



Human-Caused Climate Change Impacts on Biodiversity and Solutions for the Future

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Rutgers University Climate Institute Symposium Keynote
New Brunswick, New Jersey, November 9, 2022

Yosemite National Park, California, USA
photo P. Gonzalez

Human-Caused Climate Change Impacts on Biodiversity and Solutions for the Future

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

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INTERGOVERNMENTAL PANEL ON climate change



Terrestrial and Freshwater Ecosystems and their Services. Chapter 2

Camille Parmesan (France, USA, UK), Mike D. Morecroft (UK), Yongyut Trisurat (Thailand), Rita Adrian (Germany), Gusti Zakaria Anshari (Indonesia), Almut Arneth (Germany), Qingzhu Gao (China), Patrick Gonzalez (USA), Rebecca Harris (Australia), Jeff Price (UK), Nicola Stevens (South Africa), Gautam Hirak Talukdar (India)

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INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2022

Impacts, Adaptation and Vulnerability



WGII

Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change



IPCC Lead Authors
Durban, South Africa, 2019, photo M. Nicholai

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Human carbon emissions overwhelm natural removal

billion tons carbon per year 2011-2020

Motor vehicles, power plants $+9.5 \pm 0.5$

Deforestation $+1.1 \pm 0.7$

Vegetation and soil -3.1 ± 0.6

Oceans -2.8 ± 0.4

Accumulation in the atmosphere $+5.1 \pm 0.02$

Data Friedlingstein et al. 2022 Earth System Science Data; Intergovernmental Panel on Climate Change. 2021. Climate Change 2021: The Physical Science Basis
Photo Steve Cole, Graphic P. Gonzalez

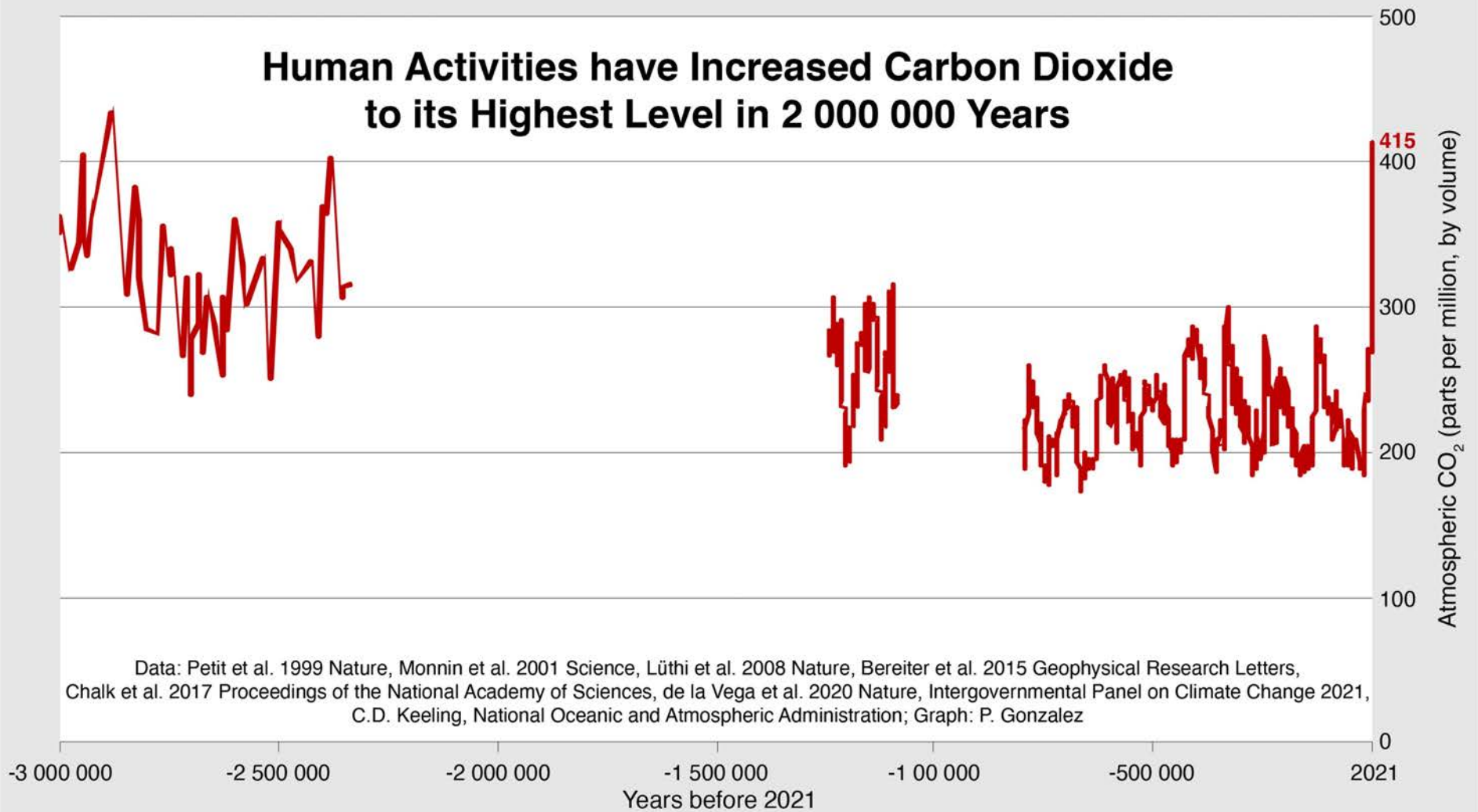
Burning for tropical deforestation and clearing peatlands generated carbon emissions of 1.8 ± 0.3 billion tons per year, 2000-2019

