Physical time series analyzed were: monthly averages of sea surface temperature, coastal upwelling, the Northern Oscillation index, and the multivariate ENSO index (MEI) were obtained from the same time period. These physical ocean variables were related to the time series of rockfish and seabird biological endpoints. Relationships among the six biological and 12 monthly physical time series were determined using statistical methods (*principal components analysis).*

Results: Correlations between the physical and biological time series indicated that cool ocean conditions, notably in February, were associated with rapid rockfish growth and seabird reproductive success in the form of early egg lay dates and increased fledgling survival.

Conclusions: As upper-trophic predators, rockfish and seabirds independently corroborate that wintertime ocean conditions are critical for productivity in the California Current ecosystem. February upwelling, in particular, could have predictive value as an early indicator of productivity in the coming year, and on longer time scales, forecasts of February ocean conditions could be highly relevant for assessing biological impacts of future climate change and variability.

Climate change, teleconnection patterns, and regional processes forcing marine populations in the Pacific. Schwing FB, Mendelssohn R, Bograd SJ, Overland JE, Wang M and Ito S (2010). *Journal of Marine Systems*, 79: 245-257. http://dx.doi.org/10.1016/j.jmarsys.2008.11.027 **PACIFIC OCEAN**

Keywords: California Current/California Current Ecosystem, teleconnections, coastal impacts, marine impacts, ocean conditions, sea level, sea surface temperature

Background/Purpose: Atmospheric teleconnections transmit climate signals over very long distances, where local environmental conditions modify their impacts on biological populations. Teleconnections play an important role in linking and possibly synchronizing climate variability in disparate large marine ecosystems. It is critical to understand how physical climate signals propagate, and what processes lead to ecosystem change. This paper addresses these issues by summarizing key processes and features that characterize the major coastal large marine ecosystems in the Pacific, as part of an effort to understand the role of past and future global climate change in driving fluctuations in marine populations.

Methods: The authors provide an overview of atmospheric teleconnections, and characterize the impacts of past climate variability on features that characterize the five major coastal large marine ecosystems (LMEs) of the Pacific Ocean. The LME responses are compared with respect to the similarities in the processes, the timing of fluctuations and probable teleconnections. The five LMEs are: the Humboldt Current System (HCS); California Current System (CCS); Gulf of Alaska (GOA); Kuroshio Current System (KCS); and Oyashio Current System (OCS).

Results: Regions that have common physical features and processes are likely to share a comparable response to climate change. The LMEs of the eastern and western Pacific have different key processes, hence their regional response to common global forcing may be different, but can occur on the same time scales. The major Pacific eastern boundary current systems, the CCS and HCS, have similar dominant processes (e.g., coastal upwelling), and share atmospheric forcing from common teleconnection patterns that vary together. The LMEs studied show persistent warming since 1900 at

similar rates, with notable variations within each one. Also, a general warming trend that rapidly accelerated in the latter half of the 20th century occurred in the five LMEs, with the following differences: acceleration began in the 1970s in the CCS; two abrupt warming events in about 1956 and 2000 occurred in the GOA; and acceleration in the HCS and the eastern Pacific did not start until about 1980. Past synchrony between disparate populations may be coincidental and cannot be confirmed due to the short observational record.

Conclusions: While teleconnections link climate variability between distant ecosystems, populations respond to more immediate influences. The interaction between regional to basin-scale climate forcing and processes and factors at the ecosystem level determine how marine ecosystems are impacted by climate variability. Future research may elucidate the mechanisms linking climate change to marine ecosystems, revealing how coastal aquatic species react to environmental variability. Such information may help forecast the response of marine populations to future impacts of climate change.

Biological communities in San Francisco Bay track large-scale climate forcing over the North Pacific. Cloern JE, Hieb KA, Jacobson T, Sansó B, Di Lorenzo E, Stacey MT, et al. (2010). *Geophysical Research Letters*, 37(21): L21602. http://dx.doi.org/10.1029/2010GL044774 **CALIFORNIA**

Keywords: coastal impacts, ecosystem impacts, Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation, atmospheric forcing, marine impacts, community variability

Background/Purpose: Long-term assessments of ocean fish stocks have demonstrated that populations of fish and zooplankton fluctuate with large-scale climate patterns such as the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). This has not been established for estuaries and bays, which have much shorter observational records. However, a unique opportunity for evaluating this relationship was presented by an abrupt change in Pacific climate around 1999, along with the availability of records on marine fish and invertebrates at San Francisco Bay beginning in 1980. Three decades of sampling data on marine fish and invertebrates in the Bay show large, unexplained population changes, including record-high abundances of common species after 1999. This study analyzes the correlations between population changes in this estuary and variability of North Pacific climate patterns.

Methods: Climate-related data analyzed were: monthly series of the North Pacific Gyre Oscillation, the Pacific Decadal Oscillation and the multivariate El Niño/Southern Oscillation Index; sea surface temperature anomalies; sea level pressure; and the upwelling index). Marine population data were obtained from the California Department of Fish and Game (18 of the most abundant marine taxa that live near the bottom were selected). Principal component analysis (PCA) was used to create a community level index for the 18 taxa to track temporal change in San Francisco Bay. Two modeling approaches were utilized to assess the association between population variability in the Bay and atmosphere-ocean changes

represented by the PDO and NPGO: the first explored the link between community variability and climate patterns (PDO and NPGO); the second, the links between population variability of individual species and PDO and NPGO.

Results: The community-level index showed significant change after 1999, reflecting 3- to 6-fold increases. Population changes indicated a restructuring of biological communities in the Bay to a state not observed in the 1980s and 1990s. These changes followed sign reversals of the Pacific-basin climate indices—that is, an abrupt transition from a predominantly warm PDO/cool NPGO to a predominantly cool PDO/warm NPGO regime. This shift is manifested in California coastal waters by such changes as the strengthening of upwelling-favorable winds, strengthening of southward transport, and cooling of surface waters. Community variability closely tracked the NPGO, while populations of individual species had varying degrees of association with the PDO and NPGO. The authors infer that synchronous shifts in climate patterns and community variability in San Francisco Bay are related to changes in oceanic wind forcing that modify coastal currents, upwelling intensity, and surface temperature, which all in turn affect the recruitment of marine species that utilize estuaries as nursery habitat.

Conclusions: Most projections of climate change impacts on estuaries represent a watershed perspective, in that they assume that altered patterns of precipitation and river inflow will drive ecosystem change. This study demonstrated the linkage between population fluctuations of key marine species in San Francisco Bay and climate-driven variability in the coastal ocean, thus indicating a need to also consider coastal oceanographic changes influenced by altered wind patterns across the Pacific basin due to climate change.

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://dx.doi.org/10.1111/j.1365-2486.2011.02422.x **CALIFORNIA**

Keywords: California Current/California Current Ecosystem; Cassin's auklet; upwelling; climate variability; coastal impacts; marine impacts; seasonality; tree rings

Background/Purpose: Coastal upwelling supports some of the most productive and economically valuable marine ecosystems in the world, including the California Current Ecosystem (CCE). CCE upwelling is generally lowest during the winter and increases to peak levels during the late spring/summer. Some biological processes in the California Current seem to relate to climate variability in the winter while others relate to summer climate variability. Upwelling may thus occur in distinct “modes” to which biological components of the California Current are differentially sensitive. The authors tested this hypothesis and describe winter and summer upwelling modes that are independent of one another and are biologically relevant.

Methods: An analysis was done on monthly coastal upwelling intensities to reveal upwelling modes. Monthly upwelling values from 1946 through 2009 were obtained through NOAA. Modes were compared to seven biological time series: splitnose

rockfish (*Sebastes diploproa*) and 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 (egg-laying date and breeding success) in the central-northern area of the California Current. Correlations were made using the data for the biological time series and two upwelling modes.

Results: There appear to be two seasonal and biologically relevant upwelling 'modes' in the California Current Ecosystem. The first mode reflected upwelling during the summer months and was characterized by low-frequency (multi-decadal) processes. 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. Salmon growth and auklet fledging success were associated with the summer upwelling mode while all the other biological time series were associated with the winter upwelling mode, indicating that CCE biology is differentially sensitive to these seasonal upwelling patterns.

Conclusions: Upwelling in the California Current seems to occur in unrelated seasonal modes. These modes distinctly impact the biology of the CCE. Seasonality is therefore an important aspect of ecosystem response to climate variability and change.

