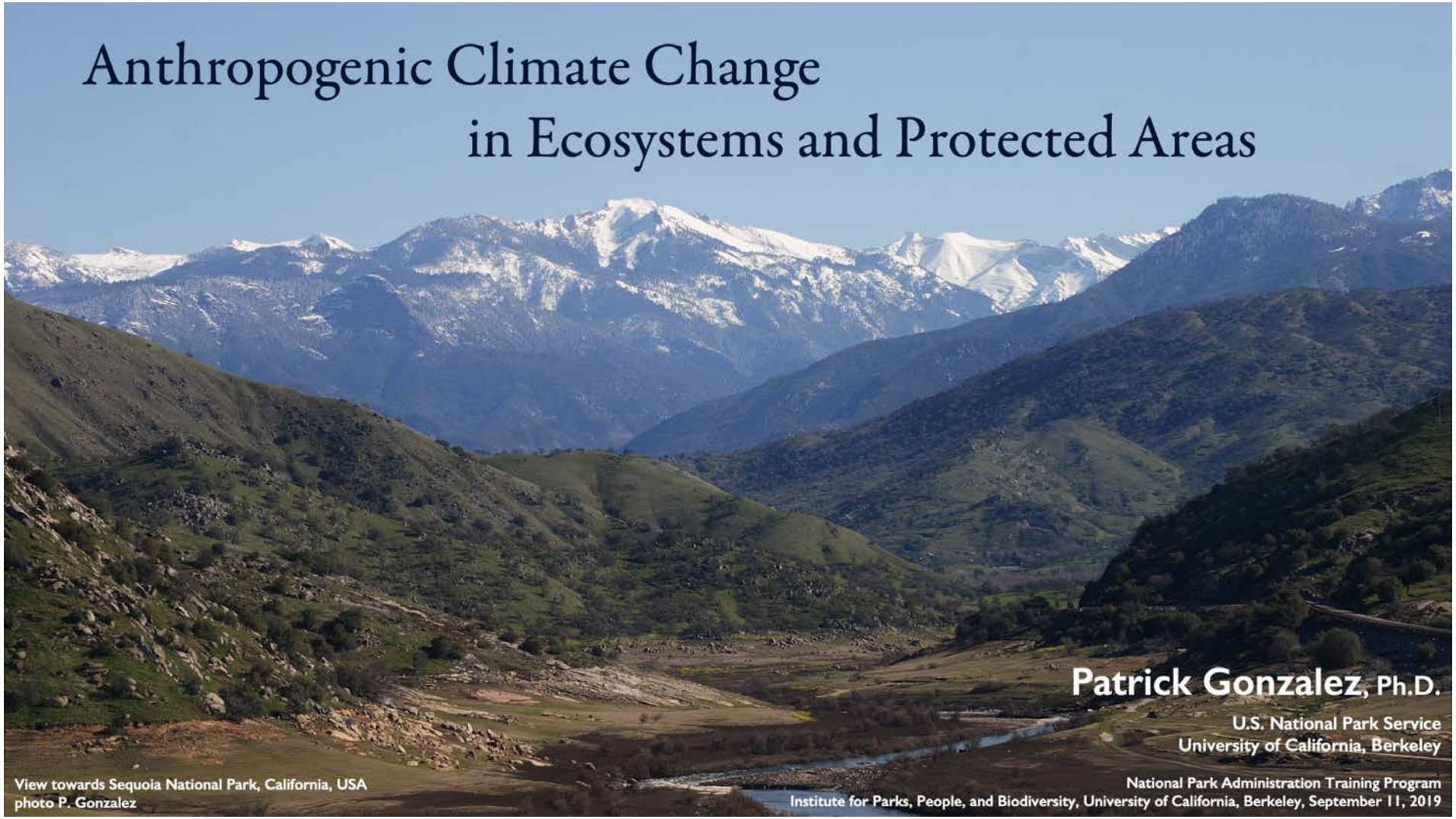
Anthropogenic Climate Change in Ecosystems and Protected Areas



Patrick Gonzalez, Ph.D.

U.S. National Park Service
University of California, Berkeley

View towards Sequoia National Park, California, USA
photo P. Gonzalez

National Park Administration Training Program
Institute for Parks, People, and Biodiversity, University of California, Berkeley, September 11, 2019

Goals of National Park Resource Management

Leopold Report (1963)

"...biotic associations be maintained, or where necessary recreated, as nearly as possible to the condition that prevailed when the area was first visited ...A national park should represent a vignette of primitive America."

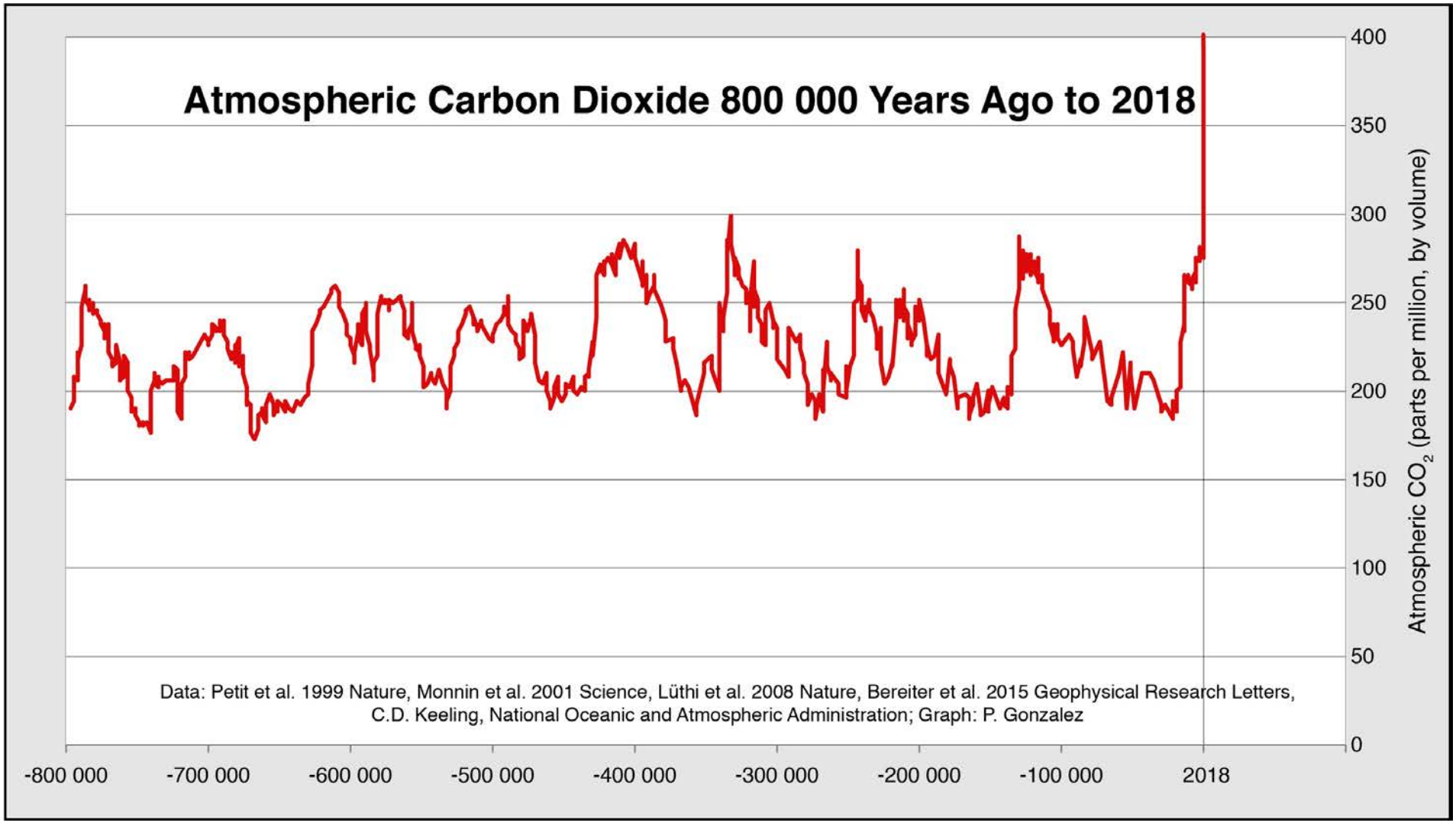
Revisiting Leopold (2012)

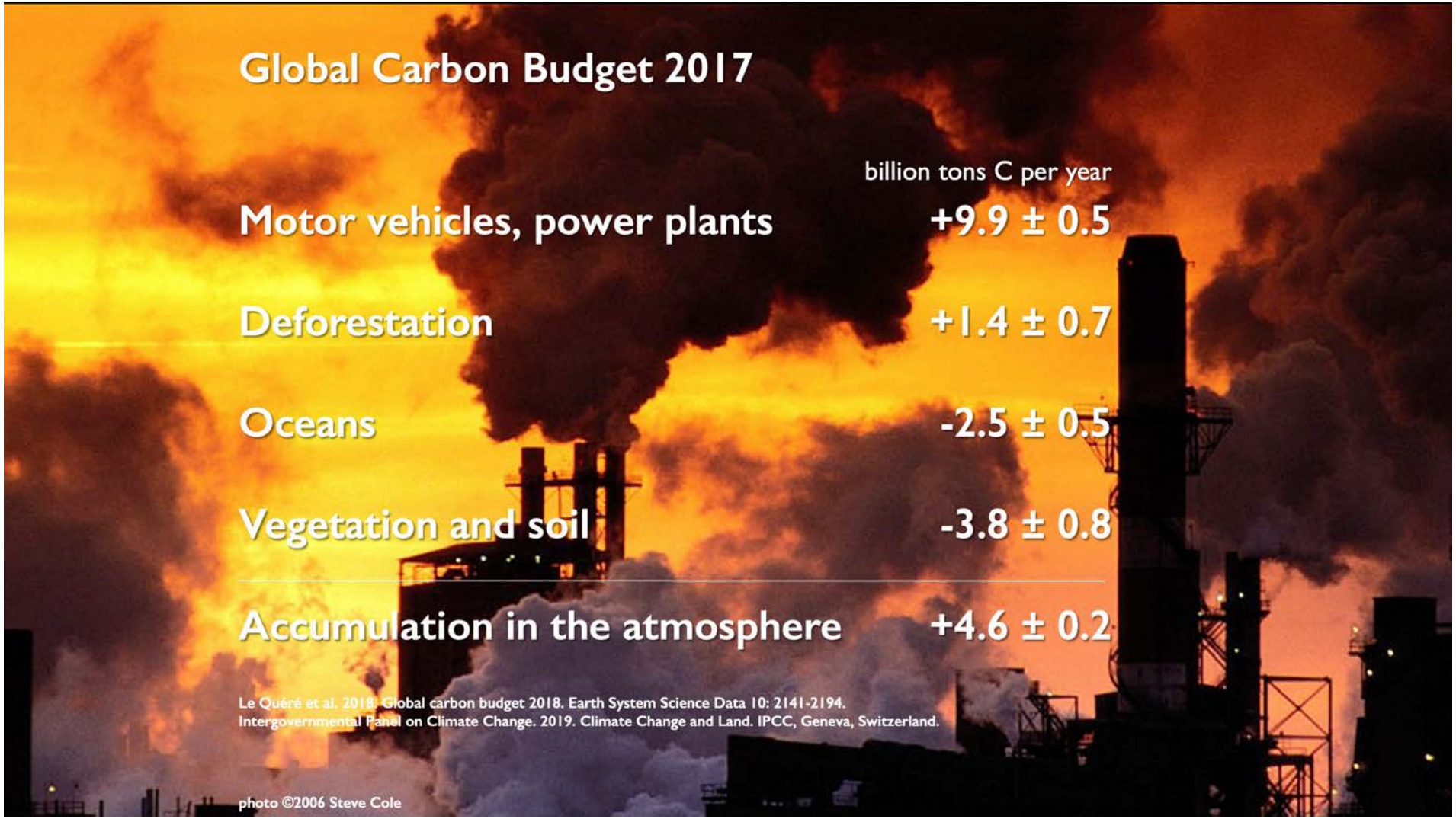
"to steward NPS resources for continuous change that is not yet fully understood, in order to preserve ecological integrity and cultural and historical authenticity, provide visitors with transformative experiences, and form the core of a national conservation land- and seascape."

Anthropogenic Climate Change in Ecosystems and Protected Areas

1. Human cause of climate change
2. Historical impacts
3. Future risks
4. Adaptation
5. Carbon solutions

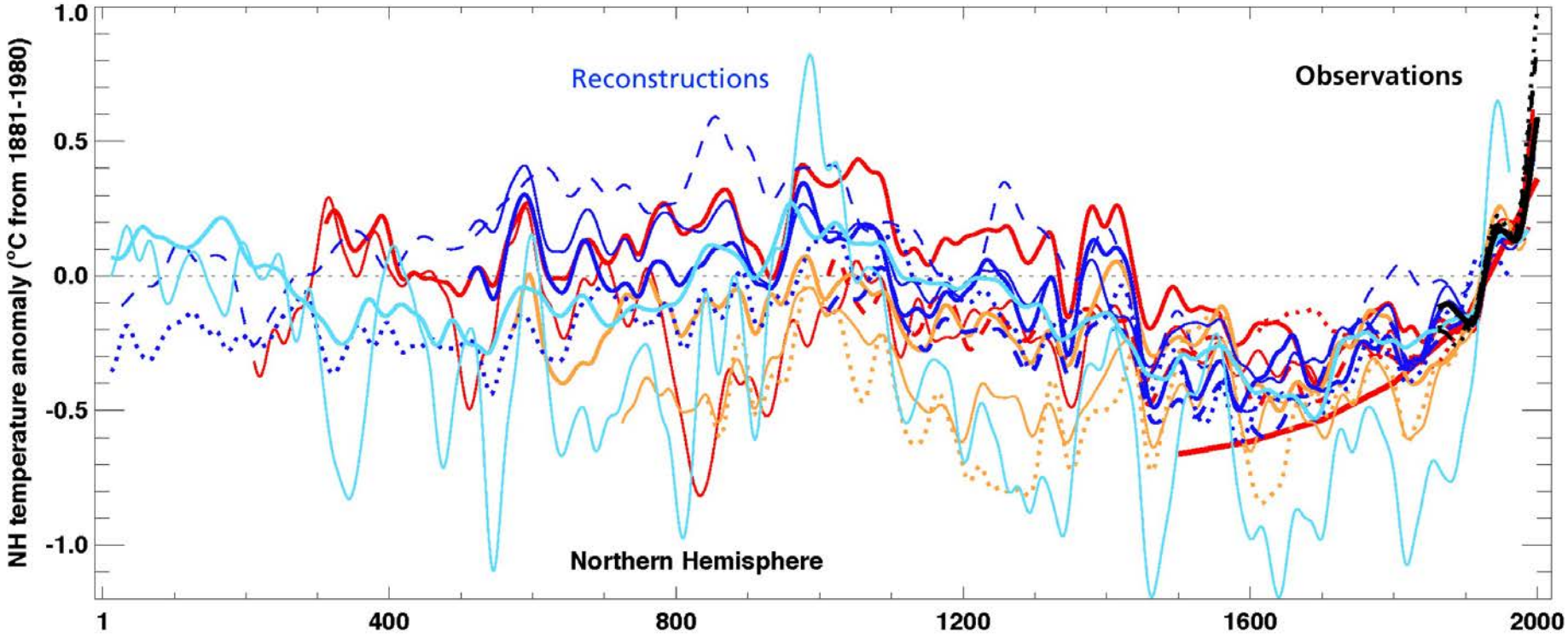
Berkeley
UNIVERSITY OF CALIFORNIA


Atmospheric Carbon Dioxide 800 000 Years Ago to 2018
400
350
300
250
200
150
100
50
0
Atmospheric CO_2 (parts per million, by volume)
Data: Petit et al. 1999 Nature, Monnin et al. 2001 Science, Lüthi et al. 2008 Nature, Bereiter et al. 2015 Geophysical Research Letters,
C.D. Keeling, National Oceanic and Atmospheric Administration; Graph: P. Gonzalez
-800 000
-700 000
-600 000
-500 000
-400 000
-300 000
-200 000
-100 000
2018


Global Carbon Budget 2017
billion tons C per year
Motor vehicles, power plants
+9.9 ± 0.5
Deforestation
+1.4 ± 0.7
Oceans
-2.5 ± 0.5
Vegetation and soil
-3.8 ± 0.8
Accumulation in the atmosphere
+4.6 ± 0.2
Le Quéré et al. 2018. Global carbon budget 2018. Earth System Science Data 10: 2141-2194.
Intergovernmental Panel on Climate Change. 2019. Climate Change and Land. IPCC, Geneva, Switzerland.
photo ©2006 Steve Cole

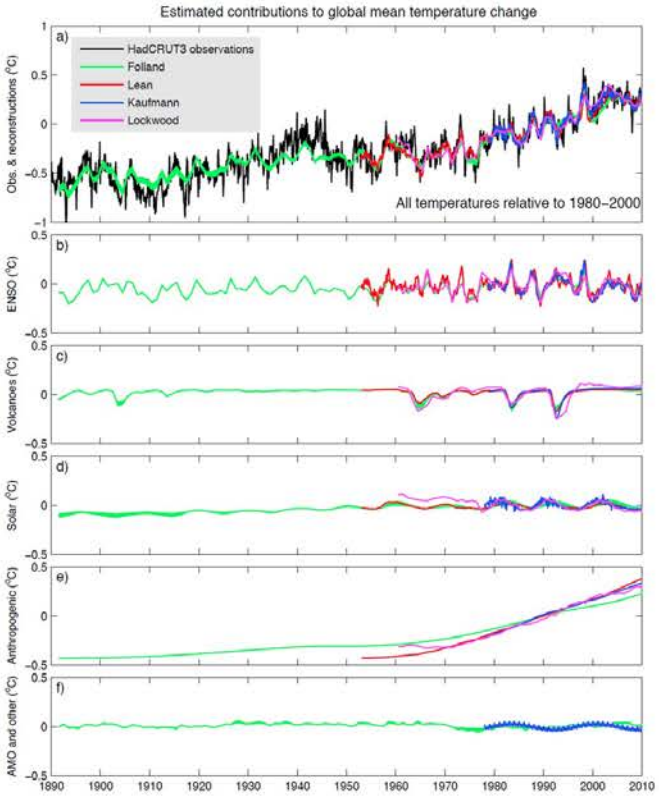
ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Temperature has increased to its hottest level in 800 years



Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

Human activities cause climate change



Heating since 1890

El Niño – up and down

Volcanoes – ash shades and cools

Solar cycles – up and down

Cars, power plants, deforestation are the only sources increasing

Atlantic Ocean overturning – up and down

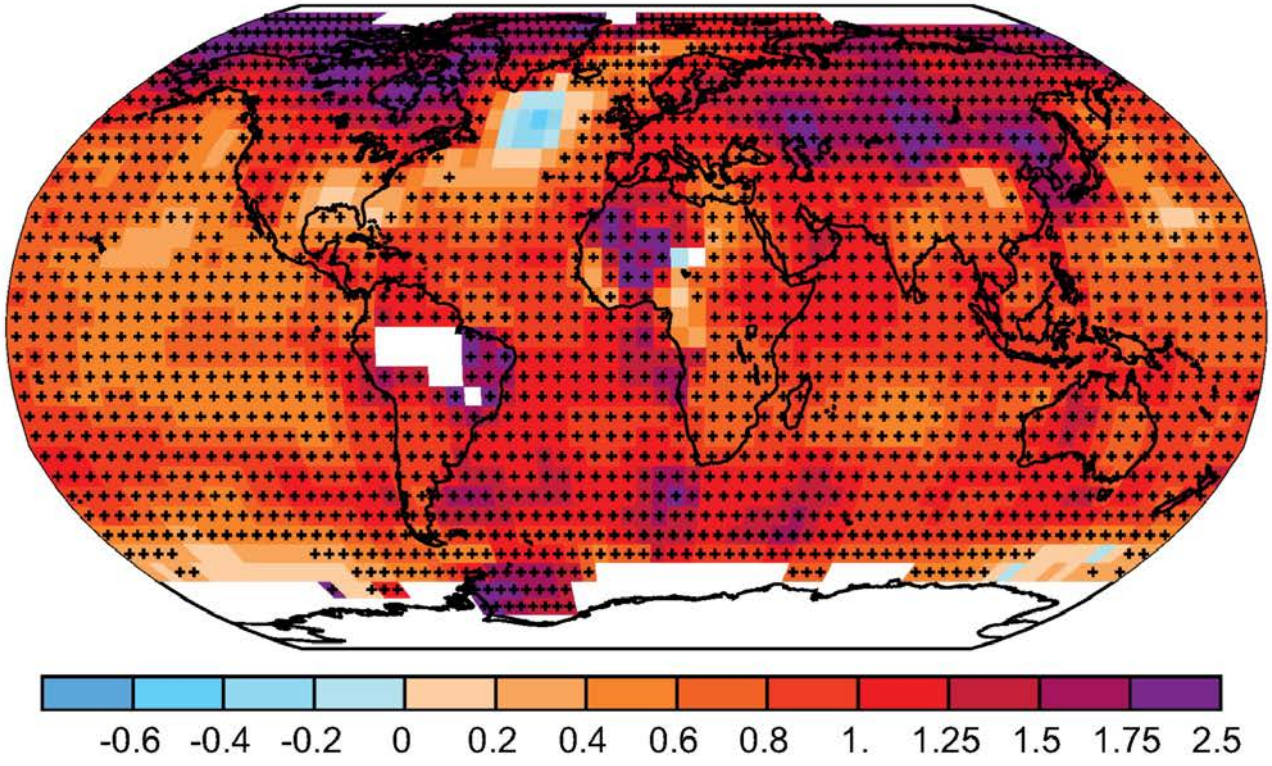
Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