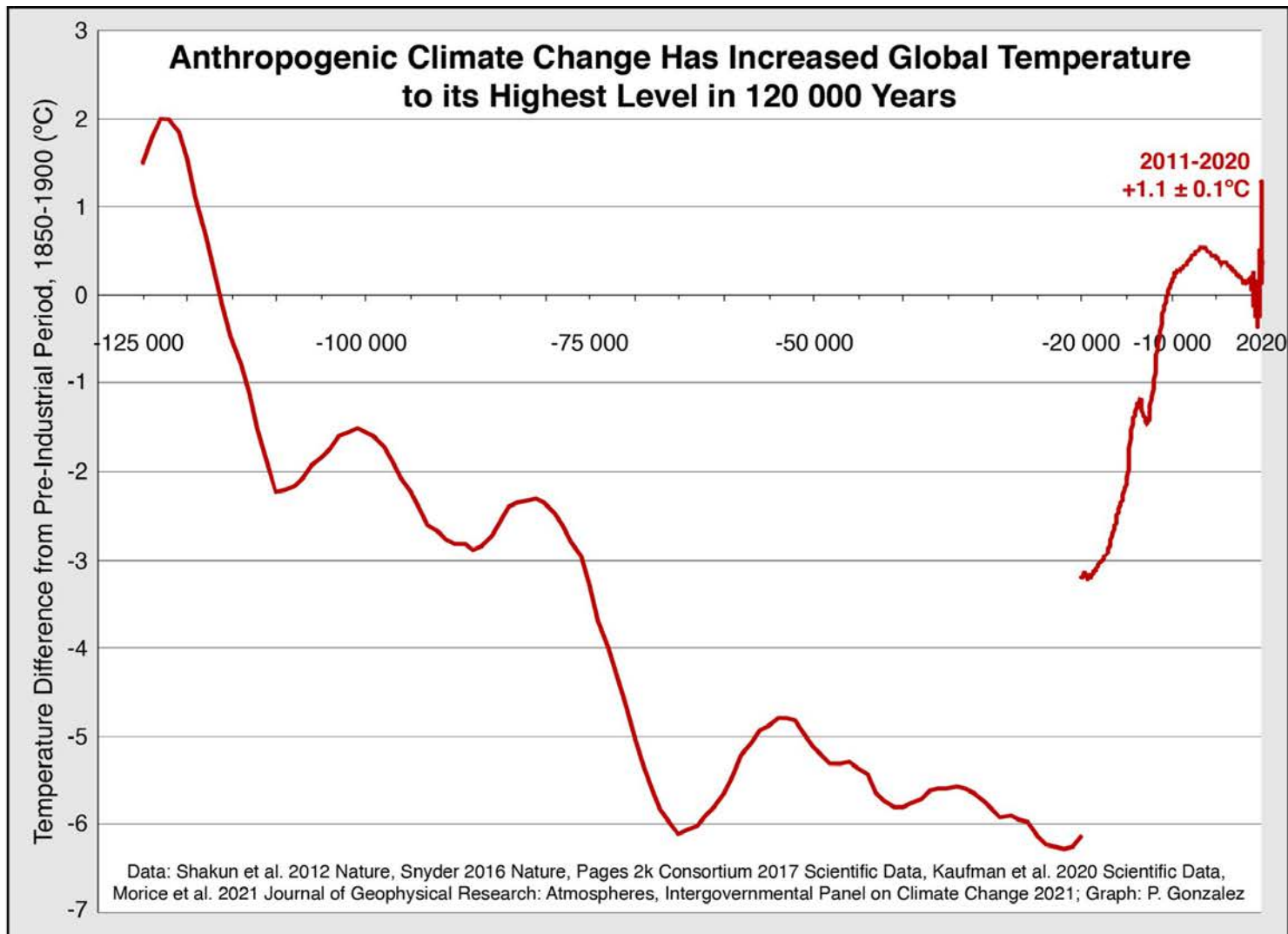
Zheng et al. 2021 Science Advances



Burning Amazon rainforest for cattle grazing, September 2019
Porto Velho, Brazil
photo Victor Moriyama

Human Activities have Increased Carbon Dioxide to its Highest Level in 2 000 000 Years

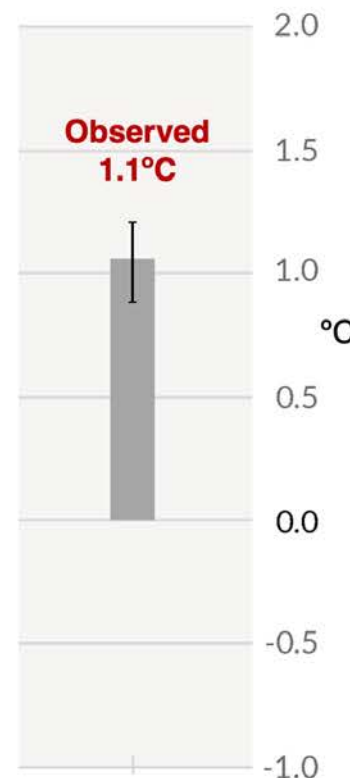




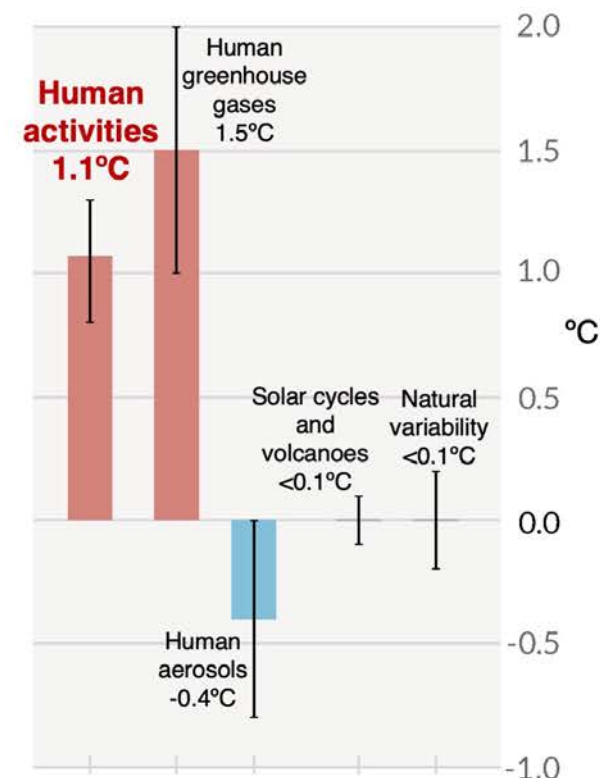
Human activities have caused >99% of the increased heat of climate change, 1850-2019

Intergovernmental Panel on Climate Change. 2021. Climate Change 2021: The Physical Science