Linking long-term, large-scale climatic and environmental variability to patterns of marine invertebrate recruitment: Toward explaining "unexplained" variation.
Menge BA, Gouhier TC, Freidenburg T and Lubchenco J (2011). *Journal of Experimental Marine Biology and Ecology*, 400(1–2): 236-249.
http://dx.doi.org/10.1016/j.jembe.2011.02.003 **WESTERN U.S.**

Keywords: recruitment, mussels, barnacles, upwelling, natural variability; coastal impacts; marine impacts; North Pacific Gyre Oscillation

Background/Purpose: In the marine environment, the rate of input of new organisms (recruitment) into communities is a key indicator of community dynamics. Detection of community dynamics in response to climatic features such as El Niño can provide insight into how ecosystems will respond to climate change. The authors examine barnacle and mussel recruitment time series and analyze this in relation to variation in large-scale climatic cycles (e.g., Pacific Decadal Oscillation or PDO; El Niño Southern Oscillation or ENSO; North Pacific Gyre Oscillation or NPGO) and coastal upwelling (a factor that can be involved in transport of larvae to shore, and thereby recruitment). This will help to understand the linkages between climate related variability and the process of recruitment.

Methods: The study was conducted at rocky sites along the Oregon coast. The period of study was 1989-2010. Plastic mesh balls for mussels and settlement plates for barnacles were repeatedly deployed in mid and low intertidal zones. Larvae were collected and analyzed. Recruitment was defined as the number of settlers that

survived up to one month after metamorphosis. Climate data (PDO, ENSO, NPGO and upwelling index) was obtained from NOAA and other online databases. To determine the magnitude and pattern of variability of organism recruitment through time, time series analyses were performed.

Results: Analysis of long-term recruitment records showed that mussels and barnacles had similar relationships to ocean climate patterns. Large-scale climate patterns explained up to 40% of the variance in recruitment of mussels and barnacles to rocky intertidal regions. Unlike mussels, barnacles showed only slight shifts in recruitment between the 1990s and 2000s. Climate and upwelling seemed to play a significant role in recruitment variance. Mussel and barnacle recruitment appeared sensitive to climate-related variation and responded similarly to the variation. The North Pacific Gyre Oscillation and upwelling had the strongest associations with recruitment of all species.

Conclusion: The analysis suggests that much variation in recruitment may be due to large-scale climatic factors. Addition of these factors to comprehensive models of recruitment that also include the smaller- and shorter-scale factors (e.g., upwelling) may provide better predictors of how recruitment in marine populations will vary under future climate change scenarios.

Drivers of variability in Euphausiid species abundance throughout the Pacific Ocean. Letessier TB, Cox MJ and Brierley AS (2011). *Journal of Plankton Research*, 33(9): 1342-1357. http://dx.doi.org/10.1093/plankt/fbr033 **PACIFIC**

Keywords: birds, coastal impacts, copepods, ecosystem impacts, marine impacts, ocean conditions, Pacific, species abundance, Euphausiids, plankton, salinity, longitude, silicate, temperature, warming, modeling, sea surface temperature, species abundance

Background/Purpose: Euphasiids are a key component of the marine foodweb. These plankton are a food source for a wide range of organisms and transport surface-fixed carbon into lower zones. Understanding the drivers of euphasiid diversity is important for purposes of managing fisheries and marine conservation. The authors use a statistical modeling approach to examine patterns and drivers of euphasiid species abundance in the Pacific Ocean in relation to a suite of environmental and physical variables. A model previously developed to examine these relationships in the Atlantic Ocean was used for purposes of comparison. The authors then modeled future species abundance in both the Atlantic and Pacific in the context of projected environmental conditions in the next 200 years.

Methods: A sampling grid with cells of uniform area was designed, spanning the ocean basin. Published euphasiid species distribution ranges were used to populate the cells with occurrence data. For each cell, five variables were obtained – latitude, longitude, seabed depth, distance to coast and to nearest ridge. The influences of environmental

variables (e.g., sea surface temperature, salinity, dissolved oxygen) on abundance were investigated using additive models.

Results: Species abundance was low at high latitudes, intermediate in the tropics and high at mid-latitude. Abundance was highest in the center of the North-Pacific subtropical gyre and South-Pacific subtropical gyre, which are large systems of rotating currents. Sea surface temperature had the most significant impact on abundance. Other drivers included salinity, longitude, distance to coast, and dissolved silicate concentration. The model predicted that species abundance in both the Pacific and Atlantic at certain areas, including the California coast, will rise due to the warming predicted over the next 200 years. Other areas in the Pacific are expected to have species depletion, and other areas in the Atlantic will not experience any changes. The model predicted that species abundance in both the Pacific and Atlantic, between latitudes 30^{o} and 60^{o} (both north and south), including the west coast of North America, will rise due to the warming predicted over the next 200 years. Low latitude areas in the South Pacific are expected to have species depletion, and little change is predicted for the Atlantic.

Conclusions: While climate, especially temperature, plays an important role in species populations, other factors like distance to coast are significant as well. Regional variations in these factors explain why different areas of the ocean are experiencing and may continue to experience different degrees of population changes.

Status and trends of the California Current region, 2003-2008, Marine Ecosystems of the North Pacific Ocean. Bograd SJ, Sydeman WJ, Barlow J, Booth A, Brodeur RD, Calamokidis J, et al. (2011). Pages 106-141 In McKinnell SM and Dagg MJ. [Eds.] Marine Ecosystems of the North Pacific Ocean, 2003-2008. North Pacific Marine Science Organization. PICES Special Publication Number 4. http://www.pices.int/publications/special_publications/NPESR/2010/PICES_PUB4_Chp3_California.pdf **CALIFORNIA**

Keywords: benthic; California Current System, Cassin's auklet; chlorophyll; coastal impacts; copepods; ecosystem impacts; fish; fisheries; marine impacts; North Pacific Ocean; plankton; upwelling, ecosystem variability; rockfish; species distribution; squid; whale

Background/Purpose: The California Current System (CCS) lies between Baja California Sur and the northern tip of Vancouver Island. A largely wind-driven system, it carries cooler, nutrient-rich water and supports large and diverse seabird and marine mammal populations. Long term observational programs provide time series of physical, chemical and biological data from which trends can be determined. This information provides the basis for this report on the status of the CCS for the years 2003-2008. This report is part of the fourth publication, titled "Marine Ecosystems of the North Pacific Ocean, 2003-2008", in a periodic series by PICES about marine ecosystems in the North Pacific.

Methods: Long-term observational data were obtained from the following programs: the *California Cooperative Oceanic Fisheries Investigations* (CalCOFI); *Line P*, and *US Global Ocean Ecosystems Dynamics* (U.S. Globec). CalCOFI are a partnership of the California Department of Fish & Wildlife, NOAA Fisheries Service and Scripps Institution of Oceanography. CalCOFI conducts quarterly cruises off southern & central California, collecting a suite of hydrographic and biological data. Line P is a Canadian program that has collected oceanographic data in the northern CCS since 1956. US Globec is a research program designed by oceanographers, fishery scientists, and marine ecologists to examine the potential impacts of global climate change on ocean ecosystems. These three programs provided time series data on physical, biological, chemical and fisheries variables within the CCS.

Results/Conclusions: The following are highlights from the report:

- The timing, duration and intensity of coastal upwelling have been highly variable, with significant intra-seasonal oscillations. 2005 saw a delayed upwelling in the northern region of the CCS, resulting in disrupted productivity, breeding, and species distributions.
- There has been lower dissolved oxygen content in the upper pycnocline, possibly leading to habitat compression for some species. Increased hypoxia has been observed off the coast of Oregon, killing benthic species.
- Surface chlorophyll$_a$ levels have increased throughout most of the CCS.
- Diversity of the zooplankton (copepod) community off Oregon has been decreasing and changes in phenology have been observed in recent years (2003-2008). In this focus period, Coho salmon had the lowest survival rates documented since recorded observations began in the 1970s. Sardine and herring recruitment have dropped. Since 1998, the Humboldt squid has expanded its range into the northern CCS.
- The CCS has shown increasing ecosystem variability. In 2005-2006, for the first time in 35 years, Cassin's auklets off central California experienced breeding failures. These breeding failures were related to changes in upwelling and corresponding changes in zooplankton populations. The distribution of cetacean populations has been variable, with the population of humpback whales increasing.

Does positioning of the North Pacific Current affect downstream ecosystem productivity? Sydeman WJ, Thompson SA, Field JC, Peterson WT, Tanasichuk RW, Freeland HJ, et al. (2011). *Geophysical Research Letters*, 38: L12606. http://dx.doi.org/10.1029/2011GL047212 **GLOBAL**

Keywords: biomass; North Pacific Current (NPC), California Current Ecosystem (CCE), poleward shifts, Argo array; ecosystem impacts; marine impacts; plankton

Background/Purpose: This paper aims to quantitatively assess the positioning of the North Pacific Current (NPC) in relation to the California Current Ecosystem (CCE) in an effort to understand how the fluctuations in the positioning of major ocean currents can influence downstream ecosystem dynamics and overall biological productivity of key

planktonic organisms. Positions mentioned in this article include poleward (towards the North or South Pole) and equatorward (towards the equator).