Anthropogenic Climate Change in Ecosystems and Protected Areas

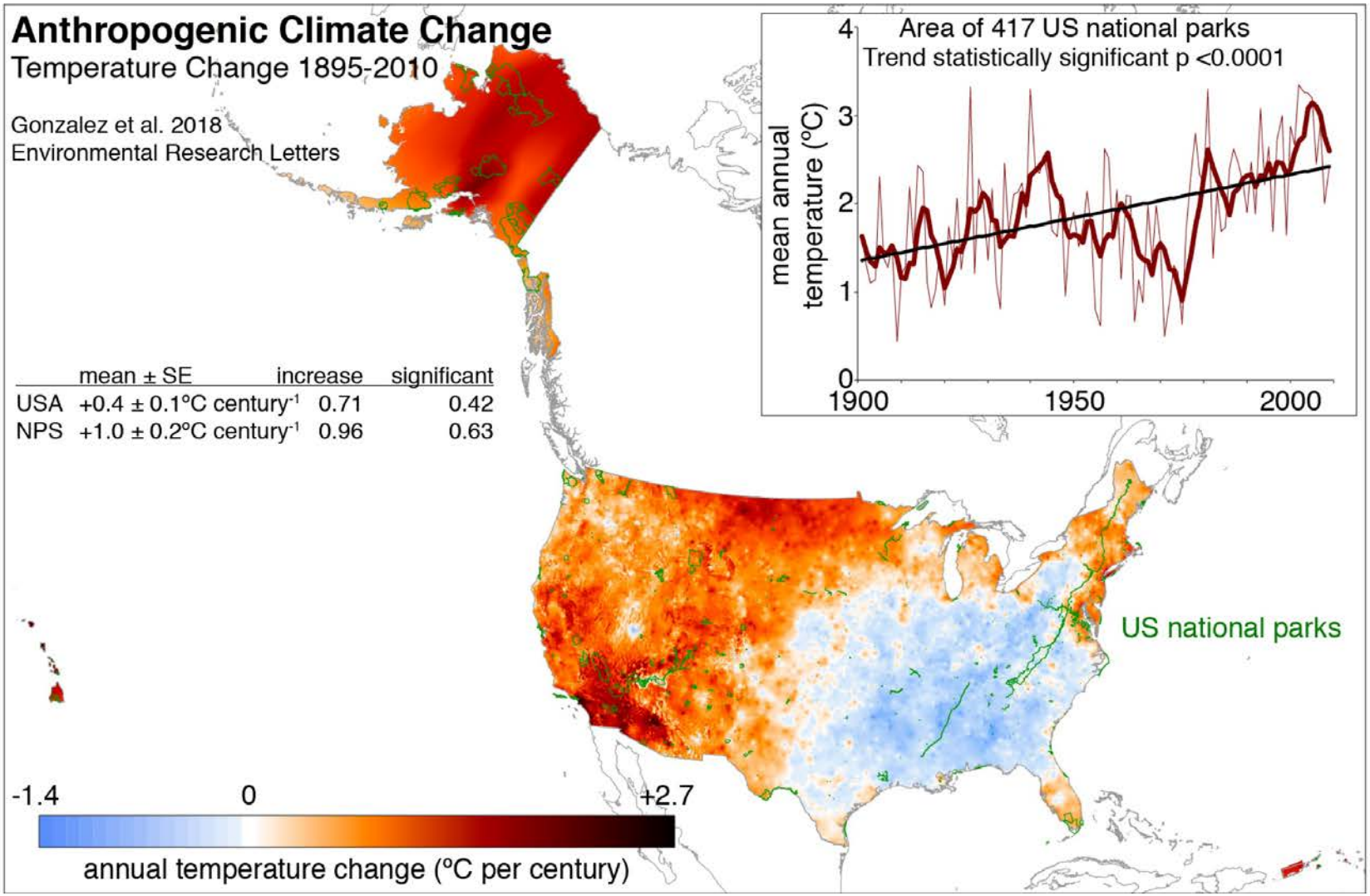
1. Human cause of climate change
2. Historical impacts
3. Future risks
4. Adaptation
5. Carbon solutions

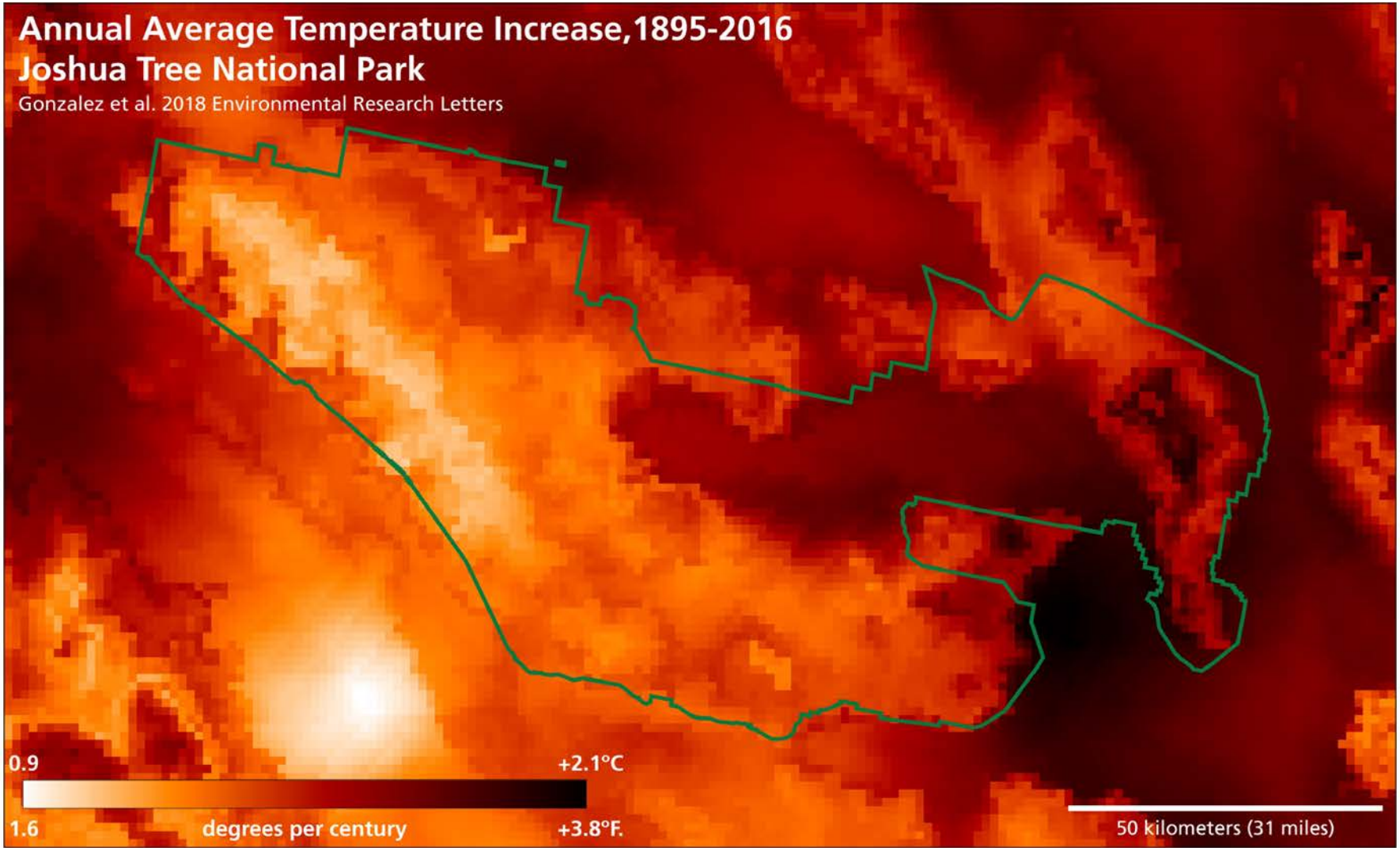
Berkeley
UNIVERSITY OF CALIFORNIA

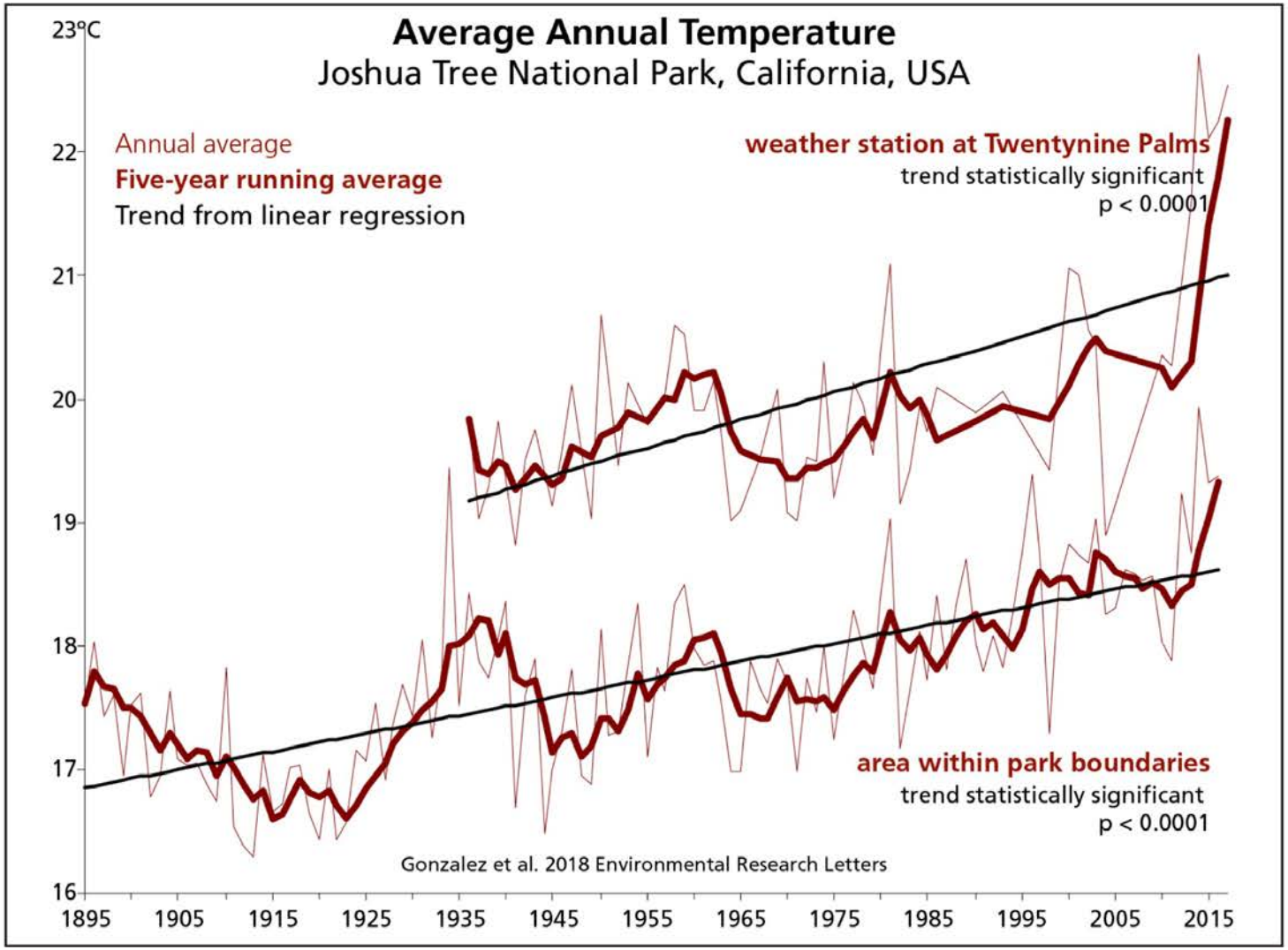
Temperature Change 1901-2012 0.8 ± 0.1°C per century



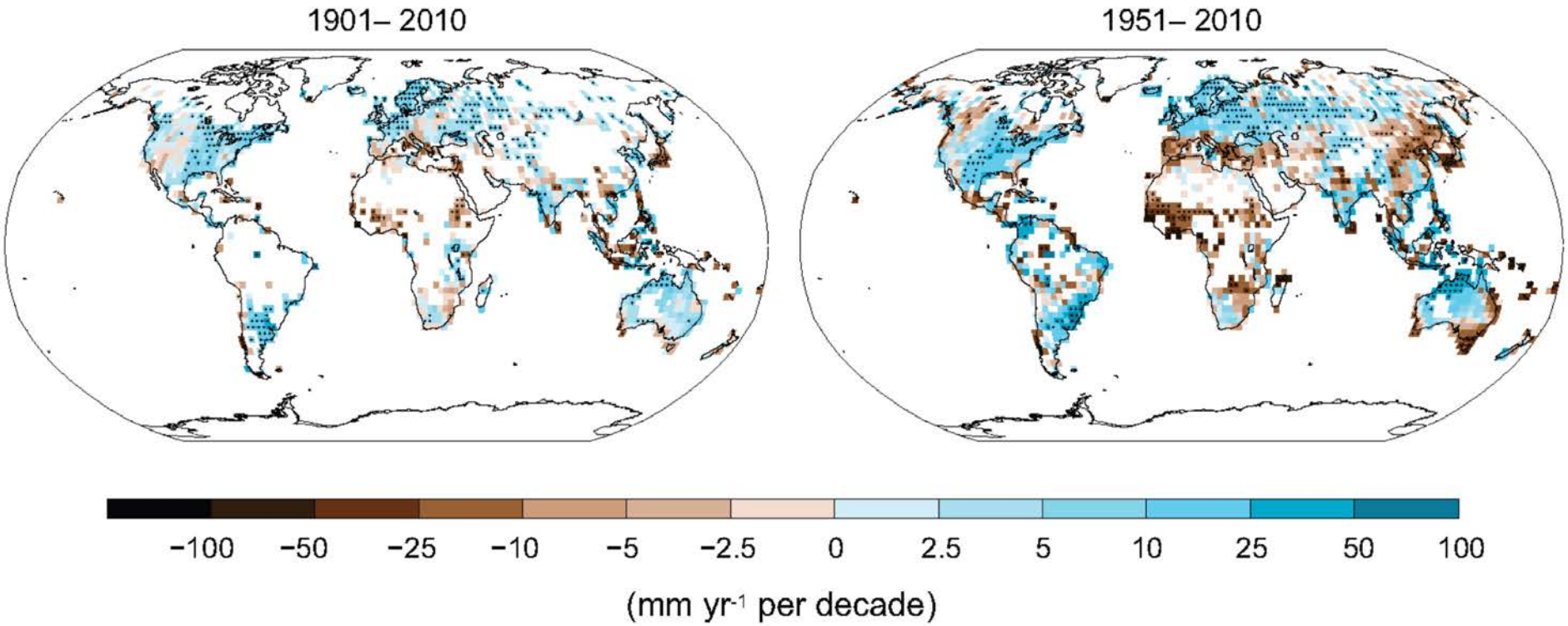
Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, New York, NY.


Anthropogenic Climate Change
Temperature Change 1895-2010
Gonzalez et al. 2018
Environmental Research Letters
Area of 417 US national parks
Trend statistically significant p <0.0001
mean annual temperature (°C)
0
1
2
3
4
1900
1950
2000
mean ± SE increase significant
USA +0.4 ± 0.1°C century-1 0.71 0.42
NPS +1.0 ± 0.2°C century-1 0.96 0.63
US national parks
-1.4
0
+2.7
annual temperature change (°C per century)

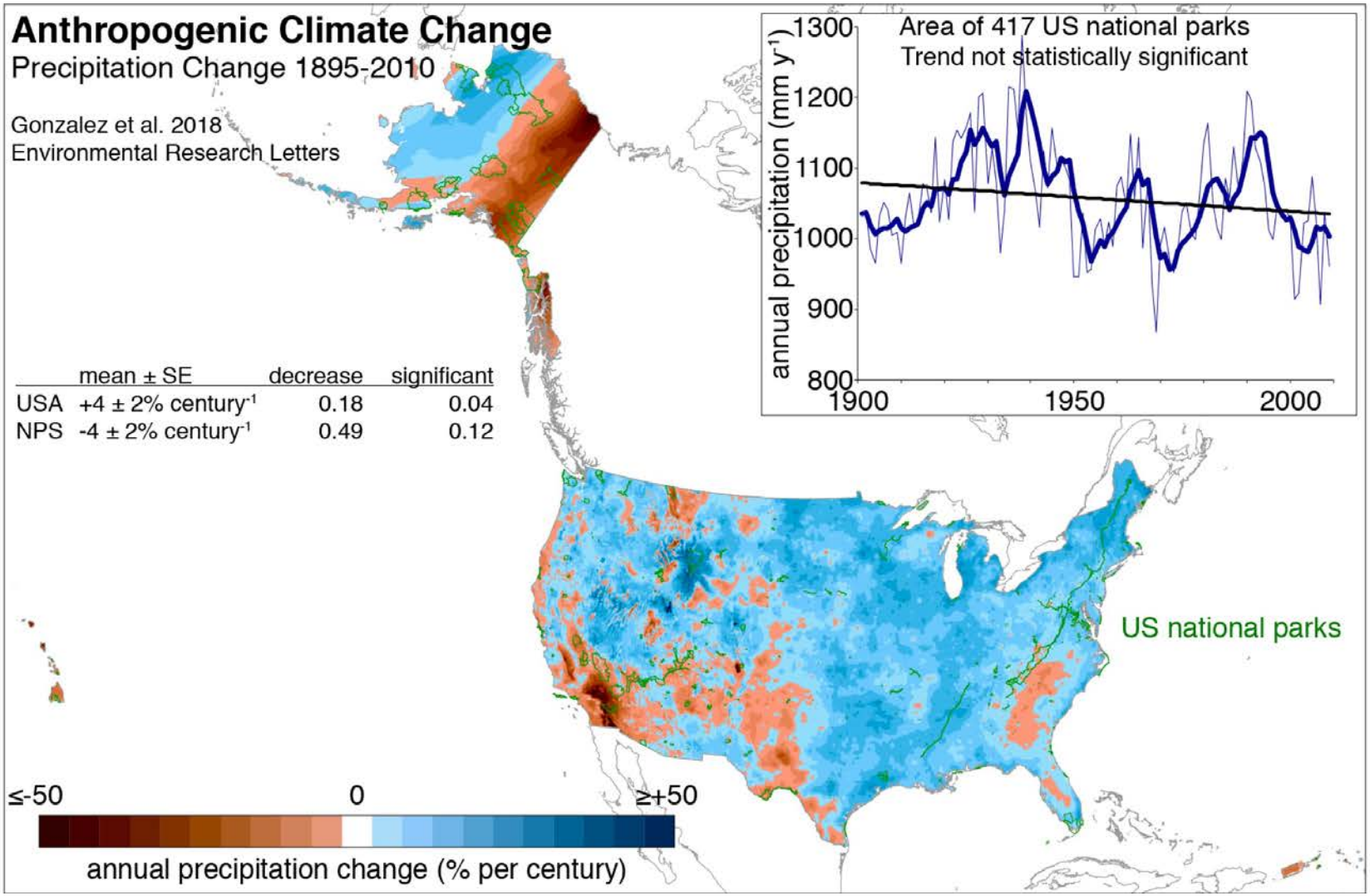

Annual Average Temperature Increase,1895-2016
Joshua Tree National Park
Gonzalez et al. 2018 Environmental Research Letters
0.9
+2.1°C
1.6
degrees per century
+3.8°F.
50 kilometers (31 miles)