Observed global temperature increase 2010-2019 compared to 1850-1900



Attribution of global temperature increase to causal factors

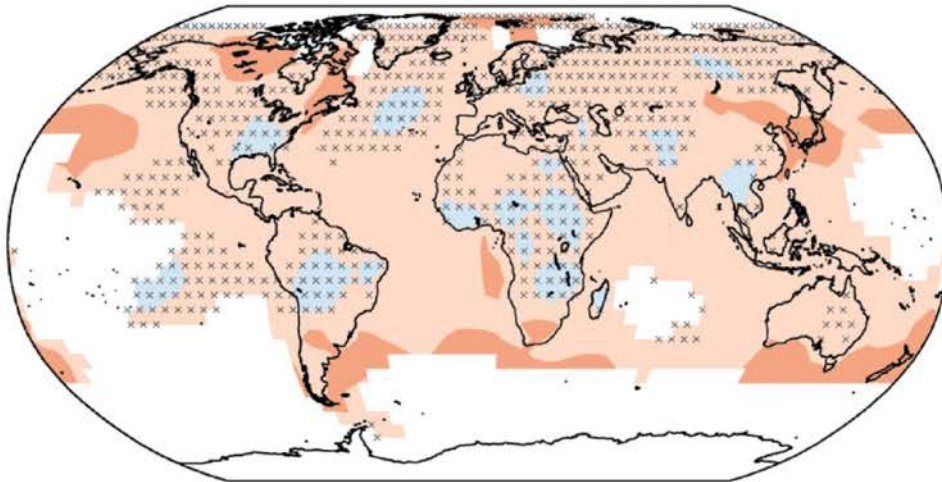


Human-Caused Climate Change Impacts on Biodiversity and Solutions for the Future

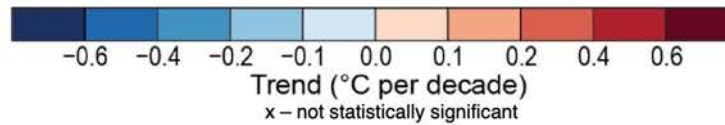
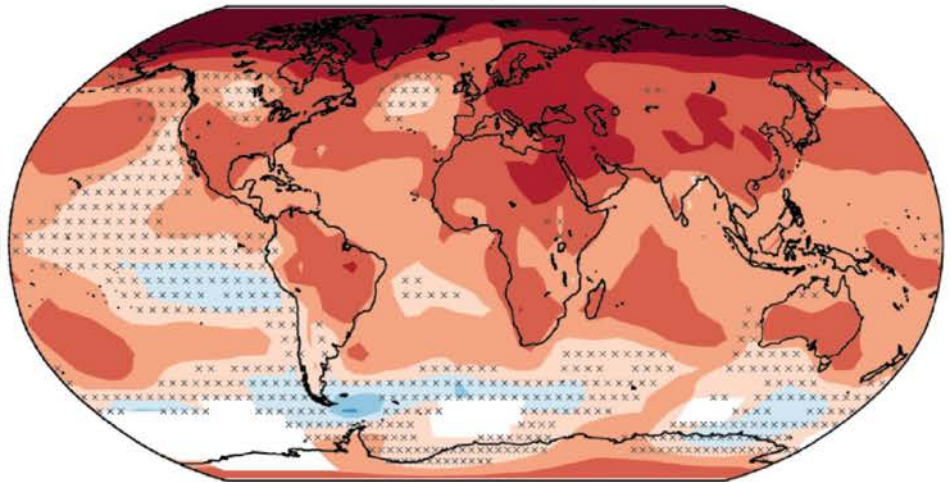
1. Human cause of climate change
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Global mean surface temperature increase $1.1 \pm 0.1^\circ\text{C}$ 1850-1900 — 2011-2020

Trend 1900-1980



Trend 1981-2020

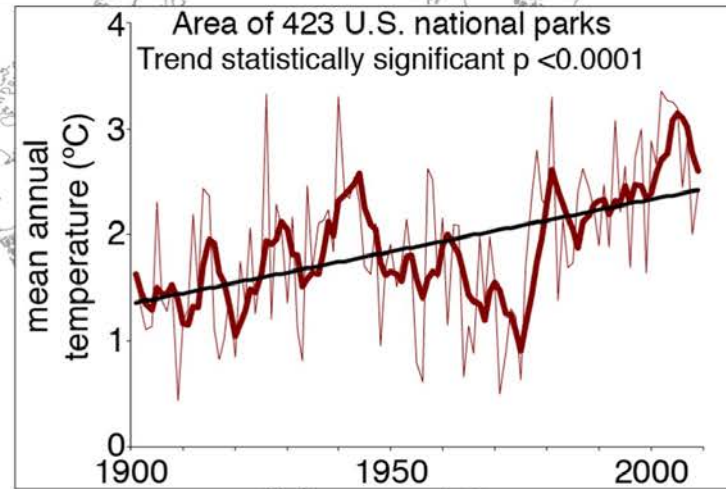


Anthropogenic Climate Change

Temperature Change 1895-2010

Gonzalez et al. 2018
Environmental Research Letters

	mean \pm SE	increase	significant
USA	$+0.4 \pm 0.1^\circ\text{C century}^{-1}$	0.71	0.42
NPS	$+1.0 \pm 0.2^\circ\text{C century}^{-1}$	0.96	0.63