Methods: Datasets were available from the Argo array and were compared with a variety of ecosystem indicators and biological information from 2002 to 2007. For the current data of the Argo array, flow in the current was calculated from the gradient of dynamic heights. From combining the different variables of biological data and indicators, this study developed a biological index that integrated measurements of abundance, biomass, diversity, recruitment success, and phenology. Statistics were heavily utilized in this study to test for relationships between the position and flow of NPC and the CCE with biological variables.

Results: The results of this study showed enhanced biomass and biological productivity of planktonic organisms when the NPC was positioned poleward. The investigation revealed that ~64% of the biological productivity observed was related to the positioning of the NPC. The positioning of the NPC between the years 2002-2007 changed from poleward to equatorward.

Conclusions: This study provided evidence for a strong relationship between the shifts of the NPC and the downstream changes in the ecosystems of the CCE. Novel indicators, such as advection or changes in supply of inorganic nutrients, offered a predictive understanding of how current positioning and ecosystem dynamics are related. From these findings, it is forecasted that a shift to a more northerly position for the NPC may result in a more beneficial CCE for many trophic-level species.

Phenology of pelagic seabird abundance relative to marine climate change in the Alaska Gyre. Thompson SA, Sydeman WJ, Santora JA, Morgan KH, Crawford W and Burrows MT (2012). *Marine Ecology Progress Series*, 454: 159-170.
http://dx.doi.org/10.3354/meps09598 **PACIFIC OCEAN**

Keywords: birds, climate, climate variability, chlorophyll, ecosystem impacts, growing season, migration timing, seabird, seasonality, sub-arctic ecosystem, plankton, species abundance

Background/Purpose: A common finding in studies linking climate change to changes in marine ecosystems is earlier annual peaks of abundance for organisms. Scientists hypothesize that earlier annual peaks of abundance of plankton are influencing changes in certain seabird populations. This study explores the relationship between the unidirectional change in the seasonality of seabird abundance and trends in marine climate and primary productivity in the Gulf of Alaska.

Methods: Sea surface temperature data from 1960 through 2009 were used to assess broad-scale temperature change, the “velocity” of climate change, and seasonal shifts in temperature in the Alaska Gyre. Satellite remotely-sensed ocean surface chlorophyll concentrations were obtained to estimate primary productivity in the study region.

Twenty-eight seabird surveys were conducted from 1996 to 2006 and observations were converted into density estimates. Using negative binomial regression, the authors tested seasonal trends in the relative abundance of 15 seabird species. Seabird abundances were compared to a multivariate climate index that incorporated water temperature, salinity, density and nitrate concentrations.

Results: Five species showed no change in abundance, one species declined, and nine species increased. By season, three species increased in winter, seven species increased in late spring, and six species increased in late summer. Eight of the 15 species showed relationships with the environmental index. Data analyses revealed a direct correlation between lengthening of the "growing season" (as indicated by early and late chlorophyll peaks) and total seabird abundance in the late spring. No significant relationships between growing season and seabird abundance were found for winter or late summer.

Conclusions: The increased seabird species abundance observed was most likely in response to changes in phytoplankton related to the extended growing season. The lengthened growing season meant more food availability to attract an extended seabird inhabitation. This growing season and long-term environmental change showed correlation on multiple time scales indicative of a very strong underlying relationship between change in climate conditions and multiple species abundance.

State of the California Current 2010–2011: Regionally variable responses to a strong (but fleeting?) La Niña. CalCOFI Reports (201**2). 52.**
http://calcofi.org/publications/calcofireports/v52/Vol_52_36-68.StateofCurrent.pdf

See summary under *Ocean circulation and patterns of variability*, Page 60.

California Sea Lions: An Indicator for Integrated Ecosystem Assessment. Melin SR, Orr AJ, Harris JD, Laake JL, and DeLong RL. (2012). CalCOFI Reports, 53.
http://calcofi.org/publications/calcofireports/v53/Vol_53_Melin_140-152.pdf

PACIFIC OCEAN

Keywords: California Current/ California Current Ecosystem; California sea lion; coastal impacts; ecosystem impacts; El Niño/La Niña-Southern Oscillation (ENSO); fish; marine impacts; ocean conditions; population indices; indicator species; La Niña/El Niño; North Pacific Gyre Oscillation; Pacific Decadal Oscillation (PDO); sea surface temperature; species distribution; upwelling

Background/Purpose: Over the past 40 years, population parameters of California sea lions in the California Current System (CCS) have shown annual variability associated with large-and small-scale oceanographic events. Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) ocean processes control coastal upwelling conditions that affect marine productivity and the distribution of prey.

Because sea lions are sensitive to changes in ocean conditions through changes in their reproductive success, pup growth and pup mortality, they were evaluated as an indicator species for "integrated ecosystem assessment" of the CCS.

Methods: The Point Bennett Study Area (PBSA), a large breeding colony of California sea lions, has been used as a long-term index site for measuring population parameters. Population indices measured were: pup mortality; number of live births; pup weights; adult female diet from fecal samples (diet type and species richness). Three indices were used to describe diet: 1) frequency of occurrence (FO), which measures the percentage of fecal samples in which a prey taxon occurred, 2) split-sample frequency of occurrence (SSFO), which measures the percentage of occurrences for each prey taxon from the total number of all prey taxa found in a sample year, and 3) species richness, which measures diet diversity. Oceanographic indices measured were the PDO, NPGO, and Multivariate El Niño/La Niña–Southern Oscillation index (MEI) during months that explain trends in pup births, pup mortality and pup weights. Upwelling and sea surface temperature (SST) indices were used to investigate the effect of small-scale oceanographic conditions on sea lion population and diet indices. SST was used as a proxy for ocean productivity, where warmer SSTs are associated with low productivity and cool SSTs with high productivity. The investigators used models to explore relationships between oceanographic conditions and California sea lion population indices.

Results: Between 1997 and 2011, annual births in the PBSA at San Miguel Island ranged from a low of 8,603 to a high of 17,203. Reproductive indices of number of sea lion pup births and pup mortality at 5 weeks or 14 weeks of age were most sensitive to large scale oceanographic indices, in particular MEI. Positive MEI values were associated with El Niño conditions and in years when this occurred, the lowest number of births and highest pup mortality was observed. In contrast, La Niña conditions tend to create a more productive CCS with more abundant sea lion prey and so a greater number of adult females reproduce and rear their pups successfully.

High pup mortality occurred in May and June 2009, during which time the SSTs were elevated, and upwelling and productivity collapsed. This highlights the importance of small-scale local oceanographic events relative to the sea lion reproductive cycle. Average weights of 14-week-old pups varied over the 15-year period. There was a negative relationship between mean pup weight and an average sea surface temperature anomaly index (SSTA). Average pup weights were lower in years when the SSTA was greater than 1^{o}C above normal.

An analysis of the sea lions' diet revealed that the sea lions consumed 13 cephalopod taxa and 45 fish taxa. Pacific Hake, northern anchovy, Pacific sardine, rockfish, Pacific saury, jack mackerel, California smoothtongue, market squid, and East Pacific red octopus were the most common prey throughout the time series with FO greater than 10% in at least one of the years. There were four diet types: Diet 1 had a low split-sample frequency of occurrence (SSFO) of market squid, high SSFO of Pacific sardine, and occurred in 2002 and 2005. SSFO is an analytical technique which gives the

proportion of the overall diet made up of any single prey type. Diet 2 was dominated by market squid and Pacific hake and occurred in 2000, 2001, 2010, and 2011. Diet 3 mostly contained northern anchovy and Pacific sardine and occurred only in 2003. Diet 4 was dominated by market squid and rocket fish and occurred in 2009. Pups tended to be heavier during years of Diets 1 and 3, average in years with Diet 2, and lightest in 2009 with Diet 4. The best model for pup weight with diet indices included species richness but was inferior to the model without model indices.

Conclusions: Data on California sea lions provided measurements of environmental changes throughout the year. California sea lions are sensitive to large and small-scale oceanographic changes, making them ideal indicator species for the integrated ecosystem assessment of the CCS.

Climate change impacts on marine ecosystems. Doney SC, Ruckelshaus M, Emmett Duffy J, Barry JP, Chan F, English CA, et al. (2012). *Annual Review of Marine Science*, 4(1): 11-37
http://dx.doi.org/10.1146/annurev-marine-041911-111611 **GLOBAL**

Keywords: California Current/ California Current Ecosystem, trophic structure, hypoxia, diversity, ecosystem impacts, energy, heat wave, fires, food webs, forests, ocean circulation, marine impacts, migration, ocean conditions, temperature

Background/Purpose: Marine ecosystems are biological networks where the success of a species is linked to the performance of other species through various biological interactions (e.g., predator-prey relationships, competition). Climate change and other human pressures are having profound effects on marine ecosystems. There have been few systematic reviews of the impacts of rising carbon dioxide (CO_2) and climate change on marine ecosystems. This paper reports the emerging science in this field and illustrates general points using three cases studies: sea ice-dependent polar ecosystems; shallow tropical/subtropical regions (coral reef systems); and the California Current upwelling system.