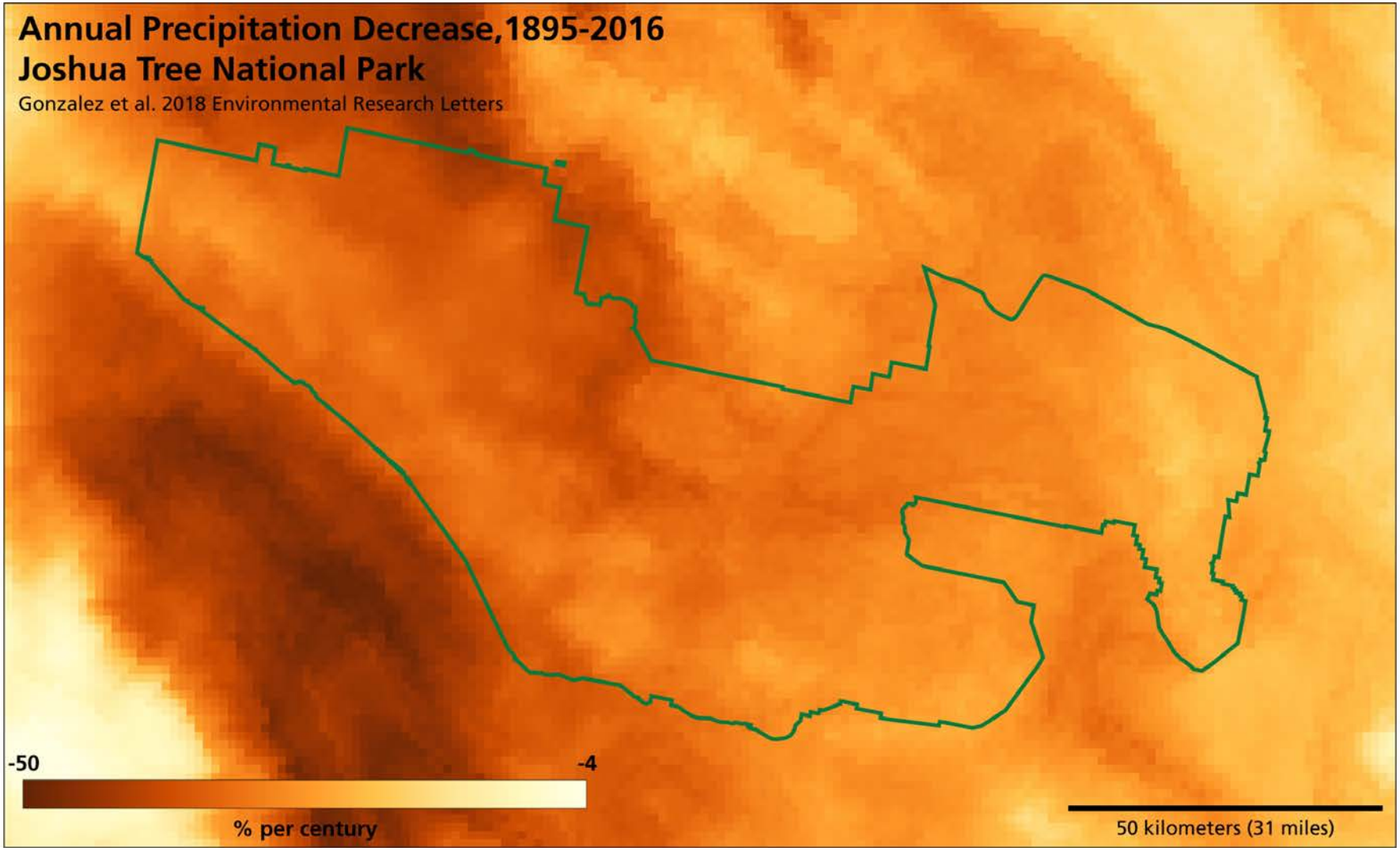

Average Annual Temperature
Joshua Tree National Park, California, USA
23°C
22
21
20
19
18
17
16
Annual average
Five-year running average
Trend from linear regression
weather station at Twentynine Palms
trend statistically significant
p < 0.0001
area within park boundaries
trend statistically significant
p < 0.0001
Gonzalez et al. 2018 Environmental Research Letters
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015

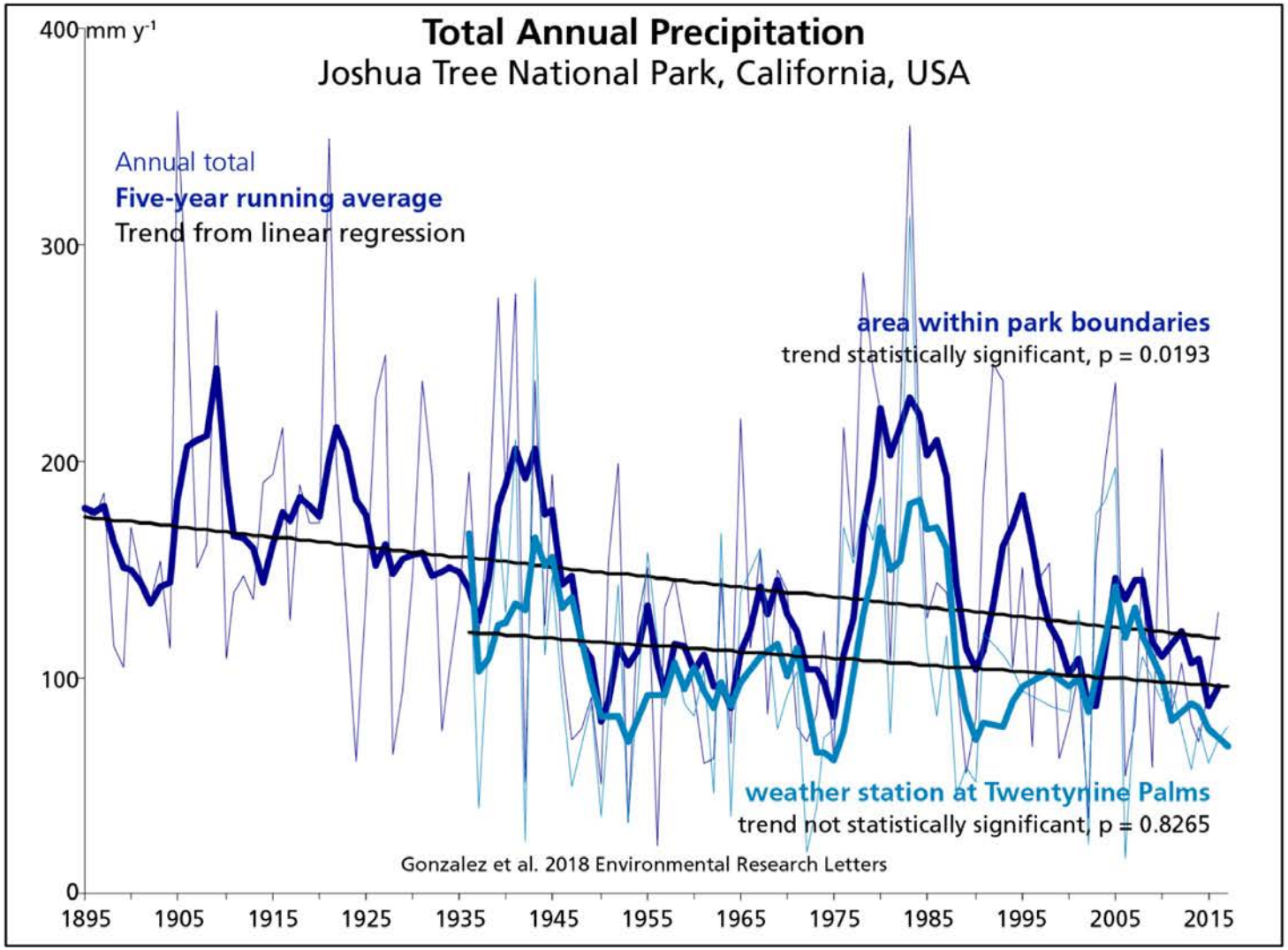
Precipitation Change 1901-2012 +100 to 200 mm per century



Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, New York, NY.


Anthropogenic Climate Change
Precipitation Change 1895-2010
Gonzalez et al. 2018
Environmental Research Letters
Area of 417 US national parks
Trend not statistically significant
annual precipitation (mm y-1)
1300
1200
1100
1000
900
800
1900
1950
2000
mean ± SE
decrease
significant
USA +4 ± 2% century-1 0.18 0.04
NPS -4 ± 2% century-1 0.49 0.12
US national parks
≤-50
0
≥+50
annual precipitation change (% per century)


Annual Precipitation Decrease,1895-2016
Joshua Tree National Park
Gonzalez et al. 2018 Environmental Research Letters
-50
-4
% per century
50 kilometers (31 miles)


Total Annual Precipitation
Joshua Tree National Park, California, USA
400 mm y-1
300
200
100
0
Annual total
Five-year running average
Trend from linear regression
area within park boundaries
trend statistically significant, p = 0.0193
weather station at Twentynine Palms
trend not statistically significant, p = 0.8265
Gonzalez et al. 2018 Environmental Research Letters
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015

Detection of Changes and Attribution of Causes

Detection

Finding of statistically significant changes from natural variability

Attribution

Determination of relative importance of different factors;
generally for at least 30 years data

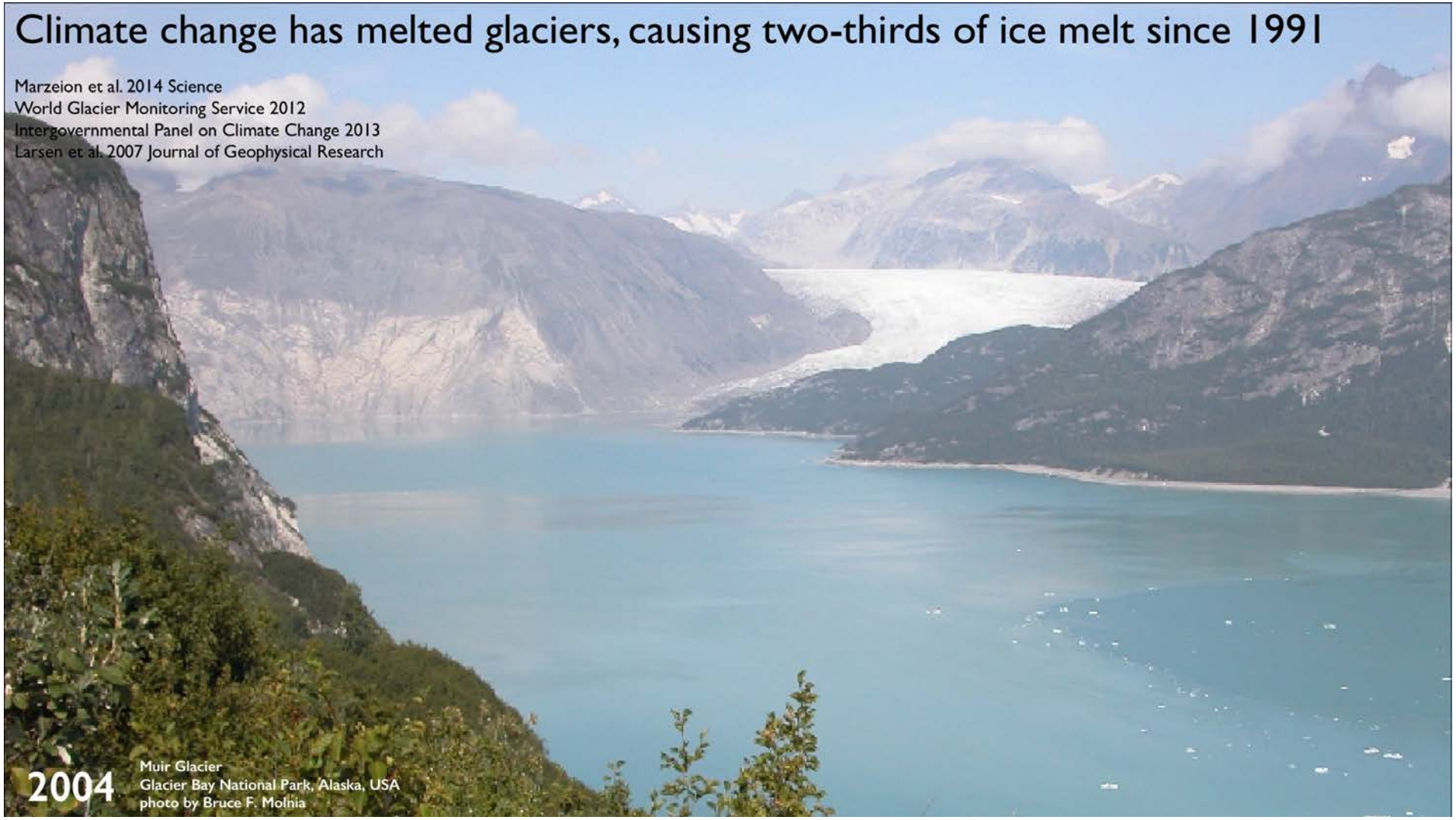
Intergovernmental Panel on Climate Change. Climate Change 2014: Impacts, Adaptation, Vulnerability. Cambridge University Press, Cambridge, UK.

1941

Muir Glacier
Glacier Bay National Park, Alaska, USA
photo by William O. Field

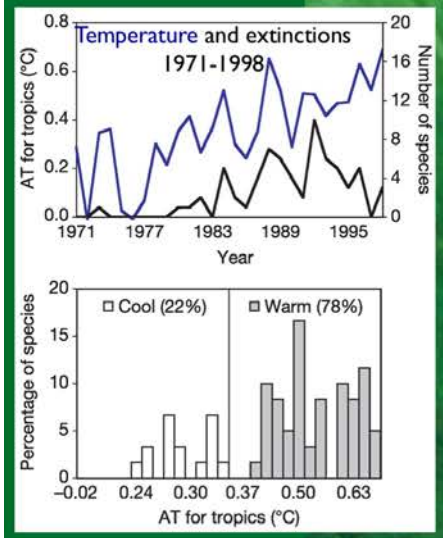

2004
Muir Glacier
Glacier Bay National Park, Alaska, USA
photo by Bruce F. Molnia

Climate change has melted glaciers, causing two-thirds of ice melt since 1991



Climate change, habitat loss, and fungal disease caused extinctions of over 70 amphibian species in Costa Rica, 1971-1998

Pounds et al. 2006 Nature
Intergovernmental Panel on Climate Change 2014



Golden toad, sapo dorado (*Incilius periglenes*)
photo U.S. Fish and Wildlife Service

Climate change doubled wildfire area across the western US 1984-2015

Abatzoglou and Williams 2016 Proceedings of the National Academy of Sciences of the USA
Littell et al. 2009 Ecological Applications

Rim Fire, August 21, 2013
west of Yosemite National Park, California, USA
photo J. Sullivan

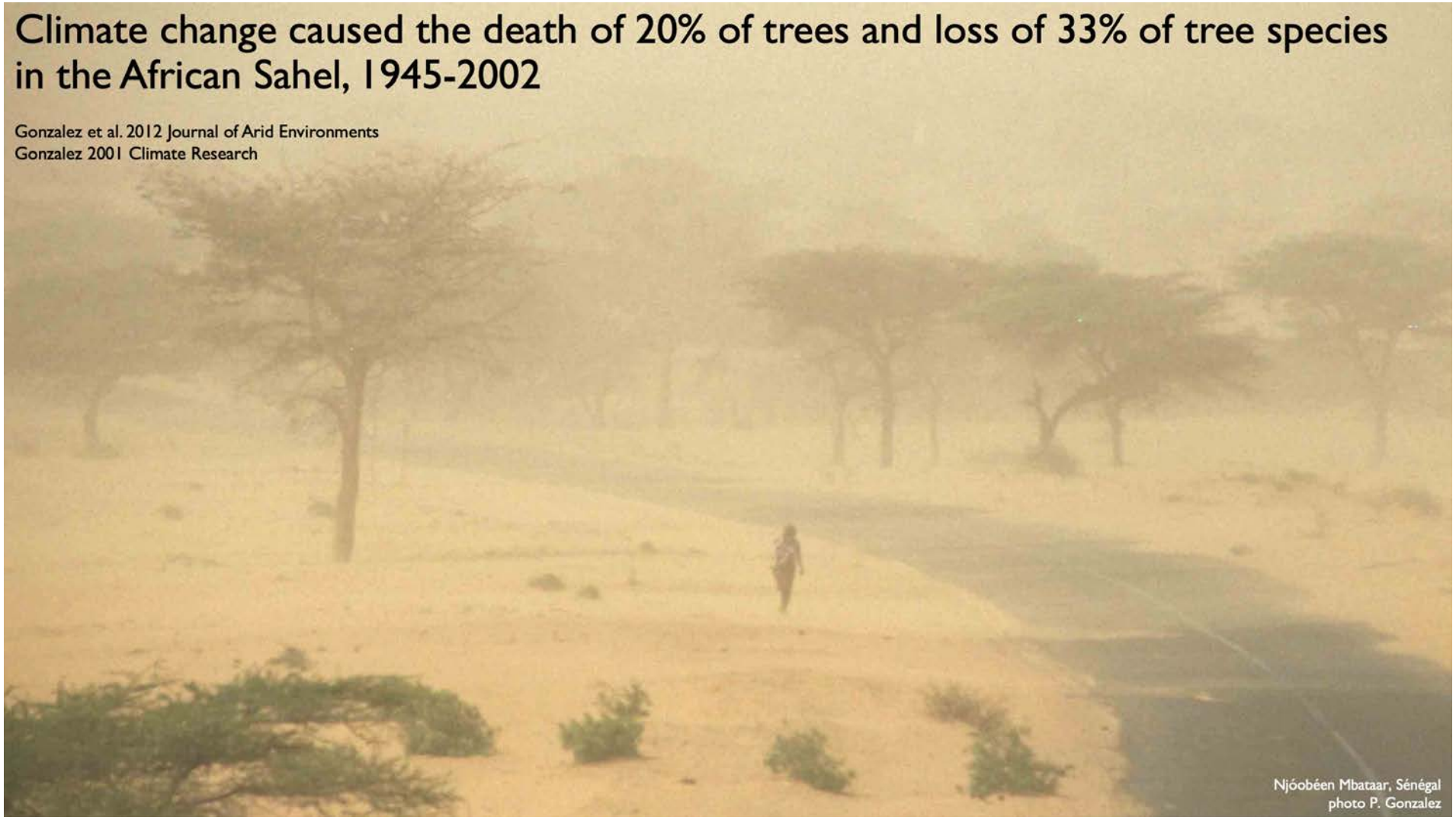
Climate change doubled tree death across the western US 1955-2007 through increased drought, wildfire, and bark beetle infestations

van Mantgem et al. 2009 Science
Fettig et al. 2019 Forest Ecology and Management
Redmond et al. 2018 Journal of Ecology
Berner et al. 2017 Environmental Research Letters

Dead lodgepole pines (*Pinus contorta*)
Rocky Mountain National Park, Colorado, USA
photo P. Gonzalez

Climate change caused the death of 20% of trees and loss of 33% of tree species in the African Sahel, 1945-2002

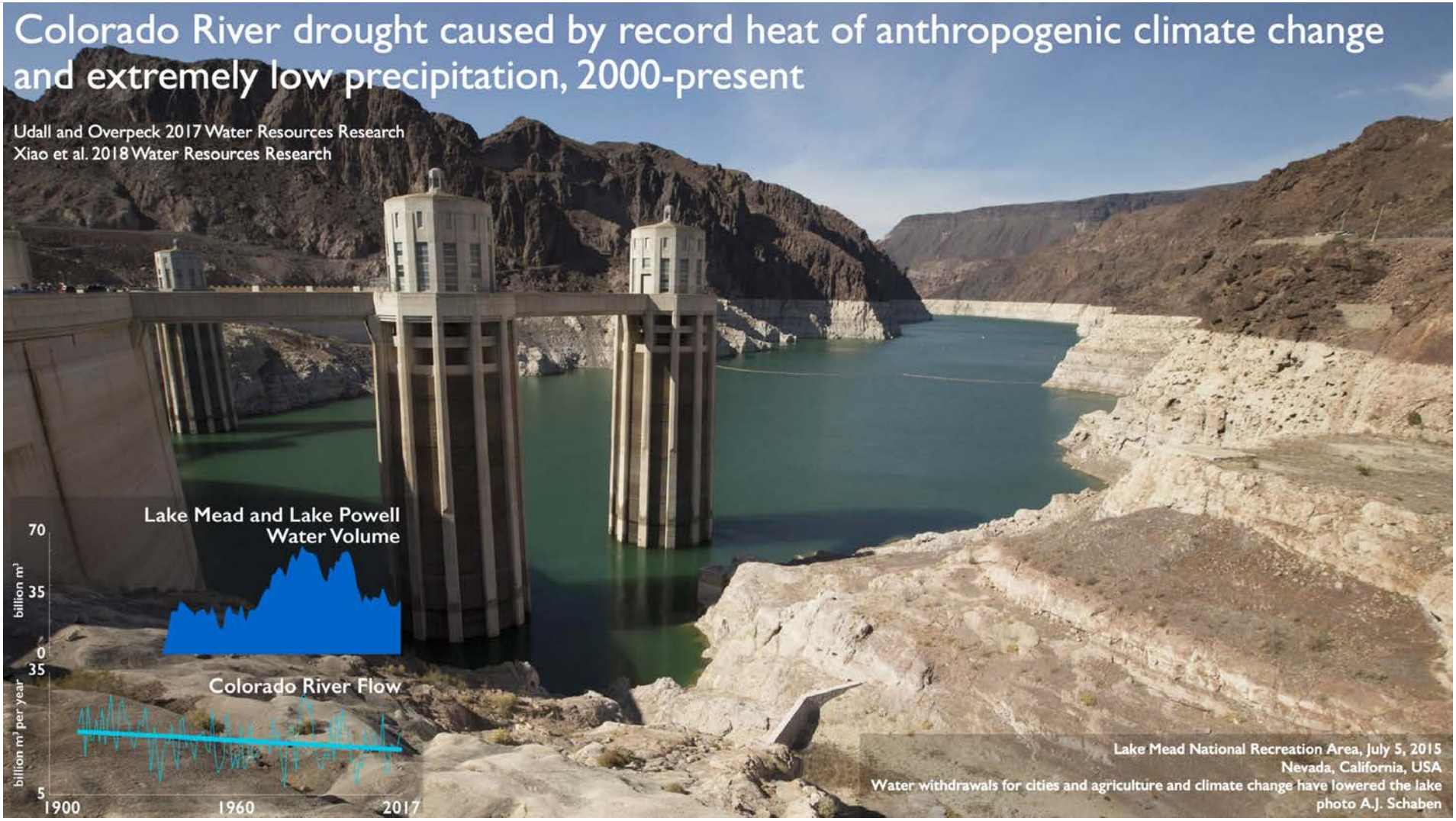
Gonzalez et al. 2012 Journal of Arid Environments
Gonzalez 2001 Climate Research