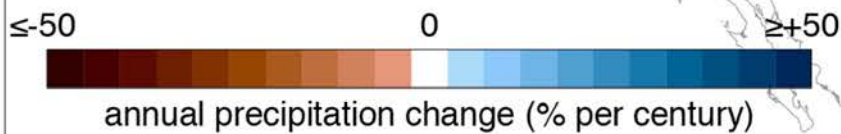
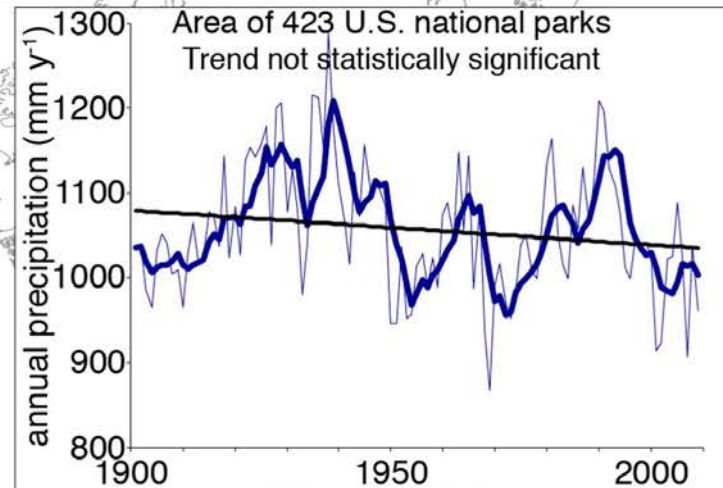
U.S. national parks

Anthropogenic Climate Change

Precipitation Change 1895-2010

Gonzalez et al. 2018
Environmental Research Letters

	mean \pm SE	decrease	significant
USA	$+4 \pm 2\%$ century ⁻¹	0.18	0.04
NPS	$-4 \pm 2\%$ century ⁻¹	0.49	0.12



U.S. national parks

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

Climate change has caused heat wave deaths of 4000–19 000 people in 43 countries analyzed around the world, 1991-2018

Vicedo-Cabrera et al. 2021 Nature Climate Change

Imada et al. 2019 Scientific Online Letters on the Atmosphere

Mitchell et al. 2016 Environmental Research Letters

Knowlton et al. 2011 Health Affairs

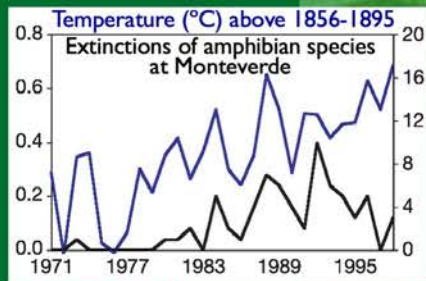
Hoshiko et al. 2010 International Journal of Public Health

Yip et al. 2008 International Journal of Biometeorology

Phoenix, Arizona, USA
photo C. Heeb

Climate change has caused two species extinctions including the golden toad from Monteverde cloud forest, Costa Rica, ca. 1989

Intergovernmental Panel on Climate Change 2022
Pounds et al. 2006 Nature
Pounds et al. 1999 Nature



Pounds et al. 2006



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

Climate change has caused two species extinctions including the Bramble Cay melomys from the Torres Strait, Australia, ca. 2009

Intergovernmental Panel on Climate Change 2022
Australia Threatened Species Scientific Committee 2019
Waller et al. 2017 Wildlife Research



Bramble Cay melomys (*Melomys rubicola*), Maizab Kaur (Bramble Cay), Australia
photos Queensland Environmental Protection Agency



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 melted 16% of global glacier ice from 1901 to 1990 then accelerated glacier melting by 2019 to its highest rate since 1901