Methods: The 14 co-authors analyzed approximately 165 peer-reviewed articles and reports. Researchers were affiliated with the Monterey Bay Aquarium Research Institute, the Farallon Institute in Petaluma and The University of California, San Diego.

Results/Conclusions: The current state of knowledge presented here highlights the need for a more comprehensive, multispecies approach to ecosystem-level analyses in order to better track and forecast changing marine ecosystems. The following summary points were provided:

- Rising atmospheric CO_2 is causing increasing ocean temperatures, which drive rising sea levels, increased vertical stratification, and altered precipitation, runoff, and wind patterns. Rising CO_2 also leads to ocean acidification.

- Non-CO_2 related pressures on ocean ecosystems (e.g., fertilizer use, invasive species, coastal degradation) interact in complex ways and should also be considered when evaluating ecosystems stressors in total.
- Climate and CO_2 changes influence many levels of ocean biological organization and function.
- Community-level impacts of climate change stem from altered physiology that translates to changing interactions among species which can alter community structure and diversity.
- The effects of climate change are particularly striking for the poles and the tropics. Acidification may accelerate the decline of tropical coral ecosystems.
- Climate variability in mid-latitude upwelling systems, like the California Current, reveals strong linkages between climate forcing and species distributions, phenology and demography.
- Rising CO_2 and climate change may modify ecosystem properties (e.g., food web dynamics, energy flows, trophic structure) and eventually impact the ecosystem services upon which societies depend.

Miscellaneous/other impacts

Quantitative approaches in climate change ecology. Brown CJ, Schoeman DS, Sydeman WJ, Brander K, Buckley LB, Burrows M, et al. (2011). *Global Change Biology*, 17(12): 3697-3713. http://dx.doi.org/10.1111/j.1365-2486.2011.02531.x

METHODOLOGY

Keywords: ecology, ecosystem impacts, marine, statistics

Background/Purpose: Understanding the extent of climate change impacts on ecosystems and their interactions with other anthropogenic stressors is a key consideration in climate change policy and adaptive management. Identifying the mechanisms driving change is especially challenging in marine ecosystems. Short-term anthropogenic influences superimposed upon natural decadal cycles in the ocean-atmosphere system can mask or accentuate climate change impacts. Appropriate statistical analyses are critical to ensure a sound basis for inferences made in climate change ecology.

Methods: This is a review paper. The authors reviewed the peer-reviewed literature for observational studies of climate change impacts that: examined impacts on marine taxa; presented data over multiple years after 1960 (when signals of anthropogenic climate change first became apparent); and investigated a primary climate variable that showed a change consistent with the physical impacts of anthropogenic climate change. A total of 267 peer-reviewed articles published from 1991 to 2010 were found, 186 of which used regularly sampled time series data. These articles were examined to assess and describe current statistical practices in marine climate change ecology.

Results: Of the articles with time series data (186), 75 percent used statistics to test for a dependency of ecological variables on climate variables. The authors identified several common weaknesses in statistical approaches, including marginalizing other important non-climate drivers of change, ignoring temporal and spatial autocorrelation, averaging across spatial patterns, and not reporting key metrics.

Conclusions: Authors provide suggestions for making defensible inferences in climate change ecology, including the following:

- Consider how spatial and temporal resolution of data will influence the strength of inferences about drivers of change
- Formulate alternative hypotheses for causal relationships between the ecological and climate variables
- Identify response variables; the most statistically reliable response variables will generally have the largest sample size and will be formulated to address the proposed hypotheses
- Formulate the identified processes as a statistical model or a series of models that ideally include all drivers of change
- Temporal autocorrelation should be considered in analysis if using time series data
- Spatial autocorrelation and patterns should be considered if using spatial data
- Metrics summarizing the rate of change for all species studied should be reported

These suggestions are equally relevant for climate change research on land.

Life histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA. Brooks ML, Fleishman E, Brown LR, Lehman PW, Werner I, Scholz N, et al. (2011). *Estuaries and Coasts*, 35(2): 603-621.
http://dx.doi.org/10.1007/s12237-011-9459-6 **CALIFORNIA**

Keywords: droughts**,** San Fransisco Bay Estuary, fish, warming, toxicity, storms, pollutants, marine impacts, salinity, temperature, toxicity

Background/Purpose: Human influences (e.g., urbanization and agricultural development) near estuaries are frequently linked to significant decreases in abundance and composition of aquatic species. Consequences of human activities include altered hydrology, which affects salinity and turbidity, as well as inputs of municipal wastewater, fertilizers and pesticides. This article examines the still largely unknown ecological effects of contaminants on fish populations in the San Francisco Estuary. One section discusses the potential effects of climate change on water chemistry and pollutant impacts on fish in the Estuary. That section is the focus of this summary.

Methods: The authors reviewed the scientific literature on studies relevant to understanding predicted climate-related effects on the San Francisco Bay Estuary. Data from the Department of Water Resources (DWR) Interagency Ecology Program

was to illustrate increasing water temperatures at representative locations (Stockton, Antioch and Rio Vista) between 1984 and 2007.

Results: Climate models are projecting increases in air temperature, severe storms and drought conditions in California. Higher temperatures could cause increases in species' metabolic rates and susceptibility to contaminants. Warming waters can increase the toxicity of compounds such as metals and carbamates and decrease the toxicity of certain chemicals (e.g., DDT). Extreme storm events can increase the frequency of pollutant discharges from runoff. Storms have reportedly increased mercury and diazinon levels by 10- to 100-fold at sites within the Estuary, exceeding water quality criteria. Droughts can concentrate pollutants through evaporation and pose a greater risk to fish. Finally, warming water temperatures can reduce or tax fish energy reserves both indirectly and directly. Fish become lethargic and decrease their foraging activity in warmer waters. In addition, warmer waters carry less oxygen, and fish will have to make physiologic adjustments to tolerate hypoxic conditions.

Conclusion: The effects of climate change will vary among species depending on trade-offs between decreased toxicity of some pesticides and greater susceptibility to other contaminants, the timing and magnitude of chemical uses, hydrologic control of exposure spikes, and predator-prey interactions.

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, 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, carbon dioxide levels and precipitation. Crops are generally grown in areas where temperatures are optimal for their growth and reproduction. Warming conditions in these areas 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.

California perennial crops in a changing climate. Lobell D and Field C (2011). *Climatic Change*, 109(1): 317-333. http://dx.doi.org/10.1007/s10584-011-0303-6

CALIFORNIA

Keywords: adaptation, agriculture, crops, climate, models

Background/Purpose: Perennial crops are among the most valuable of California's diverse agricultural products. These long-lived crops, which are commonly grown for more than 30 years, are potentially most influenced by changes in climate. This study assessed the potential impacts of climate change on perennial cropping systems in California over the next 20-50 years and identified possible adaptation strategies to minimize the potential costs and maximize the potential benefits of climate change. The focus was on the effects of changes in average monthly minimum and maximum temperature and precipitation.

Methods: County (Agricultural Commissioners) records on harvests of the 20 leading perennial crops (in terms of total cash value) and National Weather Service cooperative station data on daily minimum and maximum temperatures and precipitation from 1980 to 2005 were used to develop the statistical crop models. The crop models were then combined with climate change projections of temperature and precipitation to assess potential impacts through 2050.

Results: Warming was found to be both beneficial and harmful to crop yield, depending upon the time of year and the crop. For cherries and table grapes, warming was rarely beneficial any time of year. Projecting impacts of climate trends to 2050, the study showed cherries to be the only crop unambiguously threatened by warming, and no crops clearly benefiting from warming. Almond yields will be harmed by winter warming, although this effect may be counteracted by beneficial warming in spring and summer.

Conclusions: The study has advanced understanding of climate impacts on California agriculture and highlighted the importance of measuring and tracking uncertainties due to the difficulty of uncovering crop-climate relationships. Uncertainties related to climate change that were not addressed include: declining water resources, direct fertilization effect of higher carbon dioxide levels, and detrimental effects of high ozone levels.

Climate extremes in California agriculture. Lobell DB, Torney A and Field CB (2011). *Climatic Change* 109(Suppl 1): S355–S363. http://dx.doi.org/10.1007/s10584-011-0304-5

CALIFORNIA

Keywords: agriculture, extreme events, industry, economy, flood, heat wave, precipitation/rain, storms, wind

Background/Purpose: California crop production varies from year to year and depends in part on climate conditions such as rainfall and temperature. Extreme weather events can significantly affect crop production and are expected to increase in frequency with a changing climate. The most rapid and significant climate changes have been a decrease in freezing nights in winter and increased summertime heat waves. This study reviewed the significant extreme events between1993-2007 and their impacts on California's agriculture, as measured by insurance and disaster payments.