Njóobéen Mbataar, Sénégal
photo P. Gonzalez

Colorado River drought caused by record heat of anthropogenic climate change and extremely low precipitation, 2000-present

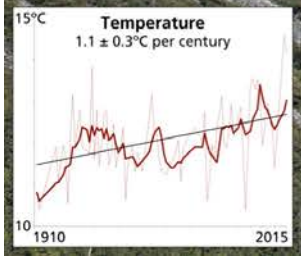
Udall and Overpeck 2017 Water Resources Research
Xiao et al. 2018 Water Resources Research



Lake Mead National Recreation Area, July 5, 2015
Nevada, California, USA
Water withdrawals for cities and agriculture and climate change have lowered the lake
photo A.J. Schaben

Climate change has shifted the temperate conifer forest biome upslope into subalpine grassland in Yosemite National Park, 1880-2002

Millar et al. 2004 Arctic, Antarctic, and Alpine Research
Lubetkin et al. 2017 Ecological Applications



Weather station, Hetch Hetchy
data NOAA, analysis P. Gonzalez

Yosemite National Park, California, USA
photo P. Gonzalez


Climate change has shifted boreal forest onto tundra
in Noatak National Preserve, 1800-1980
Suarez et al. 1999 Ecoscience
Noatak National Preserve, Alaska USA
photo © D. Betchkal

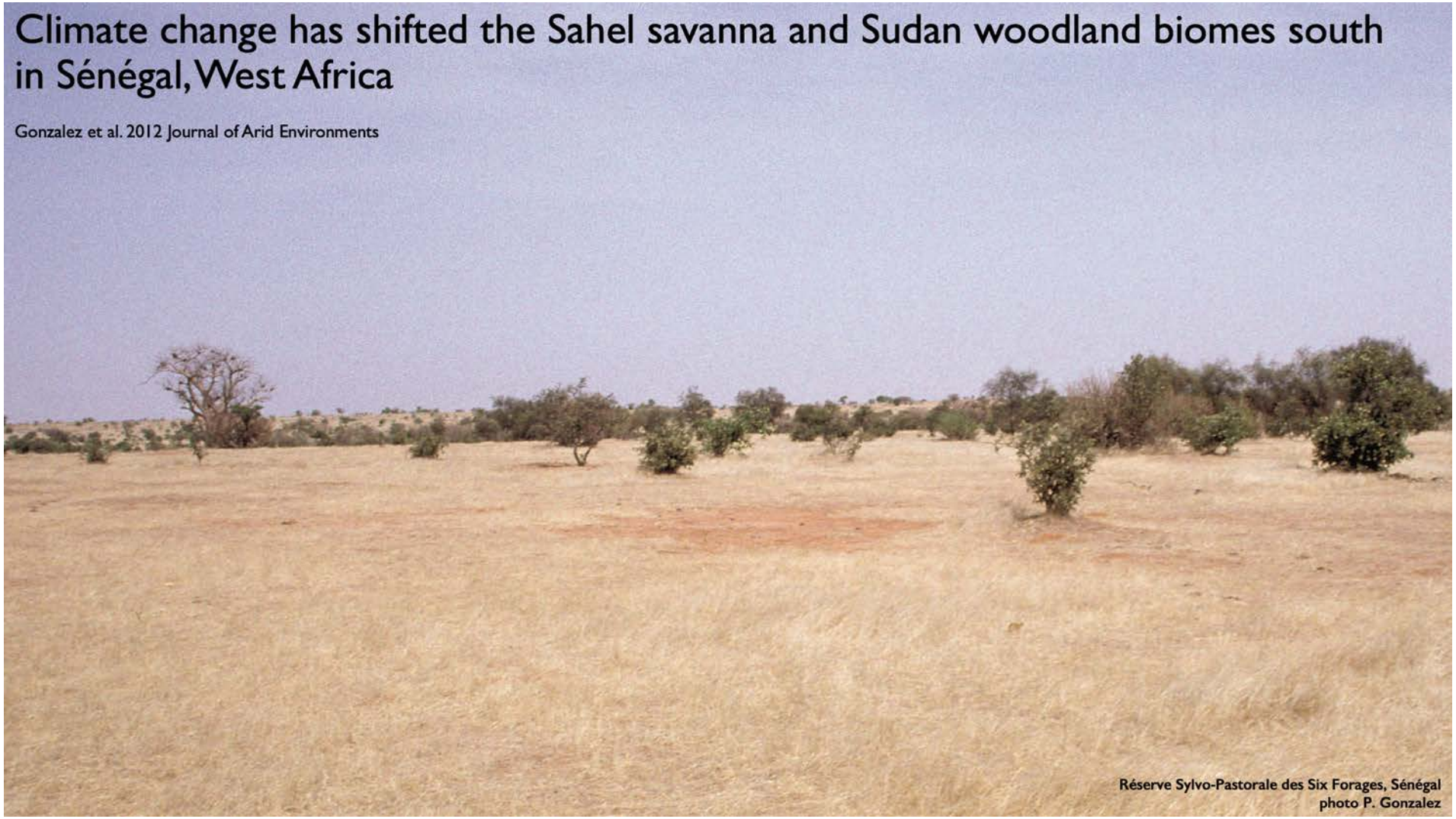
Climate change has shifted temperate broadleaf forest upslope into sub-alpine shrubland in New Zealand

Wardle and Coleman 1992 New Zealand Journal of Botany

Fjordland National Park, New Zealand
photo P. Gonzalez

Climate change has shifted the Sahel savanna and Sudan woodland biomes south in Sénégal, West Africa

Gonzalez et al. 2012 Journal of Arid Environments



Réserve Sylvo-Pastorale des Six Forages, Sénégal
photo P. Gonzalez

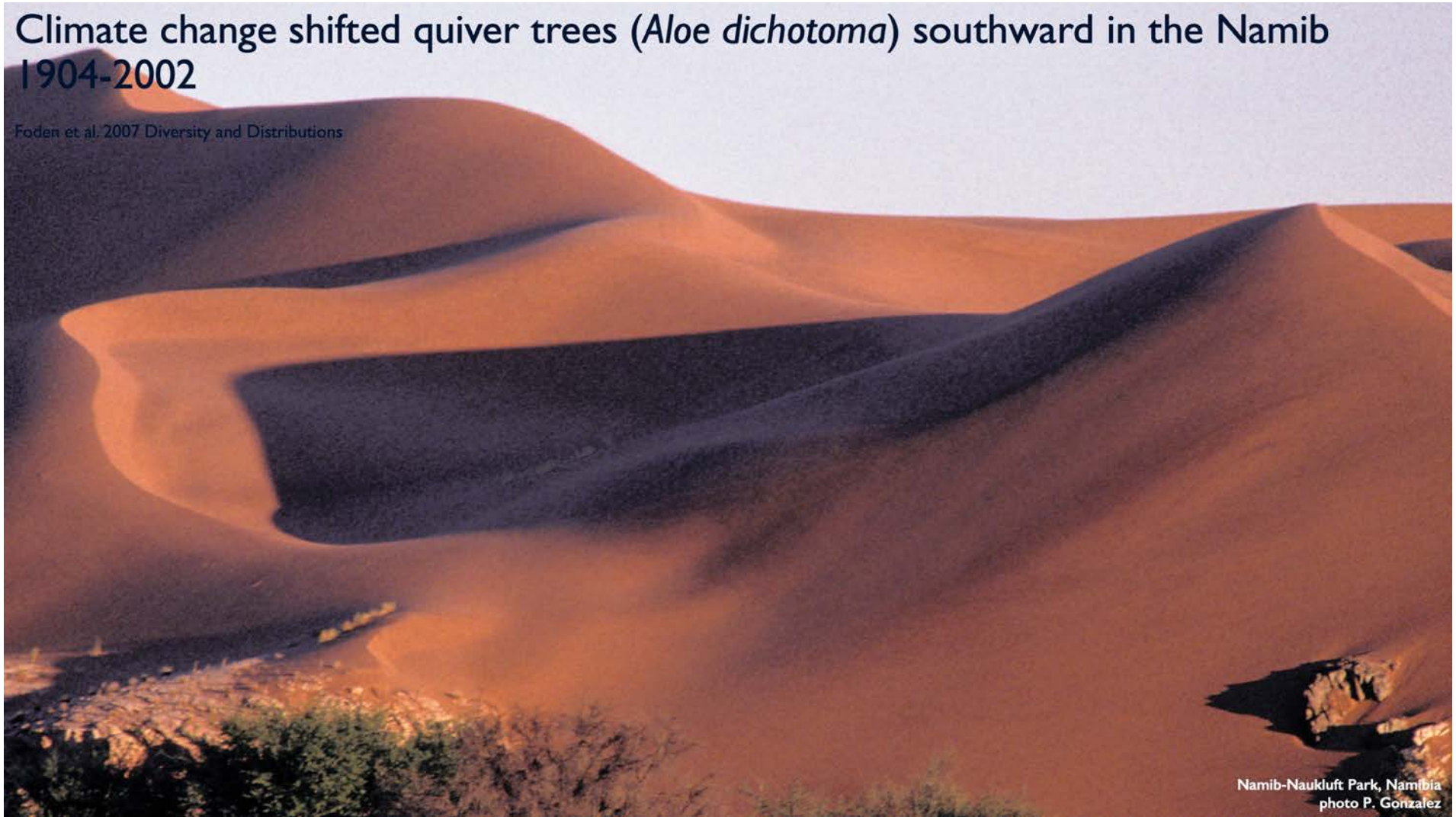
Warmer night temperatures have reduced tropical forest biomass in Costa Rica

Clark et al. 2003. Proceedings of the National Academy of Sciences of the USA
Clark et al. 2010. Global Change Biology

Estación Biológica La Selva, Costa Rica
photo P. Gonzalez

Climate change shifted quiver trees (*Aloe dichotoma*) southward in the Namib 1904-2002

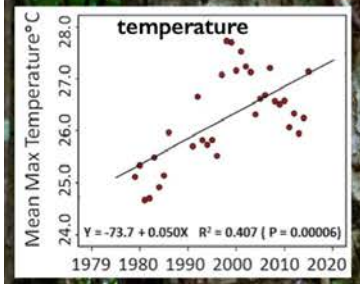
Foden et al. 2007 Diversity and Distributions

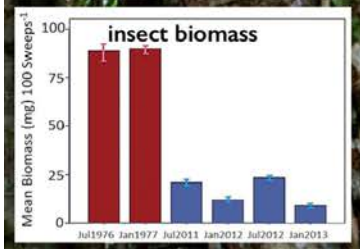


Namib-Naukluft Park, Namibia
photo P. Gonzalez

Climate change reduced forest insect abundance 75-98% in Puerto Rico, 1976-2012

Lister and Garcia 2018 Proceedings of the National Academy of Sciences of the USA



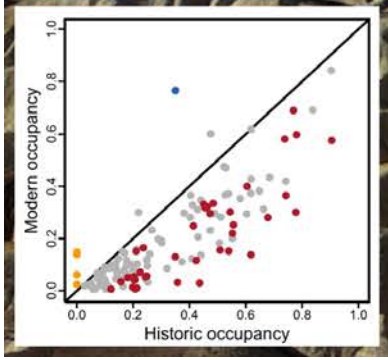


walking stick (*Lamponius portoricensis*)
Luquillo Experimental Forest, Puerto Rico, USA
photo Aurea Moragón

Luquillo Experimental Forest, Puerto Rico, USA
to Long-Term Ecological Research Network

Climate change reduced bird species richness 40% in Mojave Desert national parks and protected areas, 1908-2016

Iknayan and Beissinger 2018 Proceedings of the National Academy of Sciences of the USA



Western bluebird (*Sialia mexicana*)
photo Dawn Coyote

Death Valley National Park, California, USA
photo US National Park Service

Climate change shifted winter bird abundance 30 km north across the US, including 54 national parks, 1975-2004

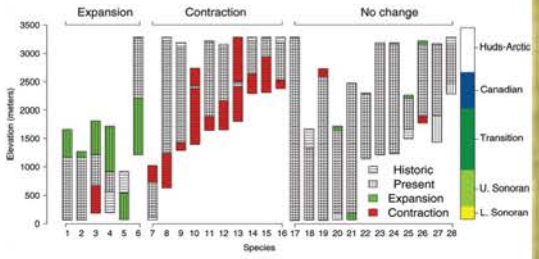
La Sorte and Thompson 2007 Ecology

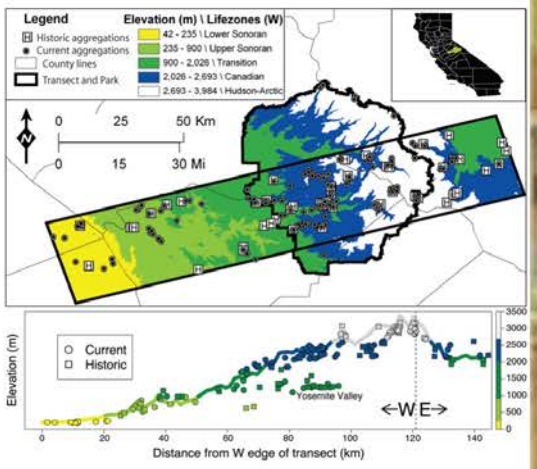
Evening Grosbeak (*Coccothraustes vespertinus*)
Extirpation across US (larger dots)
photo D. Vickers

Sleeping Bear Dunes National Lakeshore
Michigan, USA
photo W. Bond

Climate change shifted small mammal ranges upslope in Yosemite National Park 1920-2006

Moritz et al. 2008 Science

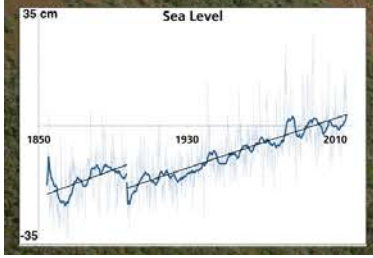




Sierra Golden-mantled (*Spermophilus lateralis*) and Belding ground squirrels (*Spermophilus beldingi*)
Yosemite National Park, California, USA
Drawing by Major Allan Brooks, ca. 1928

Climate change has raised sea level 22 cm in Golden Gate National Recreation Area, 1854-2018

Slangen et al. 2016 Nature Climate Change
Church and White 2011 Surveys in Geophysics
Intergovernmental Panel on Climate Change 2013

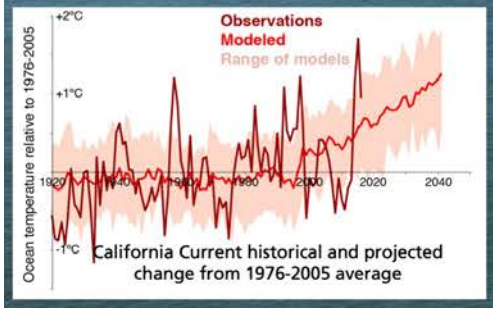


Tidal gauge, San Francisco
National Oceanic and Atmospheric Administration

San Francisco and Golden Gate National Recreation Area
California, USA, photo P. Gonzalez

Climate change has warmed Pacific Ocean waters of the California Current 0.8 ± 0.2°C, 1920-2016

Jacox et al. 2018 Bulletin of the American Meteorological Society
Rayner et al. 2003 Journal of Geophysical Research
Intergovernmental Panel on Climate Change 2013

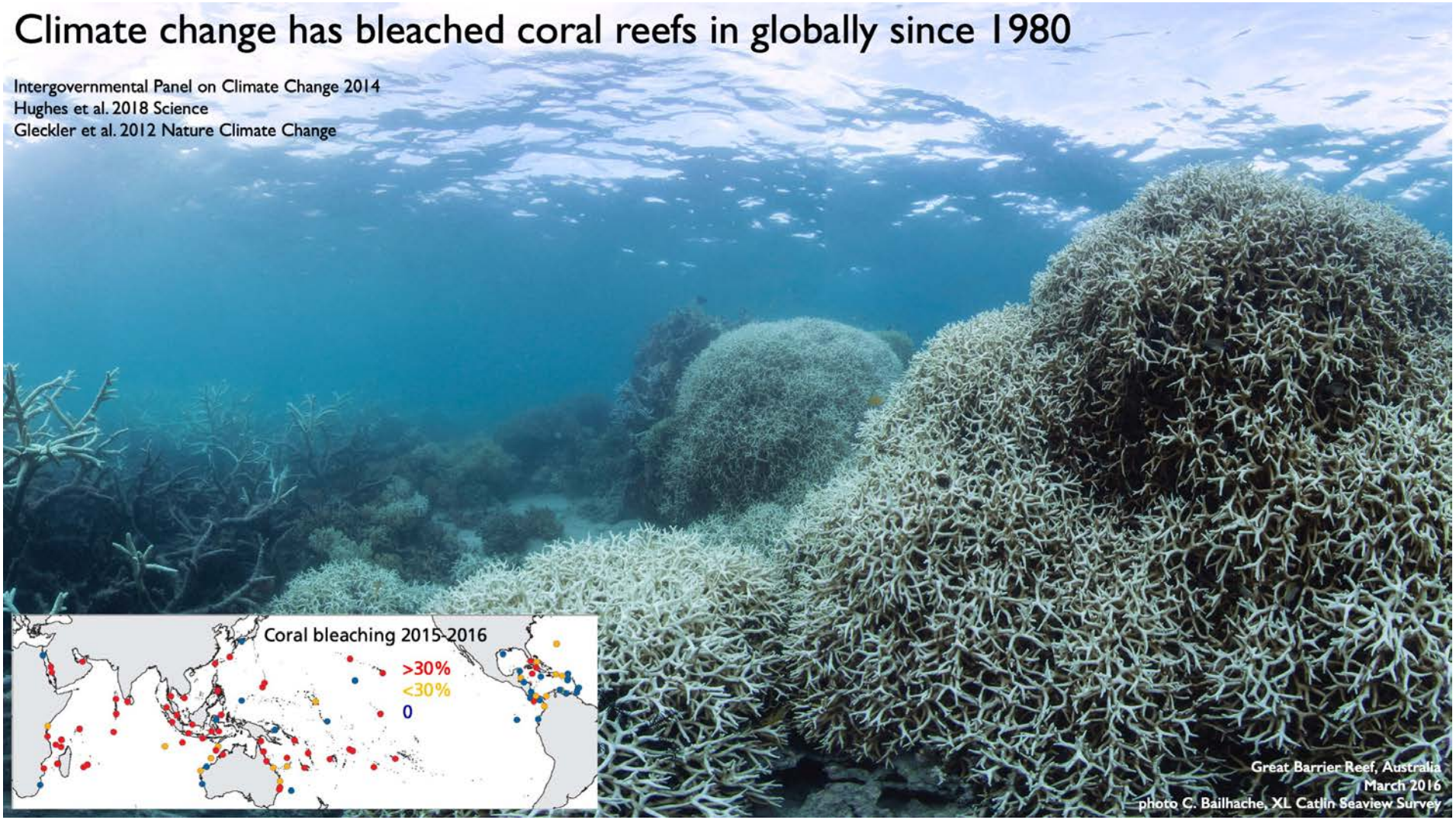


California Current historical and projected change from 1976-2005 average

Point Bonita, Golden Gate National Recreation Area
California USA
photo P. Gonzalez

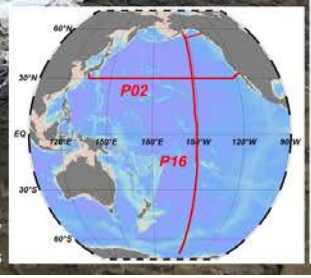
Climate change has bleached coral reefs in globally since 1980

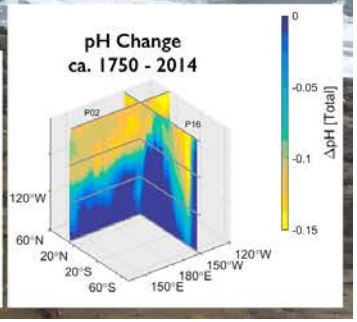
Intergovernmental Panel on Climate Change 2014
Hughes et al. 2018 Science
Gleckler et al. 2012 Nature Climate Change



Climate change has acidified Pacific Ocean waters +40% (-0.15 pH) ca. 1750–2014

Carter et al. 2017 Global Biogeochemical Cycles
Intergovernmental Panel on Climate Change 2013