Intergovernmental Panel on Climate Change 2021
Hugonnet et al. 2021 Nature
Marzeion et al. 2014 Science
Larsen et al. 2007 Journal of Geophysical Research

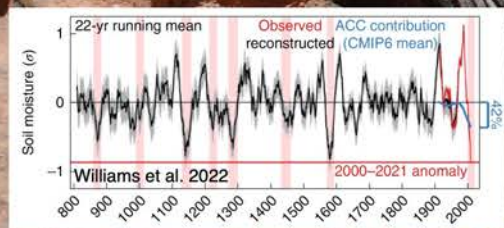
2004

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



Climate change has caused a drought in the southwestern U.S. since 2000 that is the most severe drought since the 1500s

Williams et al. 2022 Nature Climate Change
Williams et al. 2020 Science



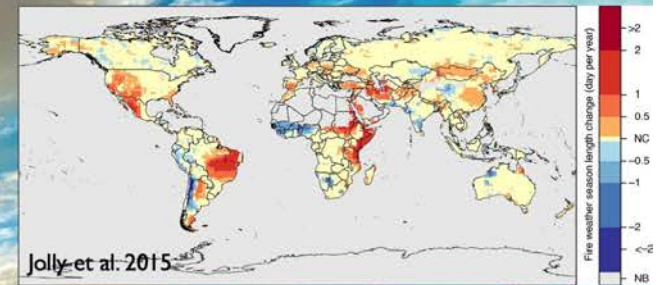
Dead one-seed juniper tree (*Juniperus monosperma*)
Bandelier National Monument, New Mexico, USA
photo P. Gonzalez

Climate change has intensified the heat that drives wildfire, lengthening fire weather season on 1/4 of global vegetated area, up to 2 months, 1979-2013

Intergovernmental Panel on Climate Change 2021

Zhuang et al. 2021 Proceedings of the National Academy of Sciences of the USA

Jolly et al. 2015 Nature Communications



Loyalton Fire tornado, August 15, 2020
Tahoe National Forest, California, USA
photo KateLynn Hewlett

Climate change doubled the area burned by wildfire across the western U.S. over natural levels, 1984-2015

Abatzoglou and Williams 2016 Proceedings of the National Academy of Sciences of the USA