Methods: Event impacts on agriculture were measured by federal crop insurance and disaster payments. Insurance records were obtained from US Department of Agriculture's Risk Management Agency which covers all major crops in California. Estimates of damages to agriculture and weather event data were obtained from the Storm Event database compiled by the National Oceanic and Atmosphere Administration (NOAA). Data was summed by year and binned into broader categories: *Heat, Cold, Fire, Excess Moisture, Wind*, and *Other*.

Results: Excess moisture from heavy rainfall caused the most financial damage. Cold and hot events were also significant. Damages from wind, fire, and other events were marginally less costly. Estimated losses from extreme events peaked at $1200 million in 1998, when a December freeze destroyed crops like oranges, lemons, olives, and cotton. 2006 saw the second highest loss of about $700 million, mostly due to a July heat wave. Heavy rainfall in spring and winter led to the next three most damaging episodes in the 15-year period.

Conclusion: A wide variety of extreme events have affected agriculture in California. The occurrences of these extreme events are likely to change as the climate changes. Frosts may become less common, while heat waves are expected to rise in frequency and duration. Understanding historical losses due to extreme events may help prepare for the future (e.g., adaptation measures) as the climate continues to evolve.

Climate Change and the Agricultural Sector in the San Francisco Bay Area: Changes in Viticulture and Rangeland Forage Production Due to Altered Temperature and Precipitation Patterns. Chaplin-Kramer, R (2012). California Energy Commission Publication Number CEC-500-2012-033.
http://www.energy.ca.gov/2012publications/CEC-500-2012-033/CEC-500-2012-033.pdf

CALIFORNIA

Keywords: agriculture, viticulture, rangeland, forage production, agriculture, Bay Area, growing season, viticulture

Summary: The San Francisco Bay Area boasts a $2 billion/year agricultural industry, with wine grapes accounting for almost half the value. Animal products (primarily meats and dairy) are the second most valuable sector of agriculture in this region. The effects of climate change on wine grape and rangeland forage production are becoming increasingly important to the success of these industries. This paper identifies the sensitive aspects of these two industries through a literature review and models for the effect of climate change on wine and forage production. This work can be used as a basis for further efforts in exploring the adaptive capacity of different agricultural operations and in decisions concerning the mitigation of the climate change impacts.

Modeled projections indicate that future conditions may enhance forage production in Bay Area rangelands. However, altered precipitation patterns may delay germination and lead to earlier senescence, causing shorter growing seasons. More dry years increases the uncertainty of forage availability for rangeland animals. Wine grape yields may rise throughout much of the Bay Area; however, grape quality may decline as the crops ripen earlier during hotter months. Aspects of the Bay Area agriculture most sensitive to climate change are thus not yields, but instead different aspects of production like quality and timing of growing events. The authors suggest that further diversifying agricultural products in this area could buffer against the uncertainty of climate change impacts.

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.

Forest responses to increasing aridity and warmth in the southwestern United States. Williams AP, Allen CD, Millar CI, Swetnam TW, Michaelsen J, Still CJ, et al. (2010). *Proceedings of the National Academy of Sciences*, 107(50): 21289-21294. http://dx.doi.org/10.1073/pnas.0914211107 **WESTERN U.S.**

Keywords: bark beetles, climate variability, drought, forest mortality, climate change, drought, fire, temperature, tree rings, wildfire

Background/Purpose: Intense droughts in recent decades have been linked to decreasing tree growth and increasing mortality in many temperate forests. Attribution of the causes of tree deaths is challenging because insect outbreaks, wildfire, land-use impacts (e.g., grazing) all interact with climatic effects. In this study, models were developed to predict forest responses using several 21st century climate scenarios in the southwestern United States.

Methods: The authors used 1,097 standardized ring-width index records from a databank maintained by the National Climate Data Center. Climate-driven growth equations were developed using climate records and annual ring widths. Growth responses were predicted by using 21st century climate projections (for precipitation, mean daily maximum temperature, mean daily minimum temperature and mean relative humidity) as inputs into the equations. Four distinct climate scenarios were used. Maps of severe wildfires and tree mortality attributed to bark beetles in southwest forests over the last two decades were generated to evaluate trends.

Results: The results suggest that if temperature and aridity rise as projected, southwestern trees will experience substantially reduced growth during this century. As tree growth declines, mortality rates may increase at many sites. Increases in wildfires and bark-beetle outbreaks in the last decade are likely related to extreme drought and high temperatures during this period. It was calculated that ≈2.7 percent of southwestern forest and woodland area experienced substantial mortality due to wildfires from 1984 to 2006 and ≈7.6 percent experienced mortality associated with bark beetles from 1997 to 2008. The paper discusses implications in terms of sustainability and management of forests and woodlands in the face of increasing temperature and drought in the coming decades.

Conclusions: The high sensitivity of growth and mortality rates within southwest forests to increased temperatures and drought will affect forest productivity, species ranges and present challenges in managing for sustainability. In addressing these challenges, decision makers will benefit by ranking vulnerabilities, assess capacities to respond and implement short and long-term adaptation plans.

Changes in climatic water balance drive downhill shifts in plant species' optimum elevations. Crimmins SM, Dobrowski SZ, Greenberg JA, Abatzoglou JT and Mynsberge AR (2011). *Science*, 331(6015): 324-327.
http://dx.doi.org/10.1126/science.1199040 **CALIFORNIA**

Keywords: land use; optimum elevation; plant species; climatic water balance, range shifts; species distribution; temperature; water availability

Background/Purpose: Scientists have reported uphill shifts in species' distributions in response to climate warming. There is evidence of non-movement and even downhill shifts in environments experiencing warming, suggesting that other non-temperature factors are influencing distribution shifts. Thus, changes in temperature alone may not be sufficient for understanding future distributional shifts of vegetation. Many species, including plants, are constrained by energy and water availability. This study analyzed how altitudinal distributions of plant species in California have changed during the 20th century and whether changes could be attributed to climate parameters.

Methods: Altitudinal distributions of 64 vascular plant species between the 1930s and the present day were compared. The study area encompassed most of the major

mountain ranges in California north of 35^{o} latitude. This area was defined based on the availability of long-term climate station data and the spatial coverage of vegetation survey data in both historical and modern time periods. Two data sets of survey plots were collected from the major mountain ranges of the state. The first data set (13,746 survey plots) was sampled in the 1930s; the second data set (~33,000 survey plots) was sampled from 2000-2005. Climatic water balance was quantified using *climatic water deficit*, a measure of the evaporative demand of a reference crop that is not met by precipitation. Species' responses were quantified by analyzing shifts in species' optimum elevations (elevation where there is a maximum probability of occurrence within the species' altitudinal distribution) between periods. Using modern and historic climate records, the authors tested whether changes in optimum elevation were consistent with patterns of observed changes in climate.

Results: Mean annual temperatures in California increased by ~0.6°C during the time period studied, with warming occurring across the entire state. Precipitation changes varied by region; increases across the northern portion of the state have resulted in a net decrease (100.0 millimeters) in the climatic water deficit compared to the early 20th century by. The investigators reported significant downhill shifts in optimum elevations (an average downhill movement of 88.2 meters), with a higher proportion of species shifting their distributions downhill (72 percent moved downhill; 28 percent uphill).

Conclusions: Plant species in this study area appear to be tracking their climate niche by shifting their altitudinal distributions downhill in response to decreased climatic water deficit, rather than tracking changes in temperature. The findings highlight the importance of characterizing climatic water balance for understanding plant responses to climate change.

Addendum

Comments on Changes in Climatic Water Balance Drive Downhill Shifts in Plant Species' Optimum Elevations (2011). Science, 334(6053): 177.

Technical Comment A. Wolf A and Anderegg WRL.
http://dx.doi.org/10.1126/science.1204607
Summary: The authors argued the validity of Crimmins *et al.*'s study design and methodology based on several points: less than 5% of the taxa in the 1930s Weislander survey were included; the study was restricted to woody species and is of limited importance to plant species in general; several Weislander survey regions were excluded from the study; bias correction was conducted incorrectly; and there was weak evidence that species were actually tracking a moisture deficit niche. This report questioned the results and the implications between species' range shifts and climate change.

Technical Comment B. Hijmans RJ.
http://dx.doi.org/10.1126/science.1203791
Summary: Hijman's greatest concern was the distinct geographical disparity between the two survey plots. He predicted that the downhill shifts observed

were not due to climate change, but rather to latitudinal differences. Although Crimmins *et al.* stated that bias correction was accounted for, bias was not defined extensively nor was information about its effect explicitly given. In addition, Hijmans found that the downhill shifts observed were not statistically significant. Finally, Hijmans disputed the term "optimal elevation" and the implications involved with its concept.