Carter et al. 2017
Global Biogeochemical Cycles

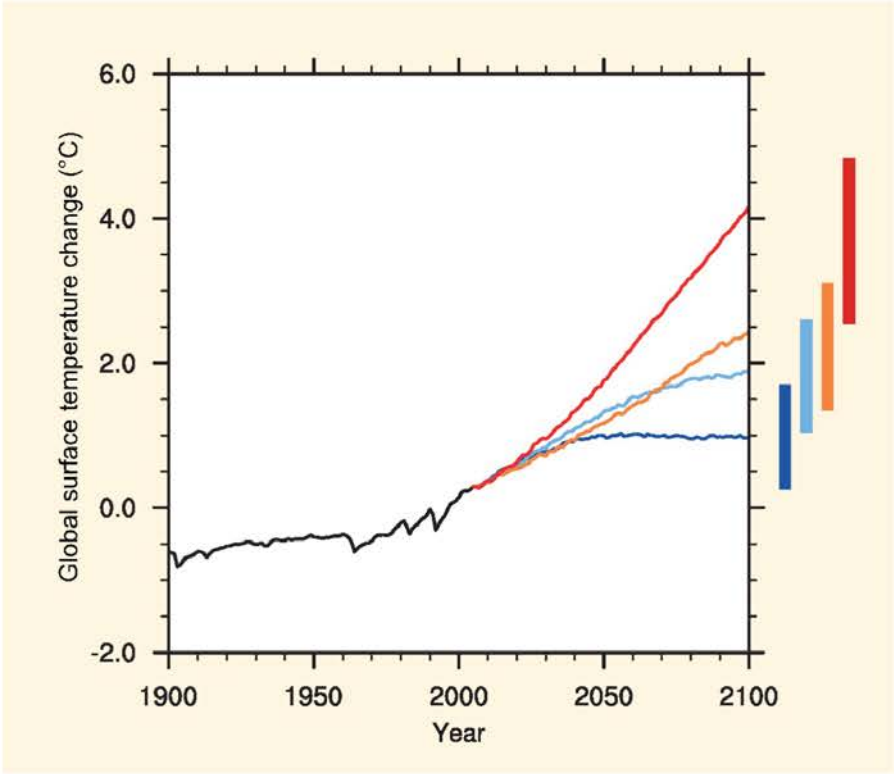
Cabrillo National Monument
California USA
photo P. Gonzalez

Anthropogenic Climate Change in Ecosystems and Protected Areas

1. Human cause of climate change
2. Historical impacts
3. Future risks
4. Adaptation
5. Carbon solutions

Berkeley
UNIVERSITY OF CALIFORNIA

Climate change projections



Four emissions scenarios

RCP8.5 Highest emissions

RCP6.0 High emissions

RCP4.5 Low emissions

RCP2.6 Emissions reductions

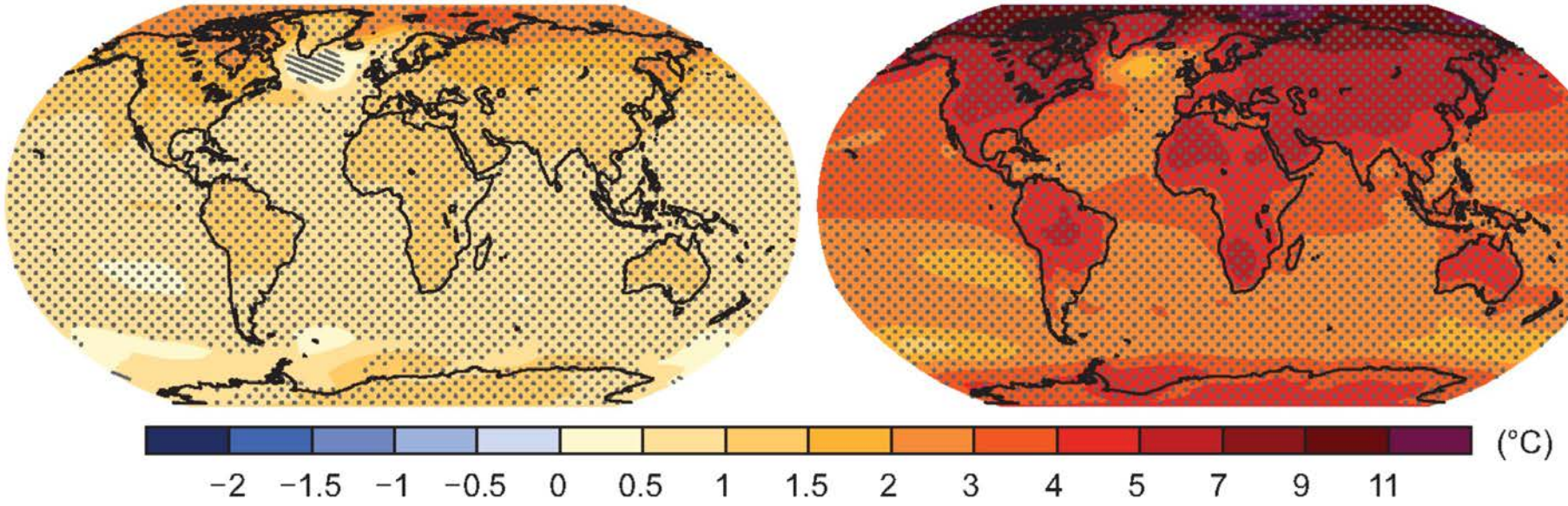
Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

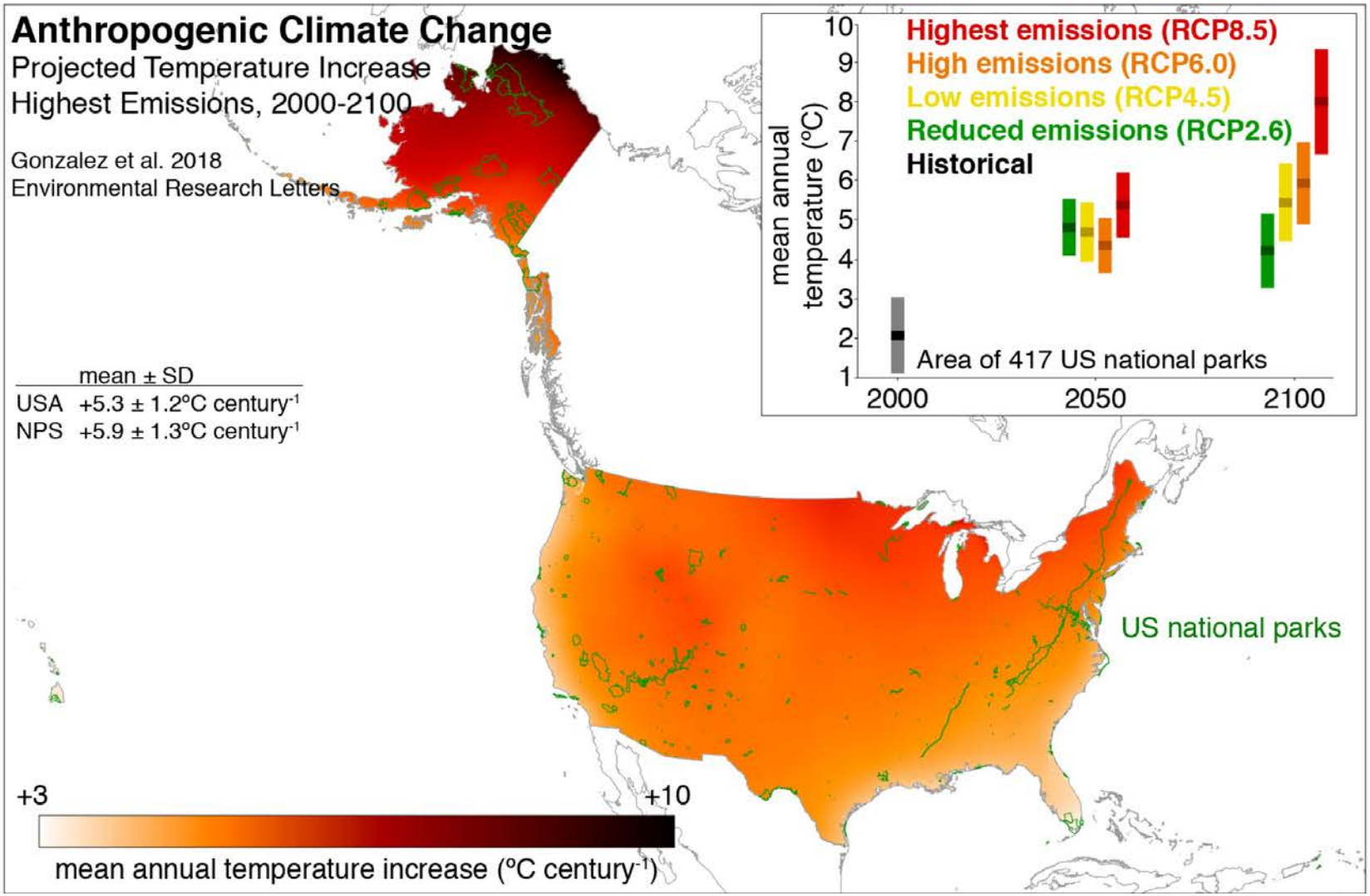
Projected Temperature Change 2005-2100 +1 to 3.7°C per century

Emissions Reductions Scenario (RCP2.6)

Highest Emissions Scenario (RCP8.5)



Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, New York, NY.

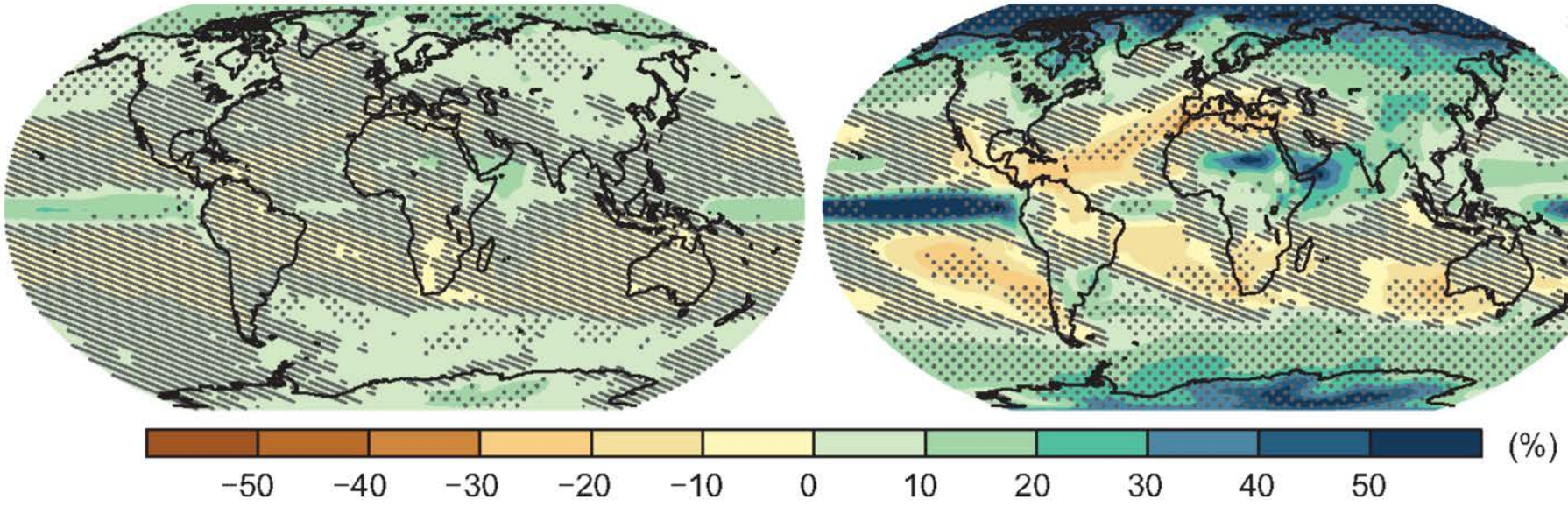

Anthropogenic Climate Change
Projected Temperature Increase
Highest Emissions, 2000-2100
Gonzalez et al. 2018
Environmental Research Letters
mean ± SD
USA +5.3 ± 1.2°C century-1
NPS +5.9 ± 1.3°C century-1
mean annual temperature (°C)
10
9
8
7
6
5
4
3
2
1
2000
2050
2100
Highest emissions (RCP8.5)
High emissions (RCP6.0)
Low emissions (RCP4.5)
Reduced emissions (RCP2.6)
Historical
Area of 417 US national parks
US national parks
+3
+10
mean annual temperature increase (°C century-1)

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

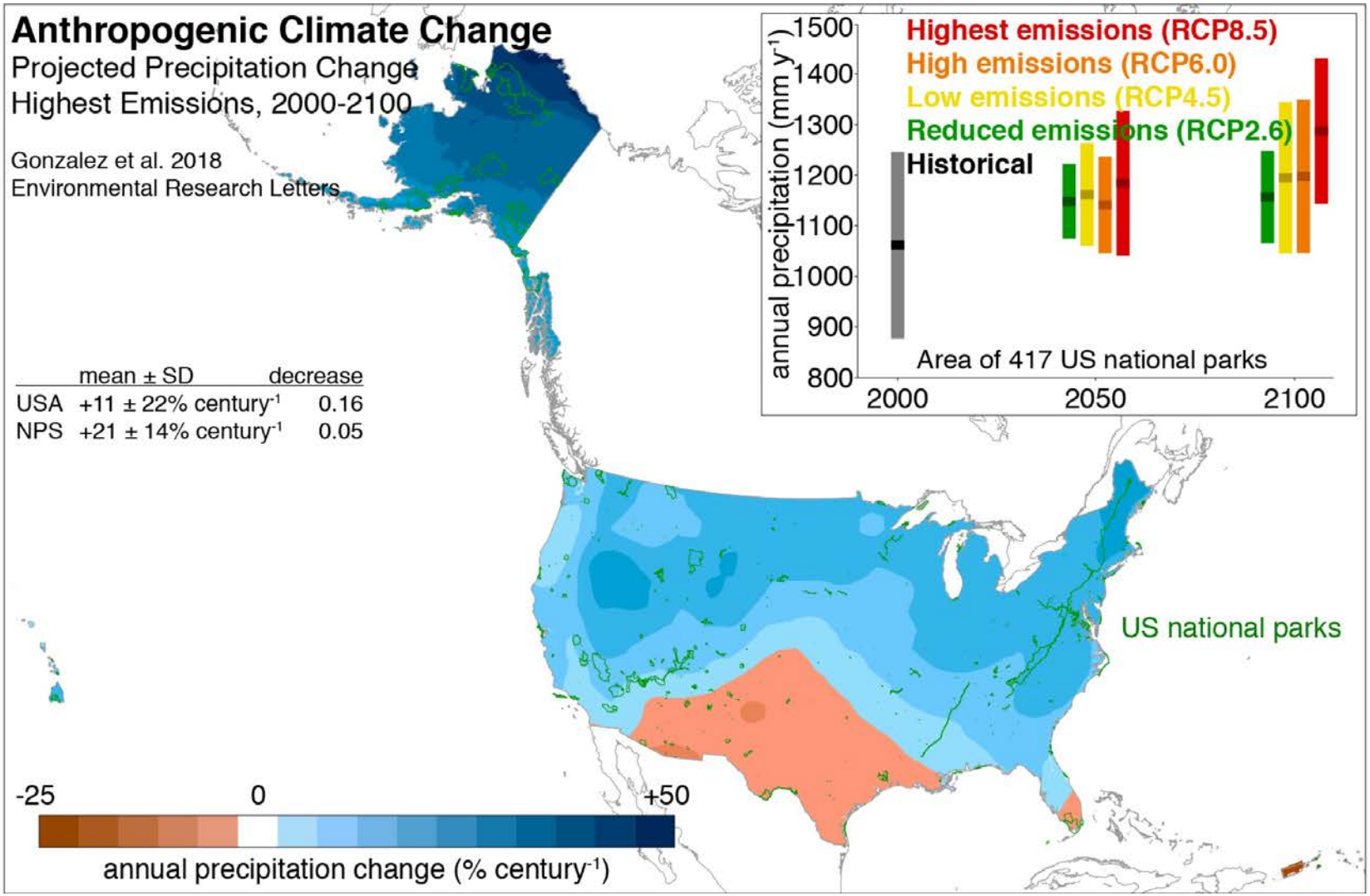
Projected Precipitation Change 2005-2100 +0.5 to 11% per century

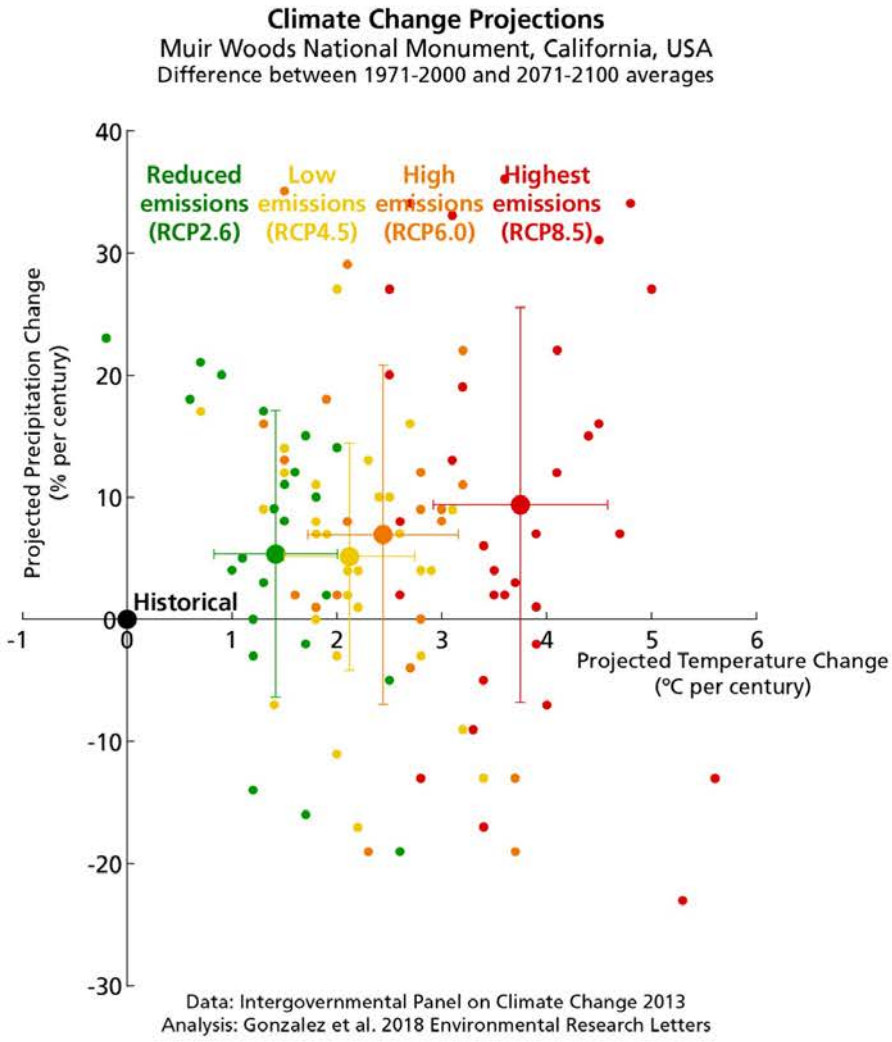
Emissions Reductions Scenario (RCP2.6)

Highest Emissions Scenario (RCP8.5)



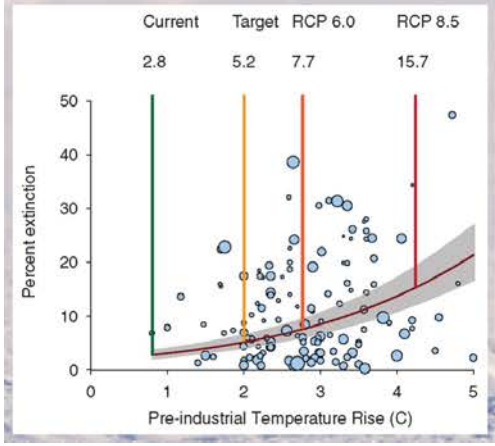
Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, New York, NY.