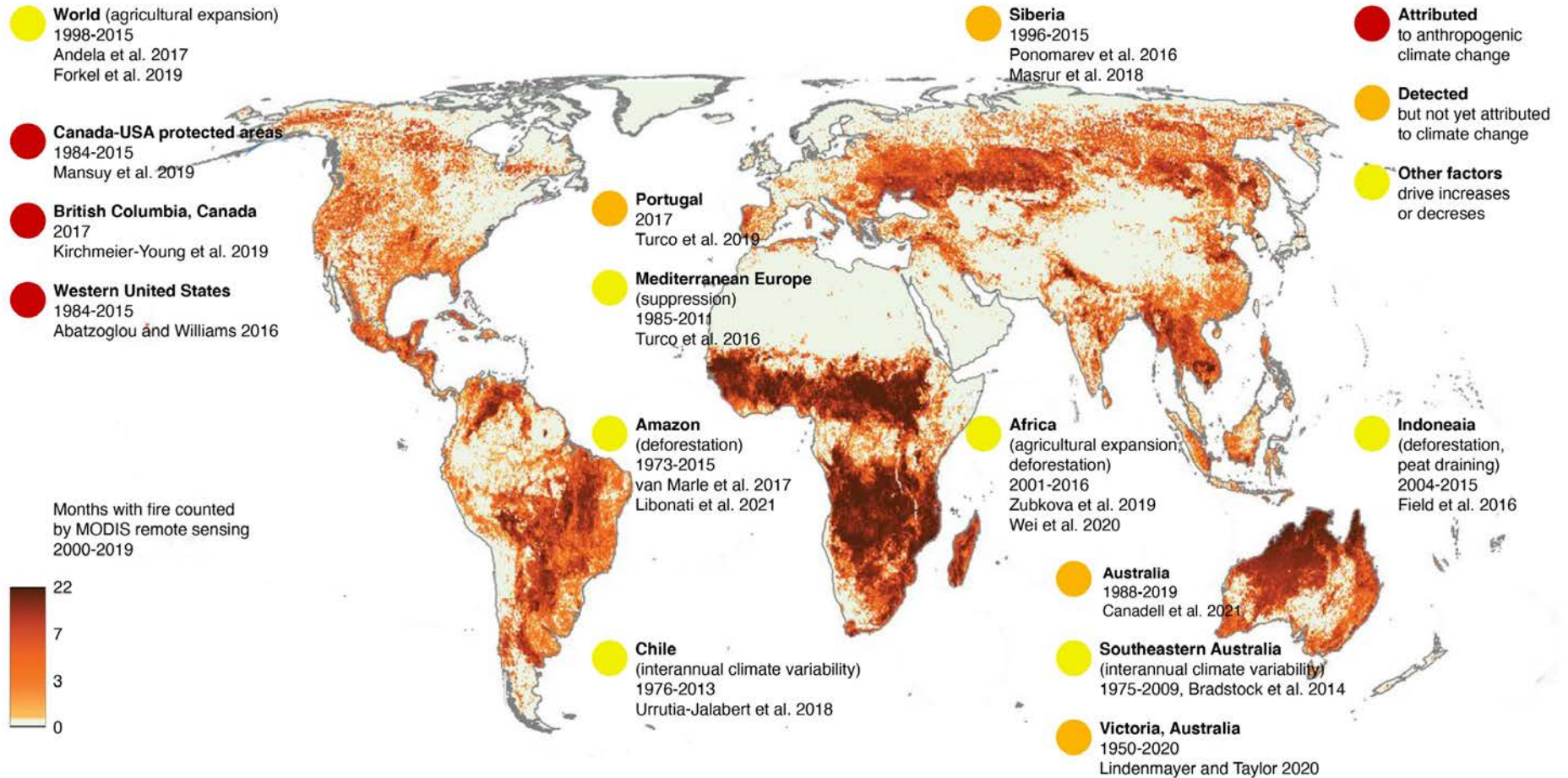


Anthropogenic climate change accounts for 49% (32-76%, 95% confidence interval)

Rim Fire, August 21, 2013
Stanislaus National Forest, west of Yosemite National Park
California, USA, photo J. Sullivan, graphics P. Gonzalez