Technical Comment C. Stephenson NL and Das AJ. http://dx.doi.org/10.1126/science.1205740
Summary: The authors argue that the climatic water deficit presented by *Crimmins et. al.* was miscalculated and that precipitation change should not be used to predict directional shifts in species' elevations. Furthermore, *Crimmins et. al.* incorrectly used the term "climatic water deficit"- it has no biological meaning and thus should not be used to indicate downward elevation shifts. The authors questioned the observed differences in the two survey plots and suggested that latitudinal bias may explain the plant shifts. They recommended factors such as altered fire regimes, logging, and other land use changes should also be accounted for when looking at potential elevation shifts. Finally, the authors stated that increasing water availability should not influence direction changes in elevation and that climatic change is expected to influence plant species to shift upward.

Response to Comments on Changes in Climatic Water Balance Drive Downhill Shifts in Plant Species' Optimum Elevations. Dobrowski SZ, Crimmins SM, Greenberg JA, Abatzoglou JT and Mynsberge AR (2011). Science, 334(6053): 177. http://dx.doi.org/10.1126/science.1205029

Summary: *Crimmins et. al.* argued that comments provided by the other authors were based on subjective selection of methods and conclusions, and insufficient evidence was provided to reject their original findings. They defended the validity of their species selection and stated that no inference was made to general plant species, only to the specific taxa they surveyed. *Crimmins et. al.* further disputes any invalidation of their conclusions based on latitudinal bias, noting that claims by other authors were either incorrect or analytically flawed. They agreed that the concept "optimal elevation" should have been avoided and presented results for changes in optimums for water balance and temperature. *Crimmins et. al.* also agreed that their use of the term "climatic deficit" is not consistent with its common usage in the literature; further, they agreed with the point raised about whether the increase in precipitation relative to the first 30-year period constituted biological usable water and have updated their estimations. Overall, *Crimmins et. al.* disagreed with many of the criticisms raised but conceded that the other authors have highlighted strengths and weaknesses of their original study.

Elevation-dependent influence of snow accumulation on forest greening. Trujillo E, Molotch NP, Goulden ML, Kelly AE and Bales RC (2012). *Nature Geoscience*, 5(10): 705-709. http://dx.doi.org/10.1038/ngeo1571 **CALIFORNIA**

Keywords: ecosystem impacts, fires, mountain forests, snowmelt, snow accumulation, warming, water availability, snowpack

Background/Purpose: Over the past 50 years, mountain forests have been negatively affected by warming and declining water availability. Earlier snowmelt has been correlated with increased wildfire activity and tree mortality in western U.S forests. Understanding feedbacks between ecological function and snowpack dynamics across elevational gradients is important in evaluating ecosystem sensitivities to climate change. The authors examined the influence of snowpack accumulation on the greenness of forest vegetation through the combined analysis of annual peak forest greenness and annual maximum snowpack accumulation in California's Sierra Nevada region between 1982 and 2006.

Methods: Interannual observational records of snow accumulation and satellite data on vegetation greenness were used for this analysis. Annual peak forest greenness was defined as the *normalized difference vegetation index* (NDVI). Land cover information was obtained from the global land cover classification collection of the Department of Geography of the University of Maryland. Daily snow water equivalent (SWE) data were obtained from the network of snow pillow stations in the California region. The data set integrates stations from the Natural Resources Conservation Service SNOTEL network and snow sensors from the California Department of Water Resources. Peak SWE values were determined for each season for the period between Water Year 1982 and 2006. Additionally, measurements were taken of carbon uptake and snow accumulation along an elevational transect.

Results: Vegetation greenness increased with snow accumulation. Variations in maximum snow accumulation seem to explain over 50% of the interannual variability in peak forest greenness across the Sierra Nevada region. The extent to which snow accumulation can explain variations in greenness varies with elevation. The strongest relationship between snow accumulation and greenness occurred at an elevation range between 1,900 and 2,600 meters (middle elevation). Measurements of carbon uptake and snow accumulation confirm the elevation dependence of this relationship. A lengthy analysis of elevational snow accumulation/water limitations and measures of CO_2 exchange and how this affects forest greenness across the study area is provided.

Conclusions: Results from this study suggest that mid-elevation mountain forest ecosystems may be especially sensitive to future warming and concurrent changes in snow accumulation and melt.

Consequences of climate change for native plants and conservation. Hannah, L et al. (2012) California Energy Commission Publication number 500-2012-024. http://www.energy.ca.gov/2012publications/CEC-500-2012-024/CEC-500-2012-024.pdf **CALIFORNIA**

Keywords:, adaptation, species distribution models, protected area connectivity, no-analogue communities, agriculture, range shifts

Summary: Species geographic ranges are dynamic and influenced by climate. In California, observed species range shifts have been linked to increases of global average temperatures through the 20th century. Models can be used to project species distributions in response to climate change. Such models correlate current species occurrences with historical climate conditions, then project this correlation onto future climate change scenarios. This study models changes for over 2,000 native California plant species at scales ranging from 90 meters to 16 kilometers, using three time periods, two global climate models, and two greenhouse gas emissions scenarios. The paper also discusses Network Flow Analysis, a conservation planning tool developed to assess landscape connectivity for species to respond to climate change. Finally, the changing climate and its effects on wine grape cultivation are studied. The results show that projected distributions of climates currently associated with California viticulture may result in adaptive responses (e.g., cropping changes), with potentially serious implications for land and water conservation.

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: 749-765. http://dx.doi.org/10.1139/X2012-031 **CALIFORNIA**

Keywords: adaptation, forests, whitebark pine, tree mortality, Sierra Nevada, drought, bark beetles, mountain pine beetle, species distribution

Background/Purpose: In recent decades, tree mortality across temperate regions worldwide has been linked to prolonged drought. Projections for increasing warming and drought in the western US in the next 20-50 years suggest high probabilities for increasing forest stress and mortality. The whitebark pine (WBP) in subalpine zones of eastern California experienced significant mortality from 2007 to 2010. This paper presents two studies that investigated this recent mortality in whitebark pine forests in this area of the state. Environmental and climatic variables that might affect growth and tree death were examined.

Methods: The two studies examined: (1) plots at six areas of high mortality in the central-eastern Sierra Nevada, from central Mono County to northern Inyo County; and (2) 2006-2010 data from air surveys by the USDA Forest Service of mid- to upper elevations from the Warner Mountains, southern Cascade Mountains and Sierra

Nevada. Historical Climate Network weather stations in Davis, Yosemite, Lake Tahoe and Independence provided long-term (1895-2009) temperature and precipitation records. Annual climatic water deficit, a measure of evaporative demand that exceeds available water, was used to assess moisture availability for plant growth. A climate model (PRISM) was used to extract data for annual, January and July temperature; annual, January and July minimum and maximum temperature. Statistical techniques were used to analyze field data and climate and tree response.

Results: In the study plots, dying stands were dense and relatively young (mean 176 years), with trees of about the same age. Mean stand mortality was 70% and were at lower elevations on northerly aspects that experienced warmer, drier climates relative to the regional species distribution. Mortality in all WBP stands was strongly associated with a multiyear drought that ran from 2006 through 2010. Mountain pine beetle infestation was the likely ultimate cause of death.

The air surveys showed highest mortality in the north (Warner Mountains at 38%), declining southward (Sierra Nevada at 5%). Regional weather records showed significant increases in minimum but not maximum temperature over the 20th century. Contrasting scenarios for the future of WBP in different regions of California are discussed in detail.

Conclusions: For most regions, tree mortality was concentrated in the lower elevation, upright tree zones of the WBP forest and on northerly aspects. Dead stands were located in climatic niches and under conditions of "global warming style drought" similar to other tree mortality events reported in western North America.

Climate Change Impacts on California Vegetation: Physiology, Life History, and Ecosystem Change. Cornell WK et al. (2012). California Energy Commission. Publication number CEC 500-2012-023.
http://www.energy.ca.gov/2012publications/CEC-500-2012-023/CEC-500-2012-023.pdf
CALIFORNIA

Keywords: state change, ecosystem services, terrestrial ecosystems, thresholds, vulnerability, exposure, sensitivity, fires, forests, vegetation, viticulture

Summary: Climate change can affect dominant plant species, which mediate important environmental processes such as water cycling and soil retention. Transitions in dominant vegetation (e.g., from forest to grassland) are termed "state changes". The objectives of this study were to evaluate projections for climate-induced change in vegetation, ecological mechanisms of vegetation change, and associations of species physiology and life history with distributions on climate gradients. The paper includes four studies: (1) a model of vegetation distributions in the Bay Area in relation to climate, and how climate change will shift these distributions; (2) a review of known mechanisms of vegetation change in coastal California and in the Sierra Nevada; (3) a review of plant functional traits in relation to species range limits along precipitation and

temperature gradients; and (4) the distribution of contrasting post-fire life history strategies in woody plants in relation to climate and fire. Physiological measurements, geographic models, historical documented cases of state change, statewide plot sampling networks and climate grids were used in this paper.