Anthropogenic Climate Change
Projected Precipitation Change
Highest Emissions, 2000-2100
Gonzalez et al. 2018
Environmental Research Letters
mean ± SD
decrease
USA +11 ± 22% century-1 0.16
NPS +21 ± 14% century-1 0.05
Highest emissions (RCP8.5)
High emissions (RCP6.0)
Low emissions (RCP4.5)
Reduced emissions (RCP2.6)
Historical
annual precipitation (mm y-1)
1500
1400
1300
1200
1100
1000
900
800
2000
2050
2100
Area of 417 US national parks
US national parks
-25
0
+50
annual precipitation change (% century-1)


Climate Change Projections
Muir Woods National Monument, California, USA
Difference between 1971-2000 and 2071-2100 averages
Reduced emissions (RCP2.6)
Low emissions (RCP4.5)
High emissions (RCP6.0)
Highest emissions (RCP8.5)
Projected Precipitation Change (% per century)
Projected Temperature Change (°C per century)
Historical
40
30
20
10
0
-10
-20
-30
-1
0
1
2
3
4
5
6
Data: Intergovernmental Panel on Climate Change 2013
Analysis: Gonzalez et al. 2018 Environmental Research Letters

Climate change increases risks of animal and plant extinctions up to five times historical rates

Urban 2015 Science

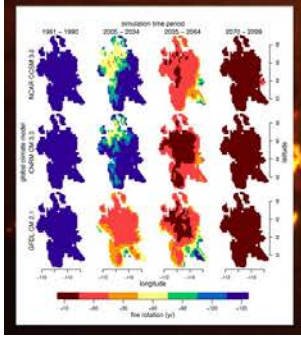


Polar bear (*Ursus maritimus*)
Listed under the Endangered Species Act as threatened
Arctic National Wildlife Refuge, Alaska, USA
photo C. Donohue

Climate change could increase fire frequency 300-1000% by 2100 in Yellowstone National Park

Westerling et al. 2011 Proceedings of the National Academy of Sciences of the USA

High Emissions Scenario A2



Norris Geyser Basin, August 20, 1988
Yellowstone National Park, Wyoming, USA
photo Jeff Henry

Climate change increases risks of tree mortality of up to a half in conifer forests of the Southwest

McDowell et al. 2016 Nature Climate Change
Buotte et al. 2019 Global Change Biology
Goulden and Bales 2019 Nature Geoscience

Yosemite National Park, California USA
photo P. Gonzalez

Indonesian rainforest is vulnerable to dieback at temperature increases above 4°C

Zelazowski et al. 2010 Proceedings of the Royal Society A

Taman Nasional Gunung Leuser (National Park)
Sumatra, Indonesia
photo P. Gonzalez

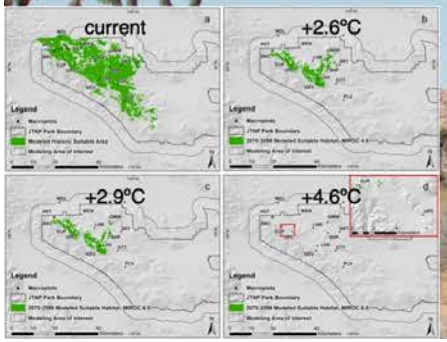
Climate change increases widespread risks of invasive species

Early et al. 2016 Nature Communications
Baxendale and Tessier 2015 Plant Species Biology

Volunteers pulling Japanese knotweed (*Fallopia japonica*)
Rock Creek Park, Washington, DC, USA
photo C. Ferranto

Climate change increases risk of mortality of Joshua trees in Joshua Tree National Park

Sweet et al. 2019 Ecography
Barrows and Murphy-Mariscal 2012 Biological Conservation
Cole et al. 2011 Ecological Applications
Dole et al. 2003 Global and Planetary Change



Joshua trees (*Yucca brevifolia*)
Joshua Tree National Park, California, USA
photo P. Gonzalez

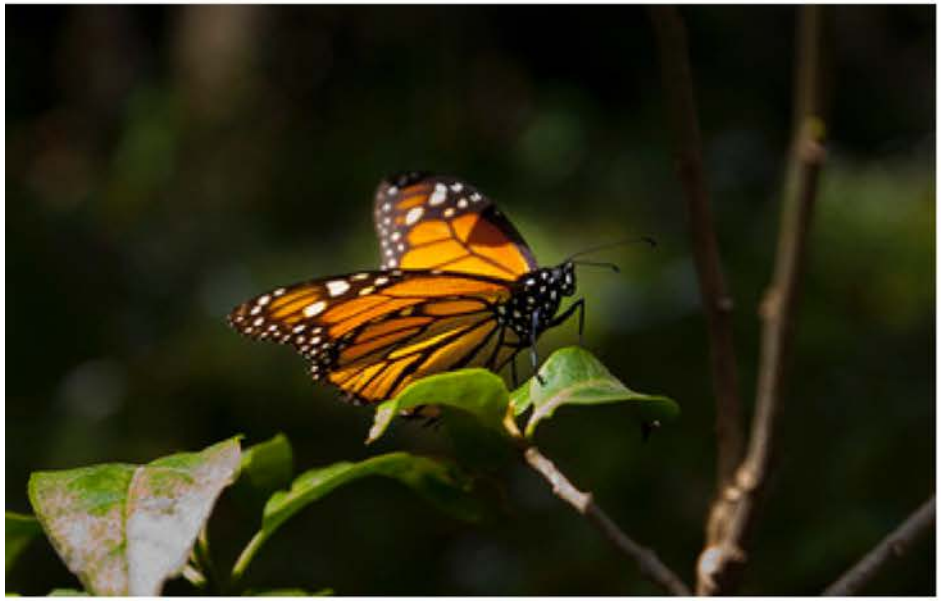
Island ecosystems particularly vulnerable to invasive species under climate change due to small populations and evolutionary isolation

Intergovernmental Panel on Climate Change 2014
Russell et al. 2017 Environmental Conservation
Harter et al. 2015 Perspectives in Plant Ecology, Evolution, and Systematics

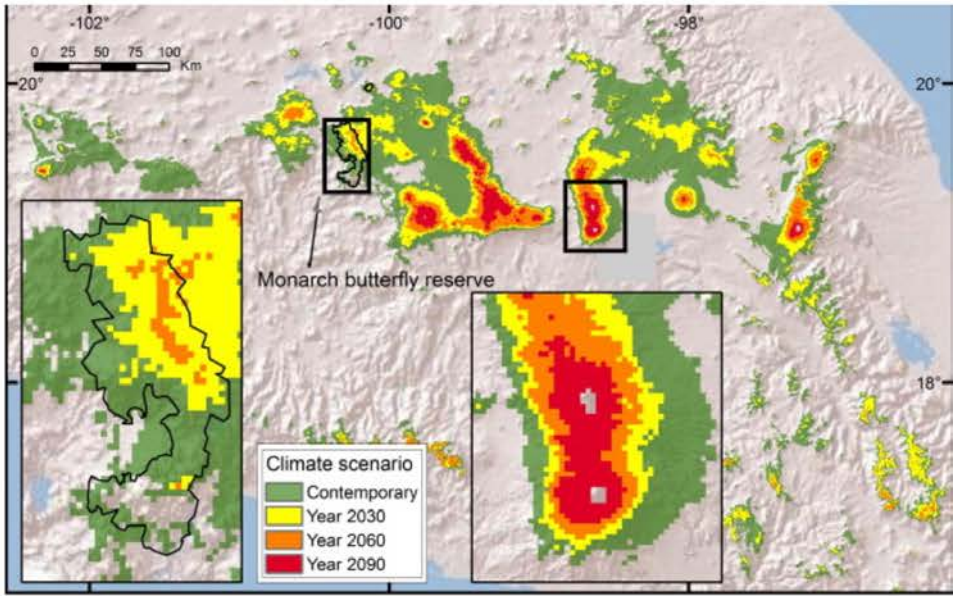
Low thickets of Chinese guava (*Psidium cattleianum*)
Black River Gorges National Park, Mauritius

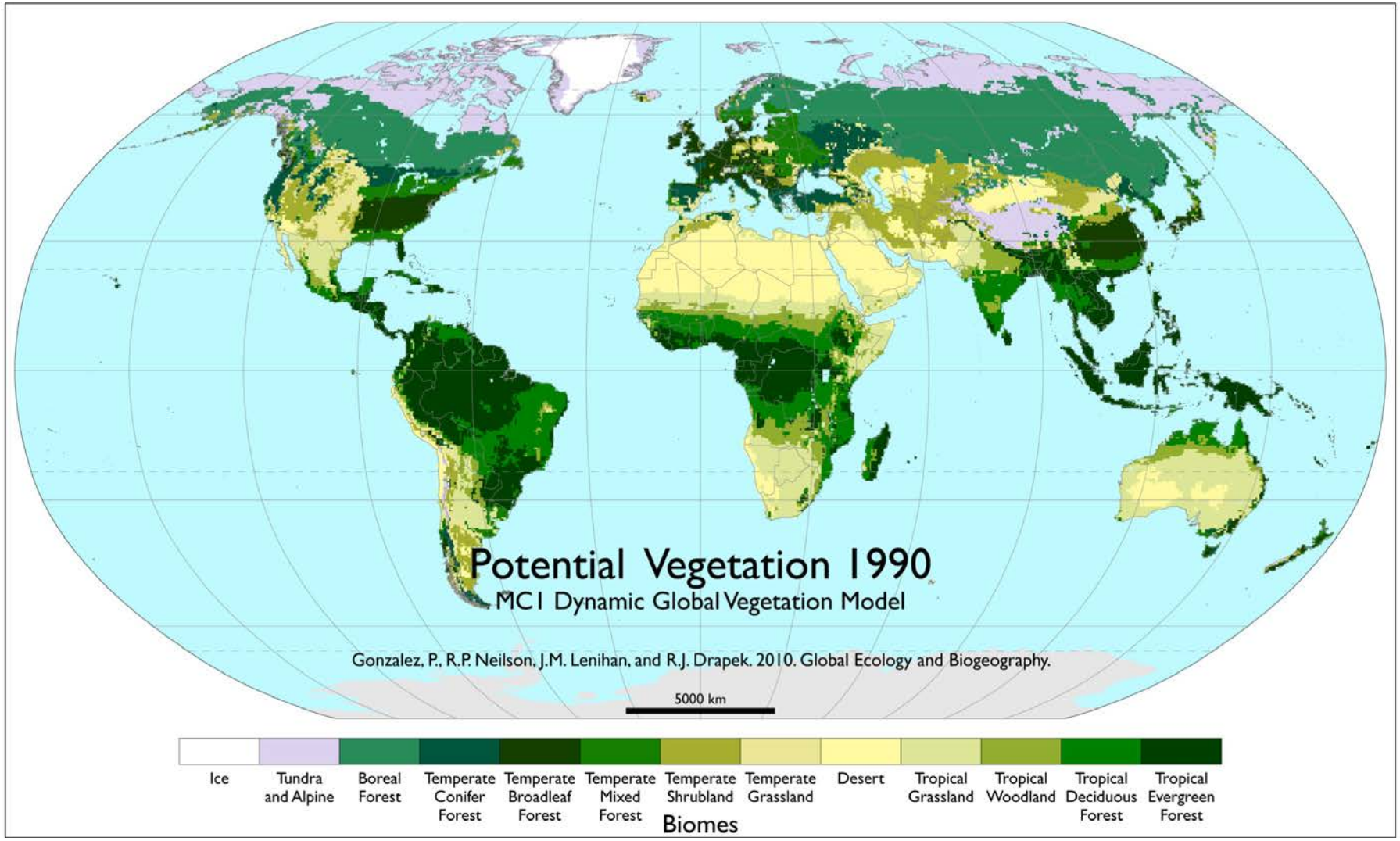
Climate change increases risk to the Monarch butterfly of an upslope shift and loss of oyamel pine (*Abies religiosa*) habitat in Mexico

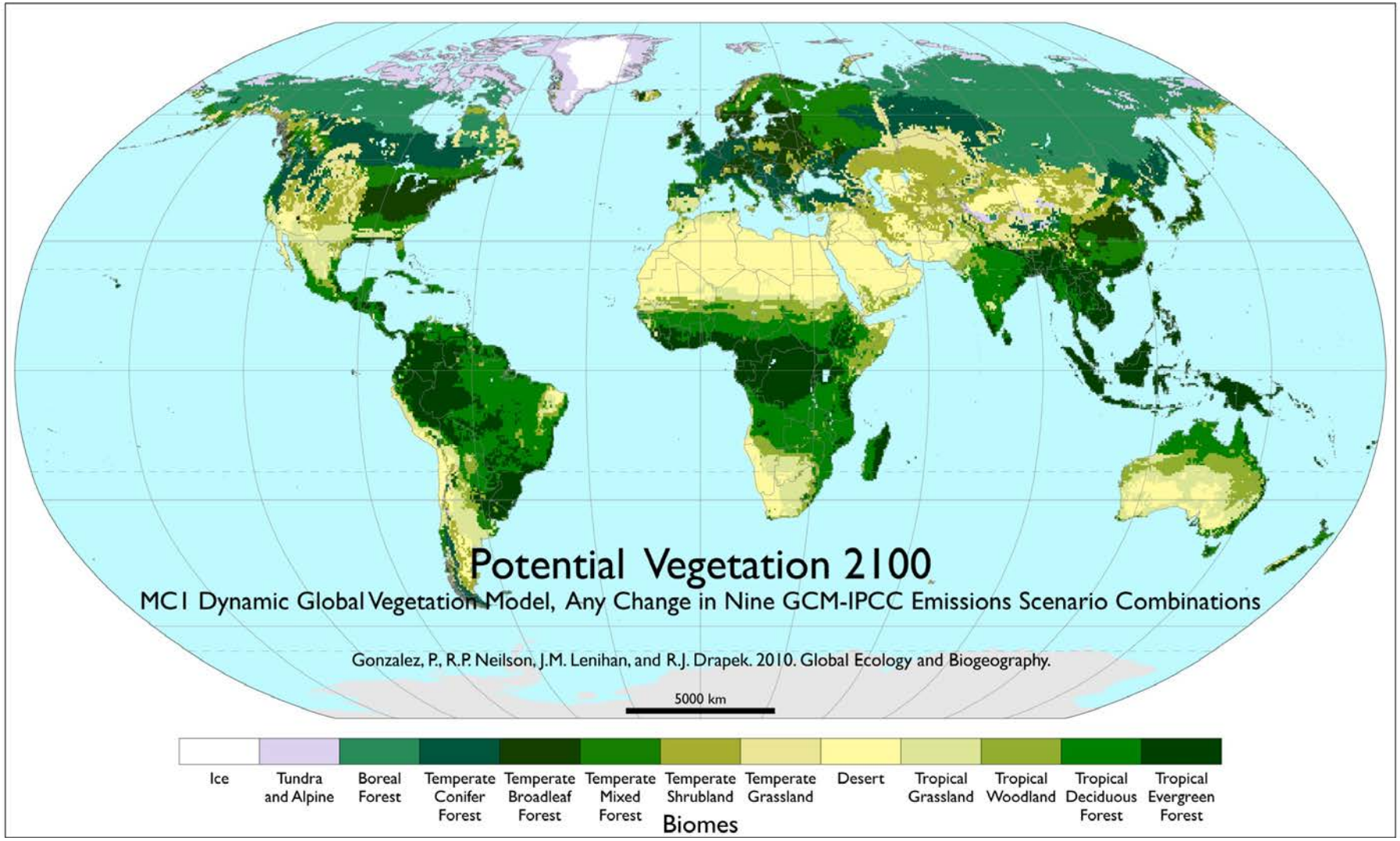
Sáenz-Romero et al. 2012 Forest Ecology and Management
Brower et al. 2009 Insect Conservation and Diversity

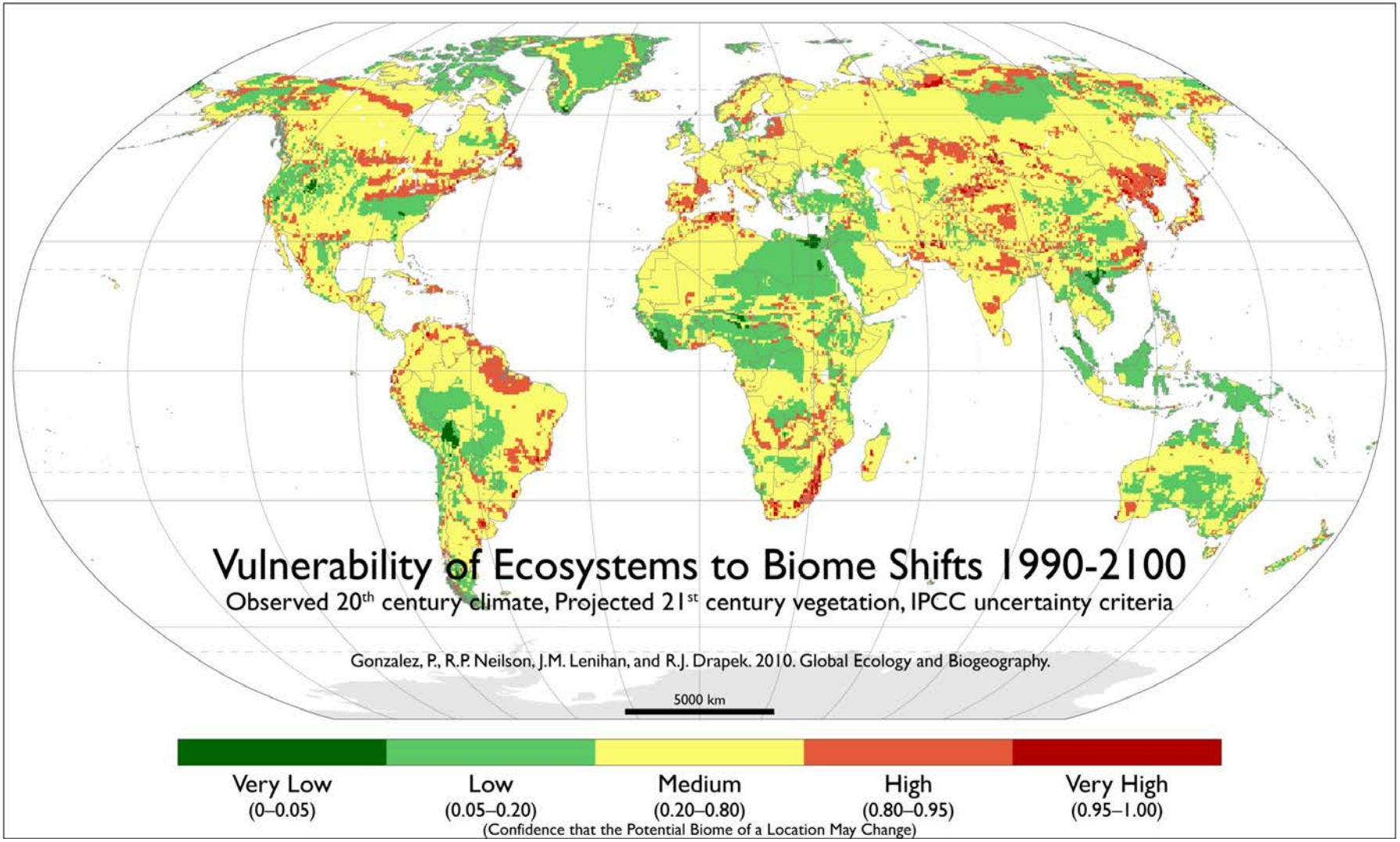


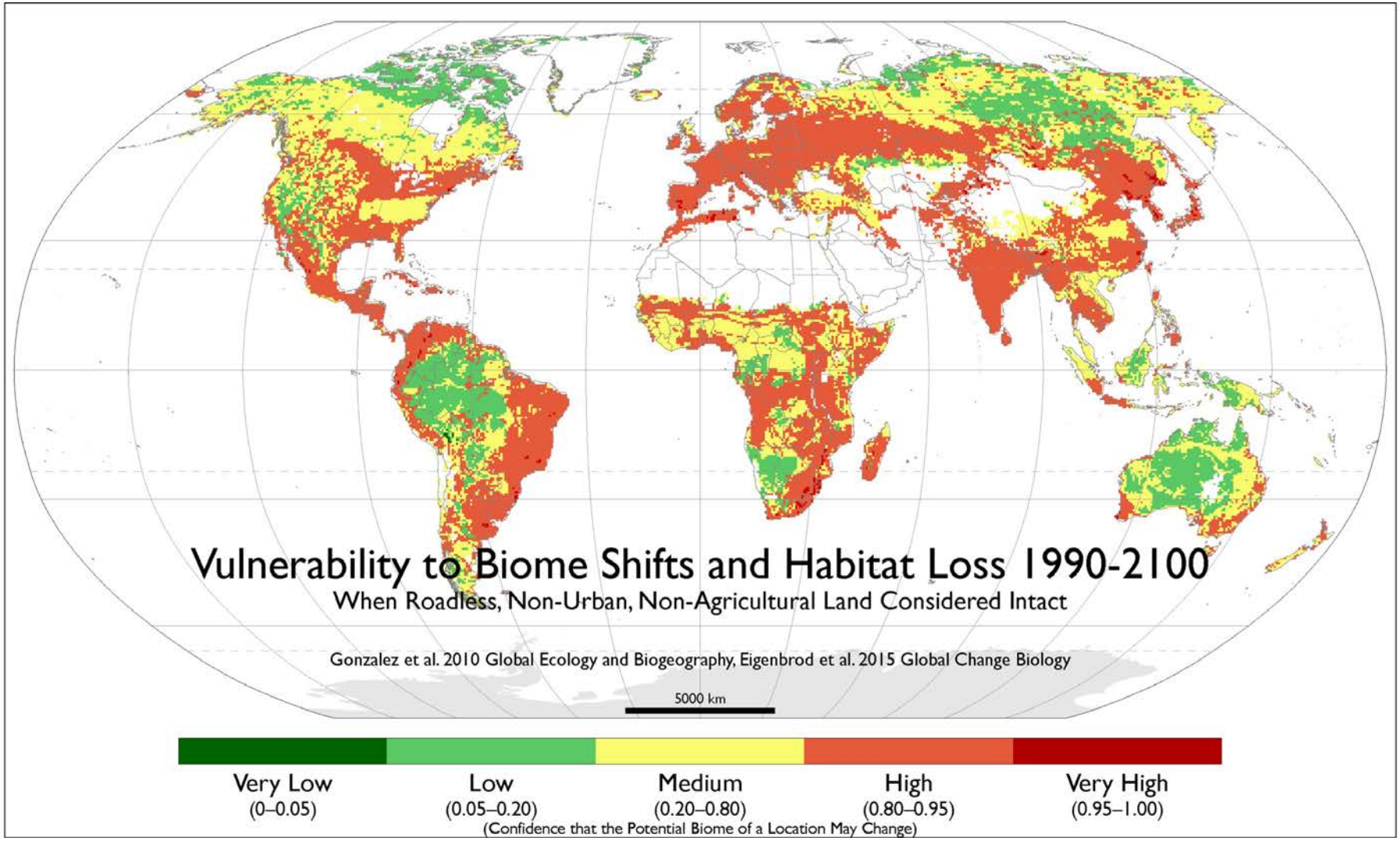
Mariposa monarca (*Danaus plexippus*)
photo Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México