Attribution of Increases in Wildfire Burned Area to Anthropogenic Climate Change

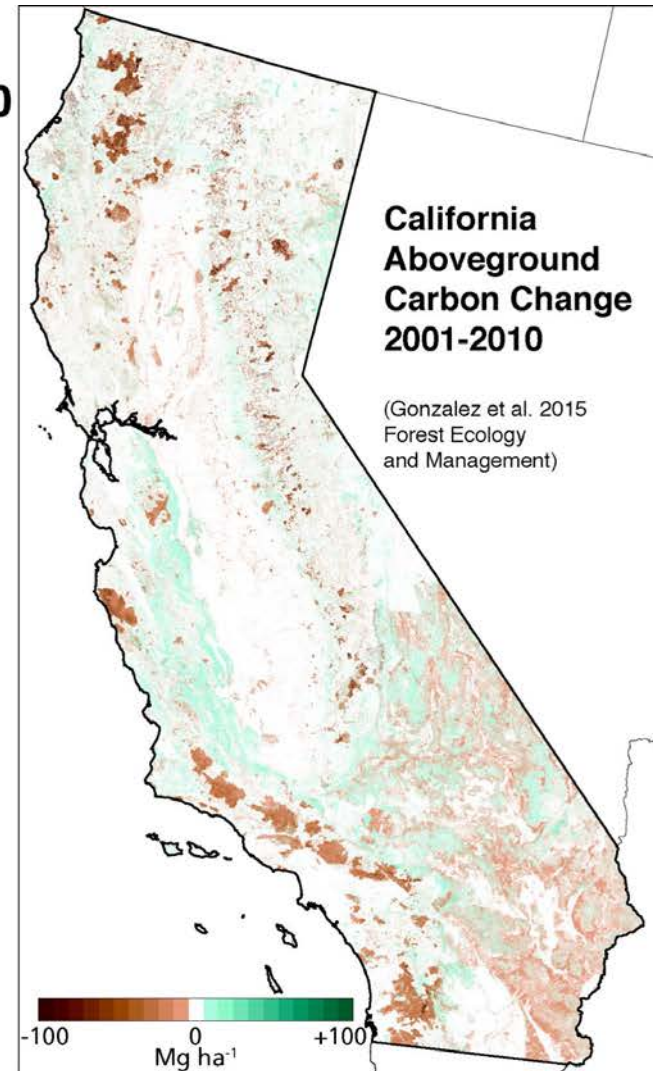
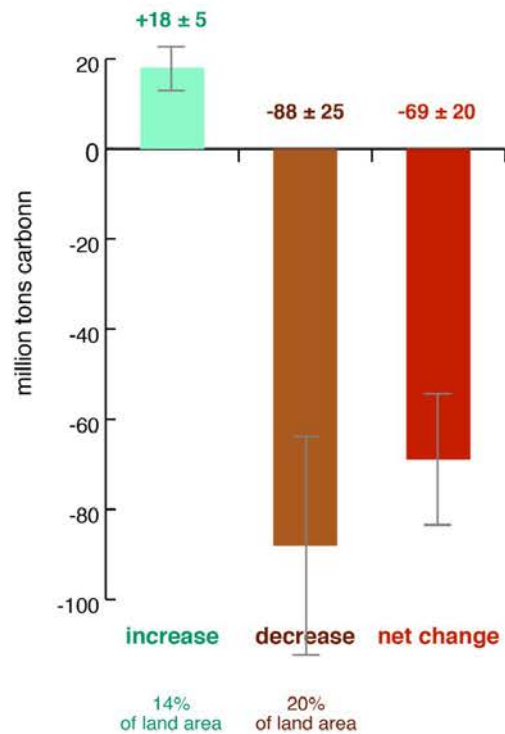
Assessment: Intergovernmental Panel on Climate Change 2022, Map: Kelly et al. 2020 Science, Graphic: P. Gonzalez