The results indicate that the proximity of climate conditions to biological thresholds for dominant species will drive the vulnerability to state change. A dominant species' sensitivity to climate change is a more important driver of climate vulnerability than the degree of climate change. Physiological measurements on the plants can determine the nature of such thresholds. There appear to be connections between certain state changes (such as forest to shrubland) and particular triggers (e.g., fire). Fire is likely to interact with climate change and significantly affect the life history strategies for native shrubs. This study suggests that the biological thresholds of dominant species are of significance to the vulnerability of California's land ecosystems. Future research should elucidate where climate change will push dominant species past their biological thresholds.

The roles of dispersal, fecundity, and predation in the population persistence of an oak (*Quercus engelmannii*) under global change. Conlisk E, Lawson D, Syphard AD, Franklin J, Flint L, Flint A, et al. (2012). *PLoS One*, 7(5): e36391. http://dx.doi.org/10.1371/journal.pone.0036391

CALIFORNIA

Keywords: fires, land use,, oak trees, migration, oak trees, range shifts, species distribution, San Diego county

Background/Purpose: An organism's response to climate change depends on the interaction of biological and physical factors that define future habitat suitability and the organism's ability to migrate or adapt. Observations and predictions show habitat shifting, usually to higher elevations and latitudes, in response to a warming climate. The interactive effects of processes such as fire and seed predation have not been thoroughly addressed in the climate change literature. The objective of this study was to examine how life history traits, short-term global change perturbations, and long-term climate change interact to affect the remaining patches of Engelmann oak in San Diego County.

Methods: The authors combined species distribution models predicting suitable habitat with metapopulation models that predict population trajectories. Current distribution data for Engelmann oak*, Quercus engelmannii*, were obtained from the California Vegetation Mapping Program (CALVEG), herbarium records, and the 1930s Wieslander surveys. Environmental predictors included climate (minimum temperature, maximum temperature and annual precipitation), soil, and terrain variables. Other modeling variables included land-use change scenarios, greenhouse gas emission scenarios and general circulation model projections. The effects of climate change, land use change

and altered fire frequency with emphasis on the roles of seed (acorn) dispersal and seed predation were evaluated.

Results: A significant loss of *Q. engelmannii* trees is predicted by the year 2100 under two scenarios widely used to evaluate climate change effects in California. As expected, the trees fared better in the scenario with greater precipitation. Climatically suitable habitat is projected to dramatically shrink and move toward higher elevations. These habitat areas are not expected to be used for urban development in the next century, so predicted land use change did not influence projected habitat suitability. A detailed discussion of how factors such as seed dispersal, fire and land use scenarios and how they will influence tree population dynamics is provided.

Conclusions: Climate change may severely reduce the number of *Q. engelmannii* trees in California. If the intensity of predicted population declines proves to be accurate, more seed dispersal would be needed to lessen the decline. The results suggest that habitat suitability predictions by themselves may under-estimate the impact of climate change for other species and locations.

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 include the increase in wildfires in California. Fires have caused concern in recent years due to their severity and expanse of affected areas. Increased wildfires will 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.

Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. Miller JD, Safford HD, Crimmins M and Thode AE (2009). *Ecosystems*, 12(1): 16-32.
http://dx.doi.org/10.1007/s10021-008-9201-9 **CALIFORNIA**

Keywords: climate variability, ecosystem impacts, erosion, fire, forests, Pacific Decadal Oscillation, Sierra Nevada, Cascade Mountains, wildfire

Background/Purpose: Recent studies report that wildfires in the western US are becoming larger and more frequent, even with stepped up fire-fighting intervention. Mean and maximum fire size and area burned annually have risen substantially since the 1980s and in concert with rises in regional temperatures. Severe forest fires have been linked to wildlife habitat availability, erosion rates and sedimentation, carbon sequestration and other ecosystem processes and properties. The authors note that

there has not been sufficient consideration of actual ecosystem impacts, or "severity" of wildfire activity in the West. This study reports results from a long-term, broad-scale assessment of patterns in high severity (i.e., forest stand-replacing) fire in California and western Nevada.

Methods: The study area was a 750 x 160 kilometer region in the Sierra Nevada and southern Cascade mountains. Fire severity was assessed for 202 wildfires larger than 40 hectares that burned between 1984 and 2006 using the interagency California digital fire history database. The data were stratified by forest type and measured temporal trends in severity, "patchiness," and area burned. The investigators assessed the role of a suite of climatic variables in explaining trends. Climate data for total precipitation and mean minimum and maximum temperatures were obtained from the Western Regional Climate Center.

Results: A large area (about 120,000 km^2) of California and western Nevada experienced an increase in high severity wildfires, mostly in lower-to middle-elevation forests, between 1984 and 2006. Fires have also gotten larger and burned greater areas since the beginning of the 1980s. The size and area burned now match, if not exceed, the size and area burned before fire suppression became national policy. The observed trends occur in conjunction with warming and a long-term increase in precipitation. In addition, forest fuels no longer seem to limit fire occurrence and behavior across much of the studied region.

Conclusions: This study provides further evidence of the association between severe forest fires in the western U.S. and climate. Trends in forest fire severity should prompt more examination of the implications of fire suppression and its ecological impacts.

Long-term perspective on wildfires in the western USA. Marlon JR, Bartlein PJ, Gavin DG, Long CJ, Anderson RS, Briles CE, et al. (2012). *Proceedings of the National Academy of Sciences of the USA*, 109(9): E535-E543.
http://dx.doi.org/10.1073/pnas.1112839109 **WESTERN U.S.**

Keywords: climate variability, external forcing/drivers, ocean conditions, wildfires, long-term, sea surface temperature, sulfates (sulphates), temperature, western United States

Background/Purpose: Fires in the western U.S. have increased in size and frequency over the past few decades. Fire regimes are primarily a product of climate, vegetation, topography and human activities (e.g., land management, fire suppression, accidental ignitions), which interact in a variety of ways at different spatial and temporal scales. Understanding the nature and extent of the impacts of these factors on fire patterns is challenging. Further, most fire history data come from recent periods when climate and anthropogenic activities have both undergone rapid transformations. This study examines linkages among long-term (multi-decadal to millennial) data on fire, changes in climate, and human activities. The authors construct variations in levels of burning for the past 3,000 years to identify baseline shifts in fire regimes and allow an evaluation

of the nature and extent of human impacts in a long-term context not previously done. By integrating 3,000 years of fire history, climate records and population data, the authors provide a more comprehensive understanding of fire response in the western U.S. to a wide range of climate and human influences.

Methods: The authors used historical (saw timber data from the U.S. Department of Agriculture), fire-scar, and charcoal data to construct three records of millennial and centennial-scale trends in fire occurrence across the entire west. Fire records from charcoal accumulation rates were compared to independent fire history data from historical records and fire scars. Historical temperature and drought data were obtained from prior studies. Historical population estimates for the western U.S. were obtained for purposes of considering the influence of human activities.

Results: There has been a slight decline in burning over the past three millennia. The lowest levels of burning occurred during the 20th century and the Little Ice Age (1400-1700). Prominent peaks in forest fires occurred during the Medieval Climate Anomaly (950-1250) and the 1800s. Temperature and drought predicted changes in biomass burning up to the late 1800s. Since then, human activities and the ecological effects of recent fires caused a large, abrupt decline in burning. There is now a "fire deficit" in the western U.S. attributable to human activities, environmental factors, and climate. A fire deficit might appear to contrast with observations of recent increases in western U.S. fire activity. However, when compared with previous centuries, the mean or baseline levels of biomass burned and fire frequency during the last century has decreased. The recent increase in fire activity is therefore occurring during a period of unusually low levels of biomass burning and the increase observed since 1980 has a short duration compared with the longer decline in burning from the 19h to 20th centuries and earlier periods.

Conclusion: Fires in the western U.S. remained in equilibrium with the climate since at least 500 to the 1800s. In general, burning increased when temperatures and droughts increased. After the late 1800s, human activities contributed to a decline in fires. More dramatic increases in temperature or drought are likely to produce a response in fire regimes that are beyond those observed during the past 3,000 years.

Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. Spracklen DV, Mickley LJ, Logan JA, Hudman RC, Yevich R, Flannigan MD, et al. (2009). *Journal of Geophysical Research*, 114(D20): D20301. http://dx.doi.org/10.1029/2008JD010966

WESTERN U.S.

Keywords: air pollution; desert; wildfires; air quality; carbonaceous aerosol concentrations; general circulation model; ocean circulation; fires; forests; temperature

Background/Purpose: The study aimed to develop models for predicting the effects of climate change on wildfire activity from present day to 2050. From those predictions,

the impact of wildfires on the future concentrations of carbonaceous aerosol emissions and overall air quality in the western U.S were assessed.