Potential Vegetation 1990
MC1 Dynamic Global Vegetation Model
Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global Ecology and Biogeography.
5000 km
Ice
Tundra and Alpine
Boreal Forest
Temperate Conifer Forest
Temperate Broadleaf Forest
Temperate Mixed Forest
Temperate Shrubland
Temperate Grassland
Desert
Tropical Grassland
Tropical Woodland
Tropical Deciduous Forest
Tropical Evergreen Forest
Biomes

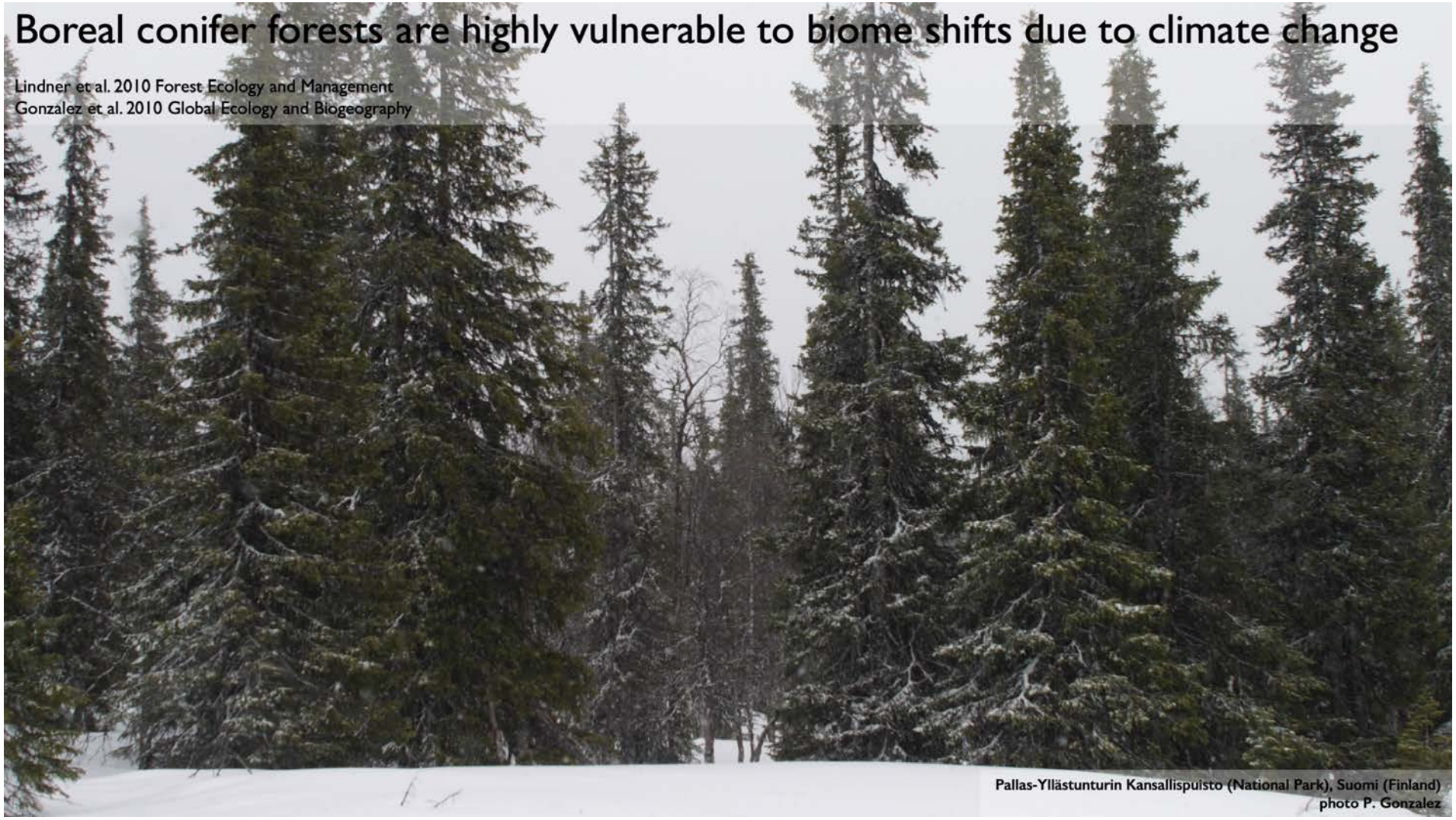

Potential Vegetation 2100
MC1 Dynamic Global Vegetation Model, Any Change in Nine GCM-IPCC Emissions Scenario Combinations
Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global Ecology and Biogeography.
5000 km
Ice
Tundra and Alpine
Boreal Forest
Temperate Conifer Forest
Temperate Broadleaf Forest
Temperate Mixed Forest
Temperate Shrubland
Temperate Grassland
Desert
Tropical Grassland
Tropical Woodland
Tropical Deciduous Forest
Tropical Evergreen Forest
Biomes


Vulnerability of Ecosystems to Biome Shifts 1990-2100
Observed 20th century climate, Projected 21st century vegetation, IPCC uncertainty criteria
Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global Ecology and Biogeography.
5000 km
Very Low
(0–0.05)
Low
(0.05–0.20)
Medium
(0.20–0.80)
High
(0.80–0.95)
Very High
(0.95–1.00)
(Confidence that the Potential Biome of a Location May Change)


Vulnerability to Biome Shifts and Habitat Loss 1990-2100
When Roadless, Non-Urban, Non-Agricultural Land Considered Intact
Gonzalez et al. 2010 Global Ecology and Biogeography, Eigenbrod et al. 2015 Global Change Biology
5000 km
Very Low
(0–0.05)
Low
(0.05–0.20)
Medium
(0.20–0.80)
High
(0.80–0.95)
Very High
(0.95–1.00)
(Confidence that the Potential Biome of a Location May Change)

Boreal conifer forests are highly vulnerable to biome shifts due to climate change

Lindner et al. 2010 Forest Ecology and Management
Gonzalez et al. 2010 Global Ecology and Biogeography



Pallas-Yllästunturin Kansallispuisto (National Park), Suomi (Finland)
photo P. Gonzalez

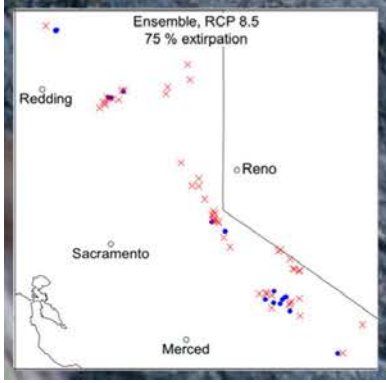
Tropical woodlands are highly vulnerable to biome shifts due to climate change

Gonzalez et al. 2010 Global Ecology and Biogeography

Fig tree (*Ficus sp.*)
Kanha National Park, India
photo P. Gonzalez

Climate change increases the risk of loss of pika from some mountain areas, including Lassen Volcanic National Park

Stewart et al. 2015 Journal of Biogeography
Beever et al. 2016 Journal of Mammalogy

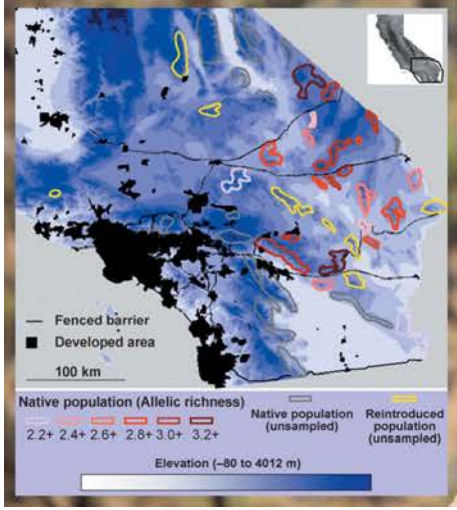


American pika (*Ochotona princeps*)
photo US National Park Service


Radiated tortoise (Geochelone radiata) is vulnerable to heat stress due to climate change and to hunting
Irwin et al. 2010 Biological Conservation
Parc National Tsimanampetsotsa, Madagascar
photo P. Gonzalez

Climate change increases risk of genetic isolation of desert bighorn sheep in southern California due to upslope shifts of suitable climate

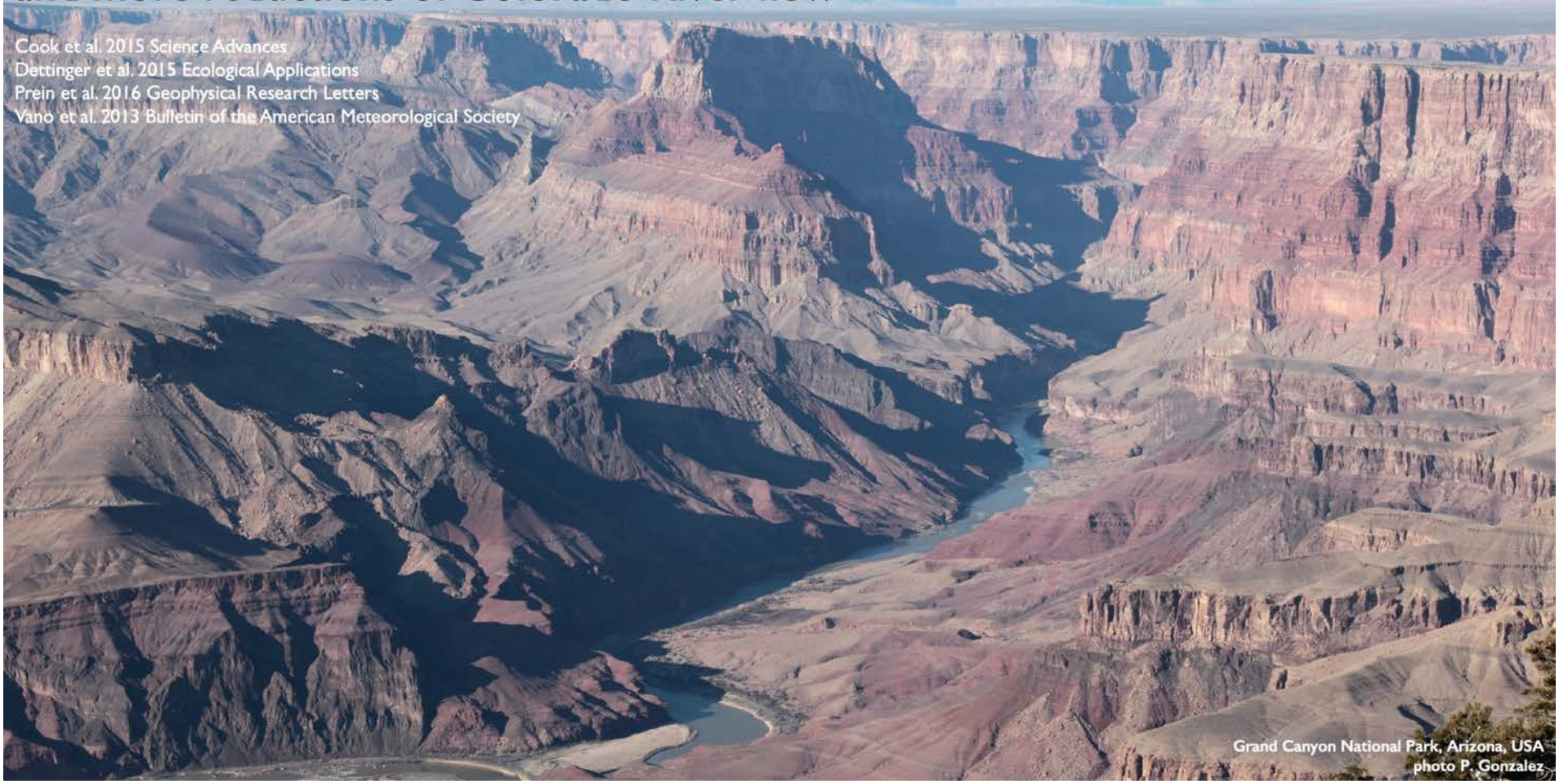
Epps et al. 2004 Conservation Biology
Epps et al. 2006 Molecular Ecology



Desert bighorn sheep (*Ovis canadensis nelsoni*)
Joshua Tree National Park, California, USA
photo G. Puig-Santana

Climate change increases risks of more decade-long droughts in the Southwest and more reductions of Colorado River flow

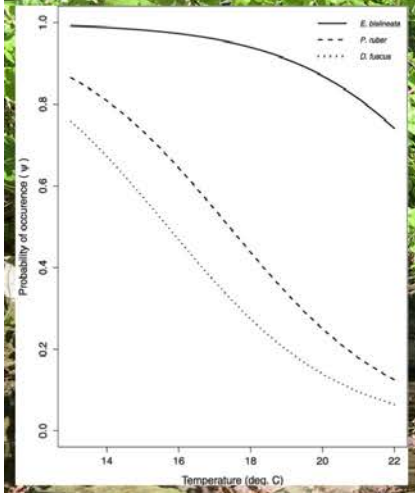
Cook et al. 2015 Science Advances
Dettinger et al. 2015 Ecological Applications
Prein et al. 2016 Geophysical Research Letters
Vano et al. 2013 Bulletin of the American Meteorological Society



Grand Canyon National Park, Arizona, USA
photo P. Gonzalez

Climate change may reduce suitable stream habitat by up to half for salamanders in three mid-Atlantic national parks

Grant et al. 2014 Journal of Herpetology



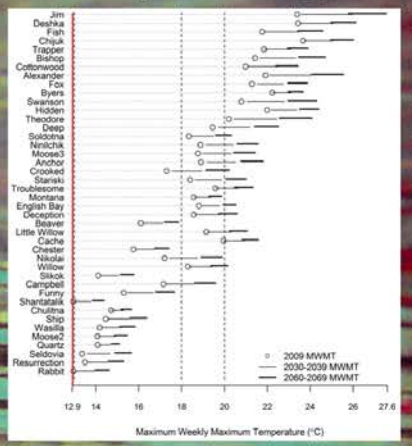
Northern red salamander (*Pseudotriton ruber*)
photo P. Sattler

Chesapeake and Ohio Canal
National Historical Park
Prince William Forest Park
Rock Creek Park

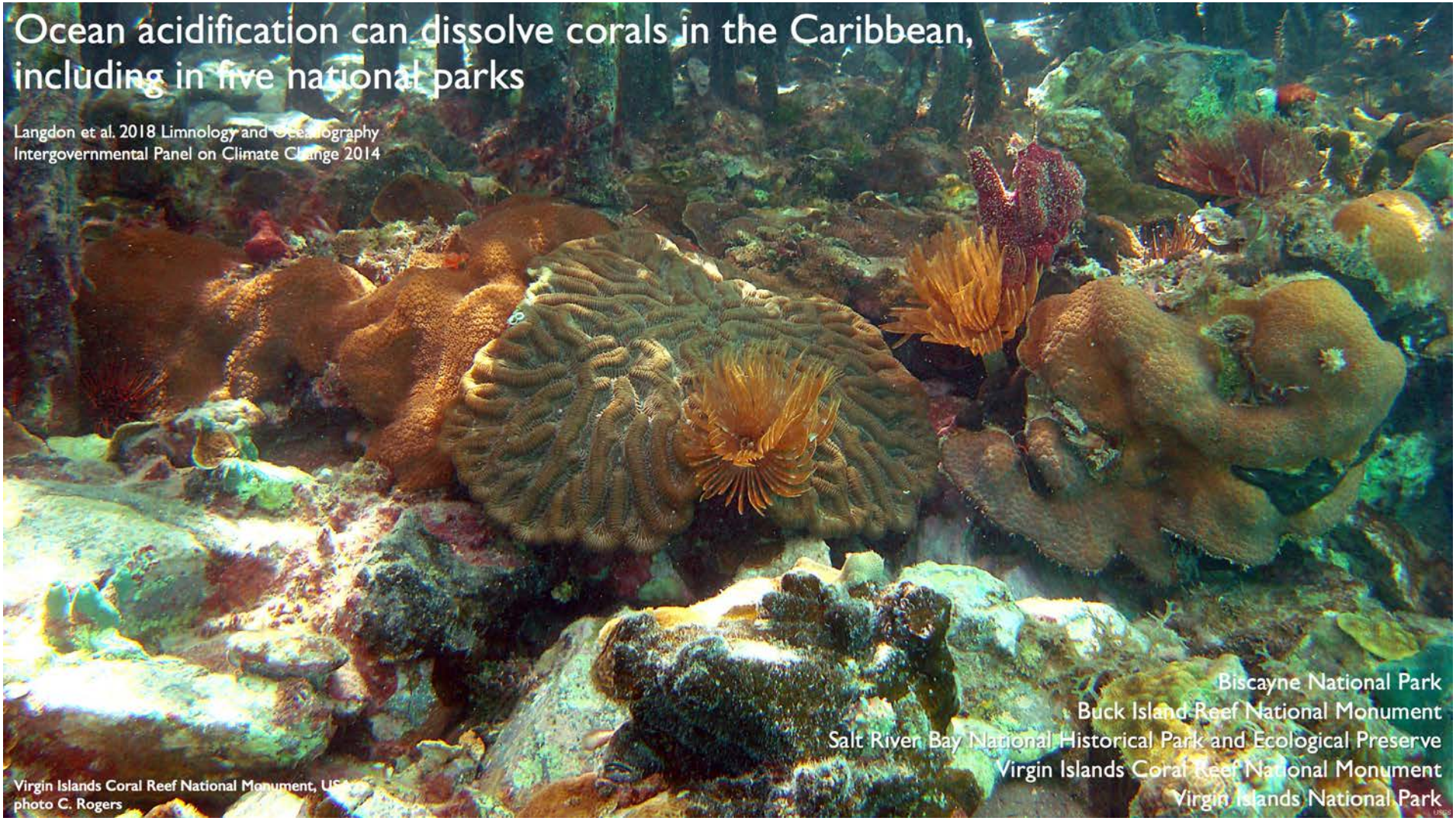
Rock Creek Park, Washington, DC, USA
photo P. Gonzalez

Climate change increases risk of lethal water temperatures for salmon spawning in Cook Inlet and Lake Clark National Park streams

Mauger et al. 2017 Canadian Journal of Fisheries and Aquatic Sciences



Sockeye salmon (*Oncorhynchus nerka*)
Lake Clark National Park, Alaska, USA
photo US National Park Service


Ocean acidification can dissolve corals in the Caribbean, including in five national parks
Langdon et al. 2018 Limnology and Oceanography
Intergovernmental Panel on Climate Change 2014
Biscayne National Park
Buck Island Reef National Monument
Salt River Bay National Historical Park and Ecological Preserve
Virgin Islands Coral Reef National Monument
Virgin Islands National Park
Virgin Islands Coral Reef National Monument, US
photo C. Rogers

Sea level rise of 50 cm (reduced emissions RCP2.6) could inundate most habitat for northern elephant seals in Point Reyes National Seashore

Funayama et al. 2013 Aquatic Conservation: Marine and Freshwater Ecosystems

Northern elephant seals (*Mirounga angustirostris*)
Point Reyes National Seashore, California, USA
photo A. Dep

Anthropogenic Climate Change in Ecosystems and Protected Areas

1. Human cause of climate change
2. Historical impacts
3. Future risks
4. Adaptation
5. Carbon solutions

Berkeley
UNIVERSITY OF CALIFORNIA

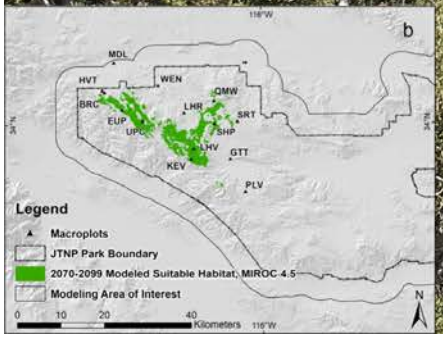
Navajo living in Canyon de Chelly National Monument use indigenous knowledge in resource management

Navajo Nation and US Government officials sign stewardship agreement, June 22, 2018
photo Northern Arizona University

Canyon de Chelly National Monument, Arizona, USA
photo M. Betts

Conserving climate change refugia in Joshua Tree National Park

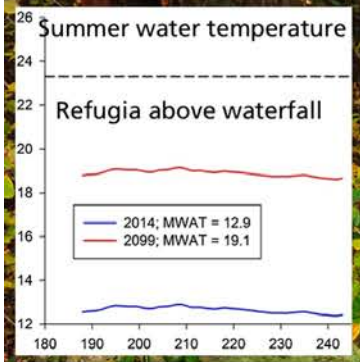
Sweet et al. 2019 Ecosphere
Barrows et al. 2014 Biodiversity and Conservation