Methods: Linear regression models were used to evaluate the relationships between the areas burned by wildfire activity and observed climate variables based on surface meteorological data. These variables were: daily 12.00 local standard time temperature, relative humidity, wind speed, and 24-hour accumulated rainfall. Six aggregated ecoregions were selected for linear regression: Pacific Northwest, California Coastal Shrub, Desert Northwest, Nevada Mountains, Rocky Mountains Forest, Eastern Rocky Mountains/Great Plains. These relationships were then applied to meteorological fields calculated by a general circulation model to simulate wildfire emissions. The simulated wildfire emissions were combined with a global chemistry model developed to assess impacts on changes in carbonaceous aerosol concentrations in a future climate.

Results: From the models, the best predictors of future area burned were temperature and fuel moisture. The total area burned across the western United States is projected to increase by 54 percent for 2045-2055, relative to 1996-2005. This increase is considered significant in all ecoregions except for the Eastern Rocky Mountains/Great Plains, with temperature playing the main role in all other regions, and precipitation being the main driver in the Eastern Rocky Mountains/Great Plains region. The projected increase in area burned for the Pacific Northwest and Rocky Mountains Forest regions are in turn projected to increase maximum concentrations of future carbonaceous aerosol over the northwest United States, including northern California. Concentrations of organic carbon aerosol in the future climate, under present-day wildfire conditions, are predicted to be 14 percent greater.

Conclusions: This is the first study to make a prediction on the effects of climate change on future carbonaceous aerosol concentrations in the western United States as a response to changed wildfire activity. By developing models to better understand the changing wildfire activity under the effects of climate change, this study has established quantitative predictions for future carbonaceous aerosol concentrations. These future levels provide indicators for several things including the role of wildfire in ecology, carbon balance, land management, and fire suppression. These findings indicate that an increase in wildfires will have a negative impact on atmospheric visibility and human health.

Climate change and growth scenarios for California wildfire. Westerling A, Bryant B, Preisler H, Holmes T, Hidalgo H, Das T, et al. (2011). *Climatic Change*, 109(0): 445-463. http://dx.doi.org/10.1007/s10584-011-0329-9 **CALIFORNIA**

Keywords: ecosystem impacts, fires, forests, large wildfires, wildfire occurrence, climate models, emissions scenarios, uncertainty, vegetation

Background/Purpose: Within the next 100 years, changes in wildfire regimes driven by climate change are likely to impact ecosystem services that Californians rely on, including carbon sequestration in forests; quality, quantity and timing of water runoff; air quality; wildlife habitat; and recreational opportunities. These changes may also impact the ability of individuals and the government to secure homes in the wildland-urban interface. The combined effects of climate change and land development on the occurrence of California's future large wildfires and burned area are the focus of this research effort.

Methods: The authors model future large wildfire occurrence as a product of both future climate scenarios and population and development scenarios, using statistical techniques developed for seasonal wildfire forecasting in California. Projections were made for three future climate periods--2005-2034; 2035-2064; and 2070-2099—and compared to a reference period (1961-1990). Variables considered in this analysis include: fire history (records from 1980-1999); vegetation and topography characteristics for study grids; local, state and federal protection responsibility areas; and population growth and development scenarios. Historical (1950-1999) climate data included maximum and minimum temperature, precipitation, radiation, and wind. The projections were based on three global climate models (CM3, CM2.1 and PCM1) and two greenhouse gas emissions scenarios (SRES B1 and SRES A2 - low and high emissions trajectories). Fire severity (e.g., percent of vegetation consumed) was not modeled.

Results: Predicted large fire occurrence and total burned area in most of the forested areas of Northern California increase over time for both emissions scenarios. In contrast to communities in the Sierras, continued sprawling growth in coastal California could actually reduce fire risks in some areas while increasing them in others. Initial increases for burned area are relatively modest: by 2020 the increases range from 6 to 23 percent. By 2050 predicted increases in burned area range from 7 to 41 percent. The increase in wildfire burned area associated with the higher emissions scenario is substantial, with increases ranging from 36 to 74 percent by 2085.

Conclusions: Increase in wildfire burned area is anticipated for most of the climate, emissions and development scenarios, although the range of outcomes is large and increases with time. The authors note that the results reflect a set of models and underlying assumptions that together combine cumulative uncertainties and results for any one time and location cannot be considered a reliable prediction.

Climatic and human influences on fire regimes in mixed conifer forests in Yosemite National Park, USA. Taylor AH and Scholl AE (2011). *Forest Ecology and Management*, 267: 144–156. http://dx.doi.org/10.1016/j.foreco.2011.11.026

CALIFORNIA

Keywords: drought, fire, Yosemite, forests, land use, regional climate, tree rings, vegetation

Background/Purpose: Fire is a major disturbance in pine and mixed conifer forests in the western US, affecting forest structure, composition and ecosystem dynamics. At large spatial scales, fire regimes are controlled by land use practices such as fire exclusion and livestock grazing. Fire occurrence and extent in forests in Pacific coast states is related to broad scale interannual and interdecadal patterns generated by ocean current systems such as El Niño/Southern Oscillation (ENSO), the Pacific North America Pattern (PNA) and Pacific Decadal Oscillation (PDO). The goal of this study was to identify the influence of both climate variation and changes in land use on fire regimes in the central Sierra Nevada in Yosemite National Park (YNP).

Methods: Fire occurrence and extent in YNP were identified in two mixed conifer forest landscapes. The authors used fire scar dendrochronology (tree ring dating) preserved in wood to quantify fire frequency and extent, fire return interval and fire season for a 400-year period. Climate data for the period 1050-2010 were averaged from three stations in YNP and historical climate data were reconstructed using five proxies of Pacific climate. Fire history was compared to regional climate reconstructions and documentation of previous land use in three time intervals: pre-settlement (before 1769), Gold Rush Settlement (1850-1900), and after1900.

Results: The authors present a lengthy and complex discussion of historical fire characteristics and climate and land use influences. The timing and extent for fires were related to interannnual and interdecadal variation in drought and temperature. Large fires were associated with La Niña conditions which are typically drier in the Park. The occurrence of large fires was also influenced by interactions among climate patterns. Decades with a high frequency of heightened PNA years experienced more widespread burning. Observations of pre- and post-Euro-American settlement and effects on forest development provide insight on how to manage forests under a changing climate.

Conclusions: The strong influence of climate on interannual and multi-decadal variation in fire regimes suggests that future climate change will affect fire regimes in Yosemite and the Sierra Nevada. Considering winter PNA could provide managers with an early indication of conditions during the fire season that are conducive to widespread fire.

Fire and Climate Change in California. Krawchuk, MA and Mortiz MA (Simon Fraser University; University of California, Berkeley) (2012). California Energy Commission Publication number: CEC-500-2012-026.
http://www.energy.ca.gov/2012publications/CEC-500-2012-026/CEC-500-2012-026.pdf
CALIFORNIA

Keywords: fires, wildfire, climate change, hydrologic models, future projections, historic transferability, probability of burning, fire return interval

Summary: This paper presents a macro-scaled perspective of fire and climate by identifying landscapes where exposure to climate change has the potential to cause alteration of fire activity. The focus is on changes in fire frequency. Using statistical models, the authors relate the probability of a 1080-meter landscape burning over a 30-year period (1971-2000) to climate variables for the same period that represent vegetation growth conditions and seasonal dryness necessary for fires. Distance to human development is factored in as a metric of human influence via ignition and/or suppression. The tendency for burning over the next 100 years was examined based on two global climate models, one simulating warmer and drier conditions and the other warmer and relatively wetter conditions. The results suggest varying degrees of increased future fire activity in more productive areas of the state. However, by 2070-2099, the two models disagree in their response for drier, less productive regions. The study also tested the temporal transferability of baseline models by back-casting using 1971-2000 model parameters but incorporating climate data from 1941-1970. This helped to understand how well projections of future fire might reflect actual future events.

Scenarios to Evaluate Long-term Wildfire Risk in California: new methods for considering links between changing demography, land use and climate. Bryant BP and Westerling AL. California Energy Commission Publication number CEC-500-2012-030. http://www.energy.ca.gov/2012publications/CEC-500-2012-030/CEC-500-2012-030.pdf **CALIFORNIA**

Keywords: fire, land use, wildfire, housing, Bay Area, Sierra foothills

Summary: This paper describes the development and analysis of over 21,000 scenarios for future residential wildfire risk in California. The authors used models of wildfire activity and measures of uncertainties to understand what factors are important for characterizing future effects of climate and growth on residential property risks. This effort examined interactions between low and high greenhouse gas emissions scenarios, three global climate models, six population growth scenarios and a range of values defining vulnerability of properties at risk of loss due to fire. Results indicate that, by the end of the century, variation across development scenarios accounts for more variability in wildfire risks than variation across climate scenarios. The most extreme increases in residential fire risks come from the combination of high-growth/high-sprawl scenarios with the most extreme climate scenarios. Parameters describing variability of expected losses with increasing housing value can affect the overall statewide risk. Additionally, case studies for the Bay Area and Sierra foothills show that, while land use decisions greatly affect future residential wildfire risks, the effects of diverse growth and land use strategies vary greatly throughout California.

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