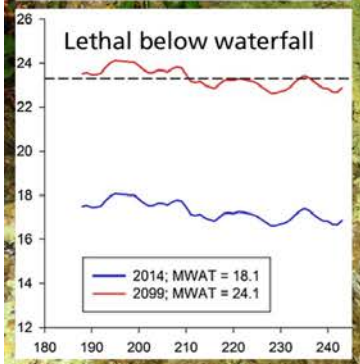


Nicholas Graver conducts plant inventory near a refugium
Joshua Tree National Park, California, USA
photo P. Gonzalez

Conservation of thermal refugia for brook trout in Shenandoah National Park

Briggs et al. 2018 Limnologica





brook trout (Salvelinus fontinalis)
Shenandoah National Park, Virginia, USA
photo J.D. Nations

Whiteoak Canyon
Shenandoah National Park, Virginia, USA
photo US National Park Service

Prescribed burning to reduce risks of high-severity crown fires

North et al. 2015 Science
Stephens et al. 2013 Science
Van Mantgem et al. 2016 Fire Ecology

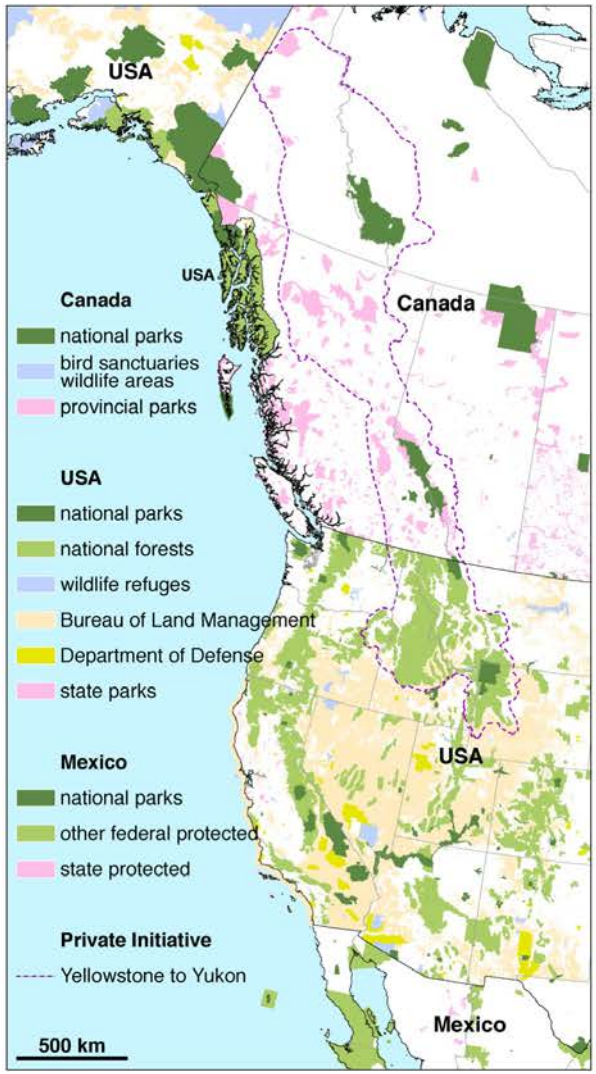
Giant Sequoia (*Sequoiadendron giganteum*) trees protected by prescribed burning Sequoia National Park, California, USA photo P. Gonzalez


Adaptation options
Crissy Field, Golden Gate National Recreation Area
SEAWALL/GATE TO PROTECT HISTORIC BUILDINGS
ADAPT HISTORIC COAST GUARD STATION, RAISE FINISH FLOOR ELEVATION TO 13.5
ADD DUCKBILL FLAPS AND PUMP STATIONS
REMOVE FORMER COMMISSARY AND EXPAND MARSH
RIPRAP AND SEAWALL TO PROTECT EAST BEACH
ELEVATION IN KING TIDE +3FT
DUNE SAND NOURISHMENT
WETLAND RESTORATION
P
P

CMG 2016

Conservation corridors for habitat connectivity under climate change

Barnosky et al. 2017 Science



Nurseries to raise local corals resistant to bleaching in Biscayne National Park

Lirman et al. 2010 Coral Reefs
Schopmeyeret al. 2017 Coral Reefs

Biscayne National Park, Florida, USA
photo T. Strom

Anthropogenic Climate Change in Ecosystems and Protected Areas

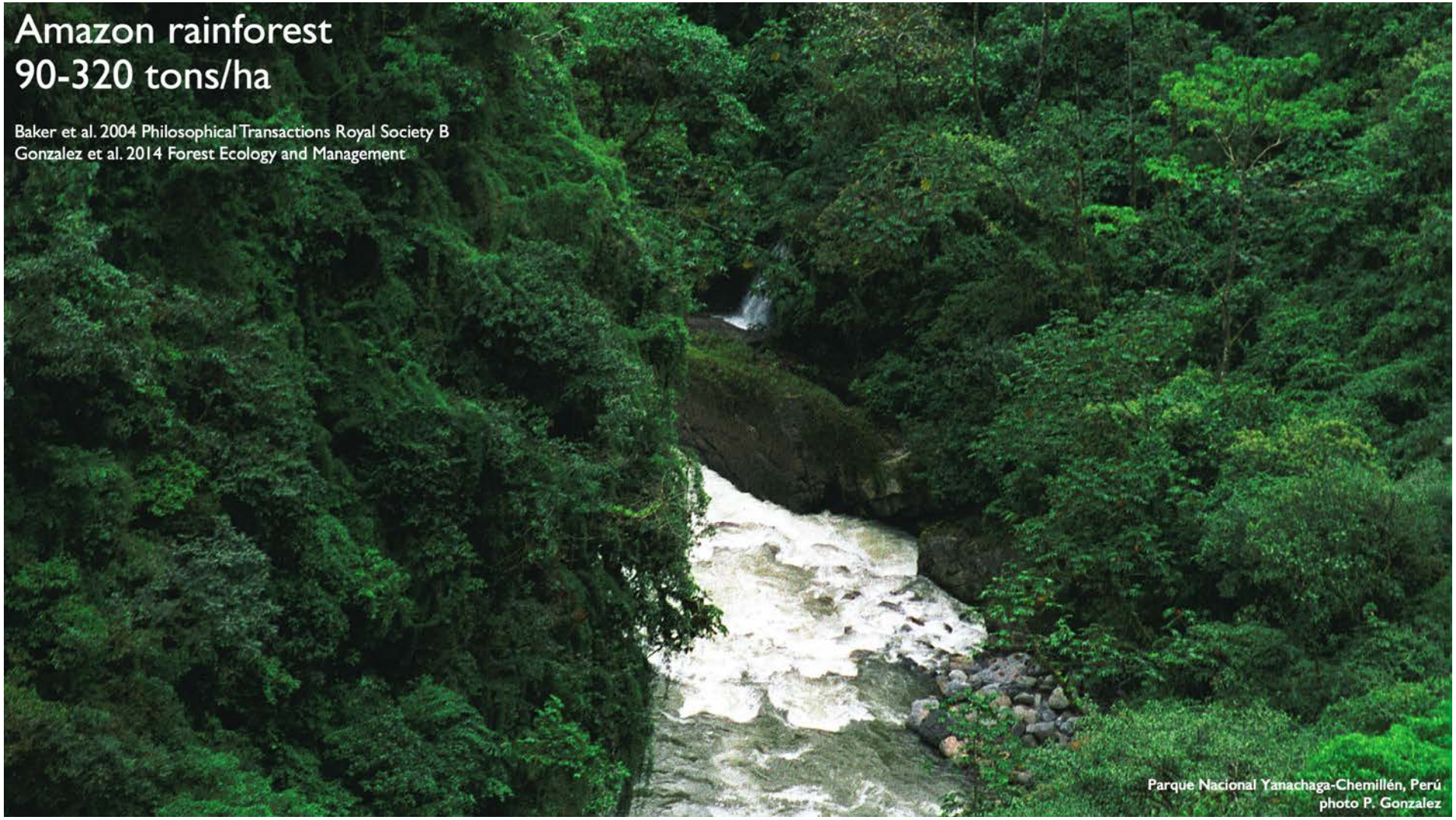
1. Human cause of climate change
2. Historical impacts
3. Future risks
4. Adaptation
5. Carbon solutions

Berkeley
UNIVERSITY OF CALIFORNIA


Coast redwood attains the highest carbon density in the world
2600 tons per hectare
Van Pelt et al. 2016 Forest Ecology and Management
Busing and Fujimori 2005 Plant Ecology
Coast redwoods (*Sequoia sempervirens*)
Muir Woods National Monument, California, USA
photo P. Gonzalez

Amazon rainforest
90-320 tons/ha

Baker et al. 2004 Philosophical Transactions Royal Society B
Gonzalez et al. 2014 Forest Ecology and Management



Parque Nacional Yanachaga-Chemillén, Perú
photo P. Gonzalez

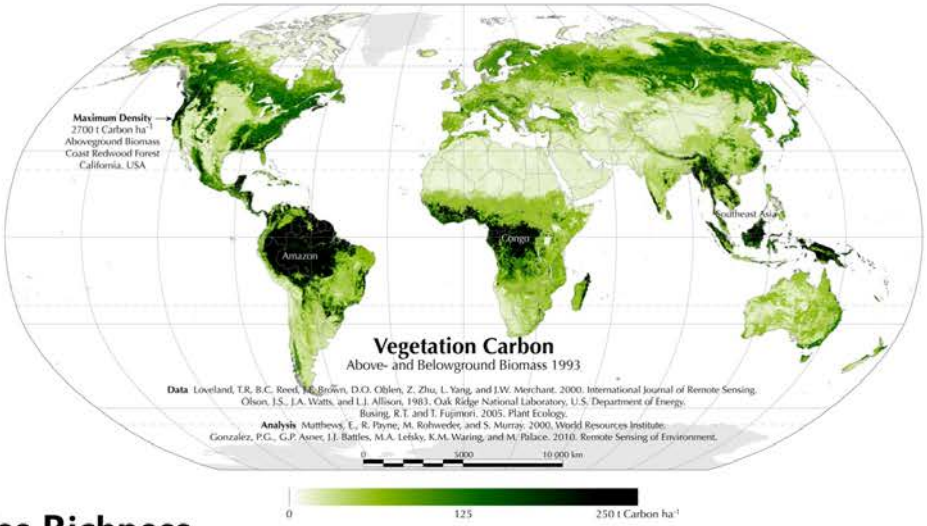
Mangrove soils and peat
300-1000 tons/ha

Donato et al. 2011 Nature Geoscience
Duarte et al. 2013 Nature Climate Change
Murdiyarso et al. 2015 Nature Climate Change

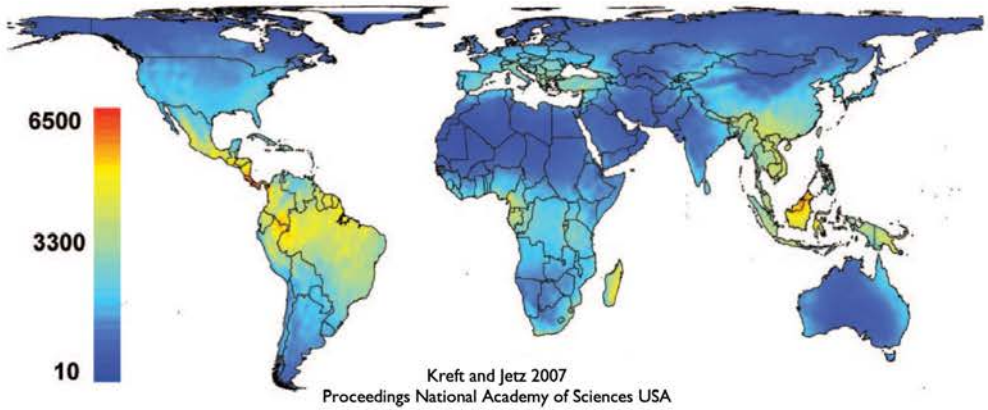
Amazonian mangrove forest
Parque Nacional de Anavilhanas, Brasil
photo P. Gonzalez

Protected areas ~15% of global land

Vegetation Carbon



Plant Species Richness



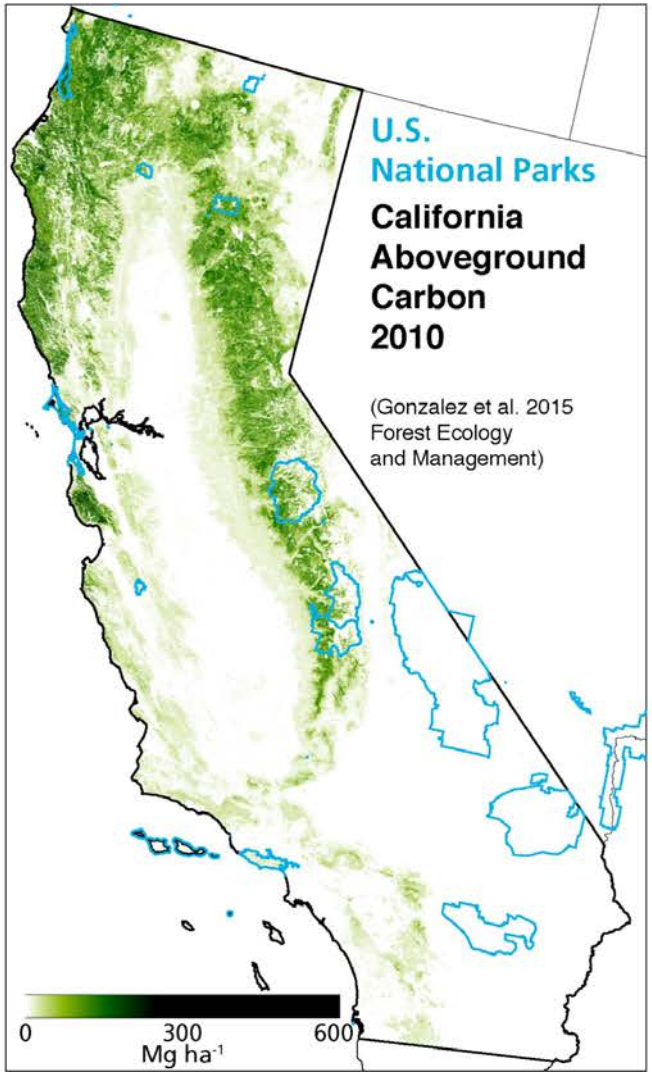
Ecosystem Carbon

U.S. National Parks in California
store 42 ± 15 million tons of carbon

Equivalent to 1 year of carbon emissions
from 7.4 ± 2.6 million Americans

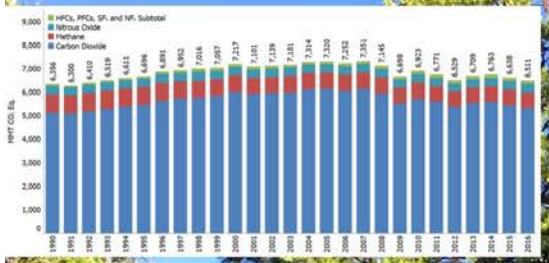
Population of the cities of:
Boston
Charlotte
Dallas
Kansas City
Los Angeles
Miami

Gonzalez et al. 2015 Forest Ecology and Management



U.S. cut greenhouse gas emissions 11% from 2007 to 2016

U.S. Environmental Protection Agency 2018 Inventory of U.S. Greenhouse Gas Emissions and Sinks

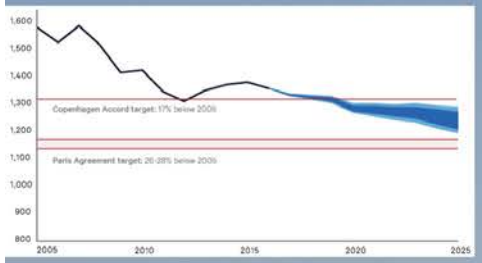


Lassen Volcanic National Park, California, USA
photo P. Gonzalez

U.S. Climate Alliance cut greenhouse gas emissions 14% from 2005 to 2016

California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nevada, New Jersey, New Mexico, New York, North Carolina, Oregon, Pennsylvania, Puerto Rico, Rhode Island, Vermont, Virginia, Washington, Wisconsin

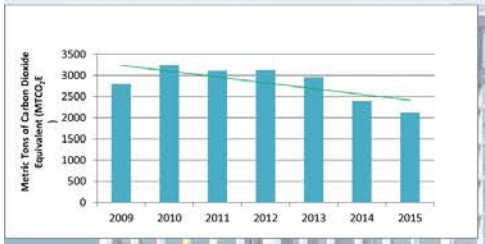
U.S. Climate Alliance 2018 Annual Report



San Gorgonio Pass
Adjacent to Joshua Tree National Park, California, USA
photo P. Gonzalez

Golden Gate National Recreation Area cut greenhouse gas emissions 25% from 2010 to 2015

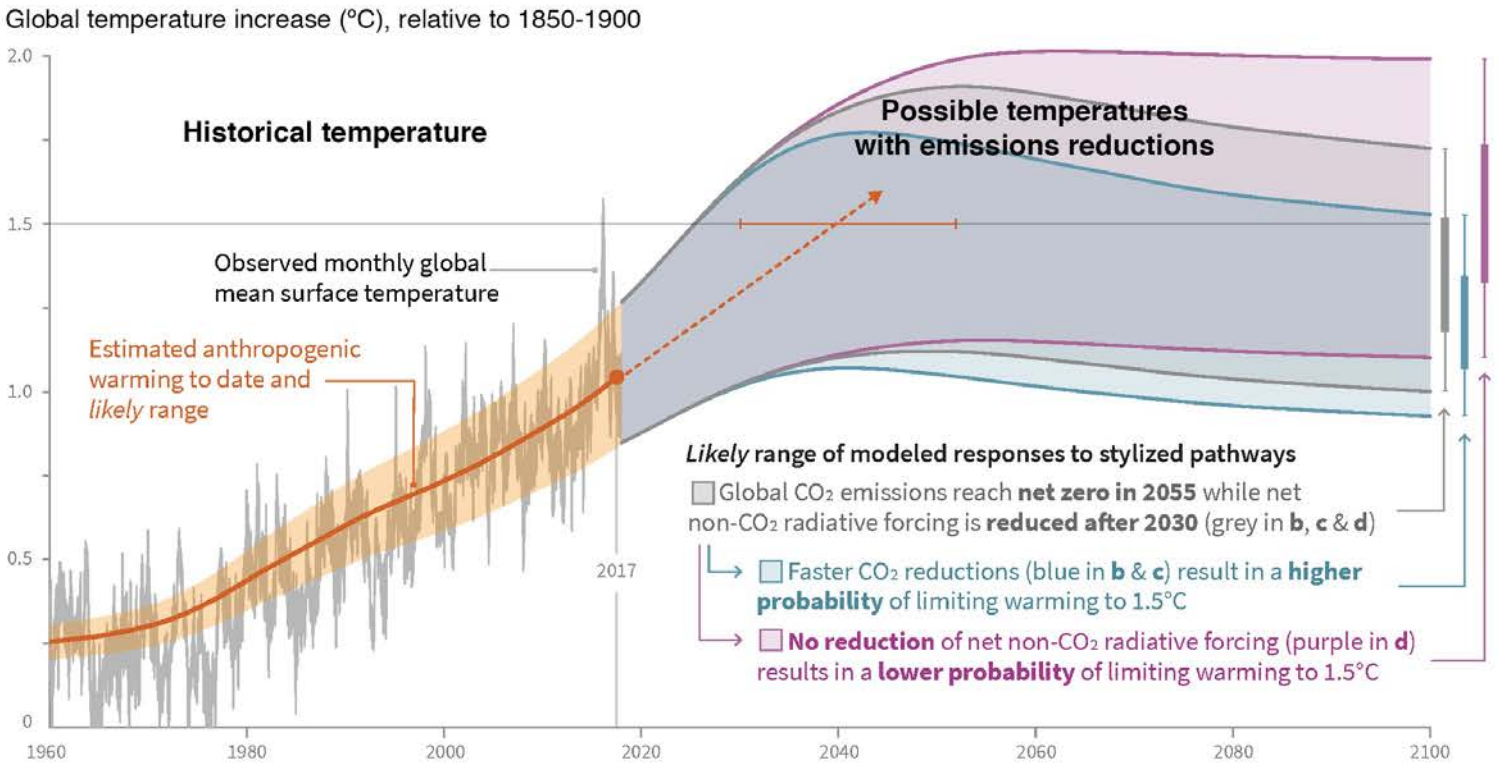
National Park Service 2016 Golden Gate NRA Climate Change Action Plan



Photovoltaic solar energy panels
Alcatraz island
photo National Park Service

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Limiting global temperature increase to <2°C is possible with global action



Intergovernmental Panel on Climate Change (IPCC). 2018. Special Report on Global Warming of 1.5°C. IPCC, Geneva, Switzerland.

Yosemite Area Regional Transit System (YARTS)
Public transit to Yosemite National Park, California, USA
photo P. Gonzalez