California ecosystems are a net carbon emitter, with two-thirds of emissions from wildfire, 2001-2010

Gonzalez et al. 2015 Forest Ecology and Management

California Wildland Carbon Balance 2001-2010



Climate change and deforestation for timber and agriculture have caused the Amazon to become a net emitter of carbon, 2010-2019

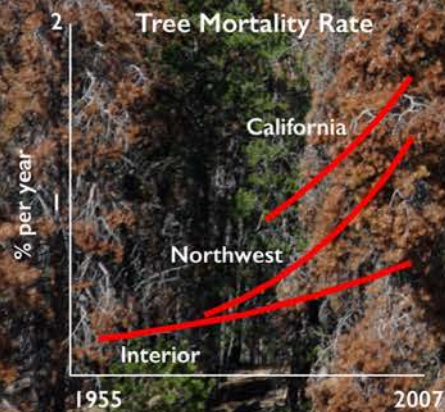
Intergovernmental Panel on Climate Change 2022
Qin et al. 2021 Nature Climate Change
Hubau et al. 2020 Nature



Fire in Amazon rainforest, August 24, 2019
Candeias do Jamari, Rondônia, Brazil
photo Victor Moriyama

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

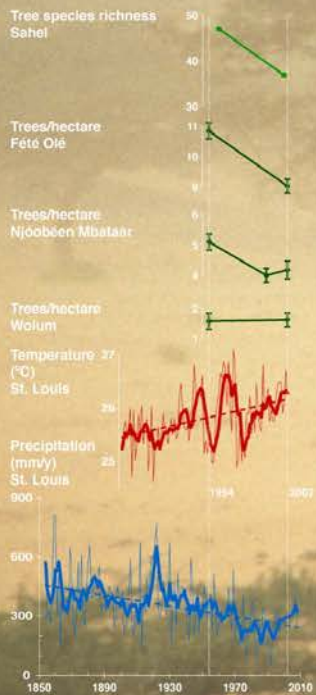
van Mantgem et al. 2009 Science
Fettig et al. 2019 Forest Ecology and Management
Redmond et al. 2018 Journal of Ecology
Berner et al. 2017 Environmental Research Letters



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

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

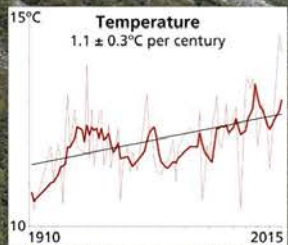
Gonzalez et al. 2012 Journal of Arid Environments
Gonzalez 2001 Climate Research



Njoobeen Mbataar, Sénégal
photo P. Gonzalez

Climate change has caused a biome shift of subalpine forest upslope into subalpine meadows in Yosemite National Park, 1880-2002

Millar et al. 2004 Arctic, Antarctic, and Alpine Research



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

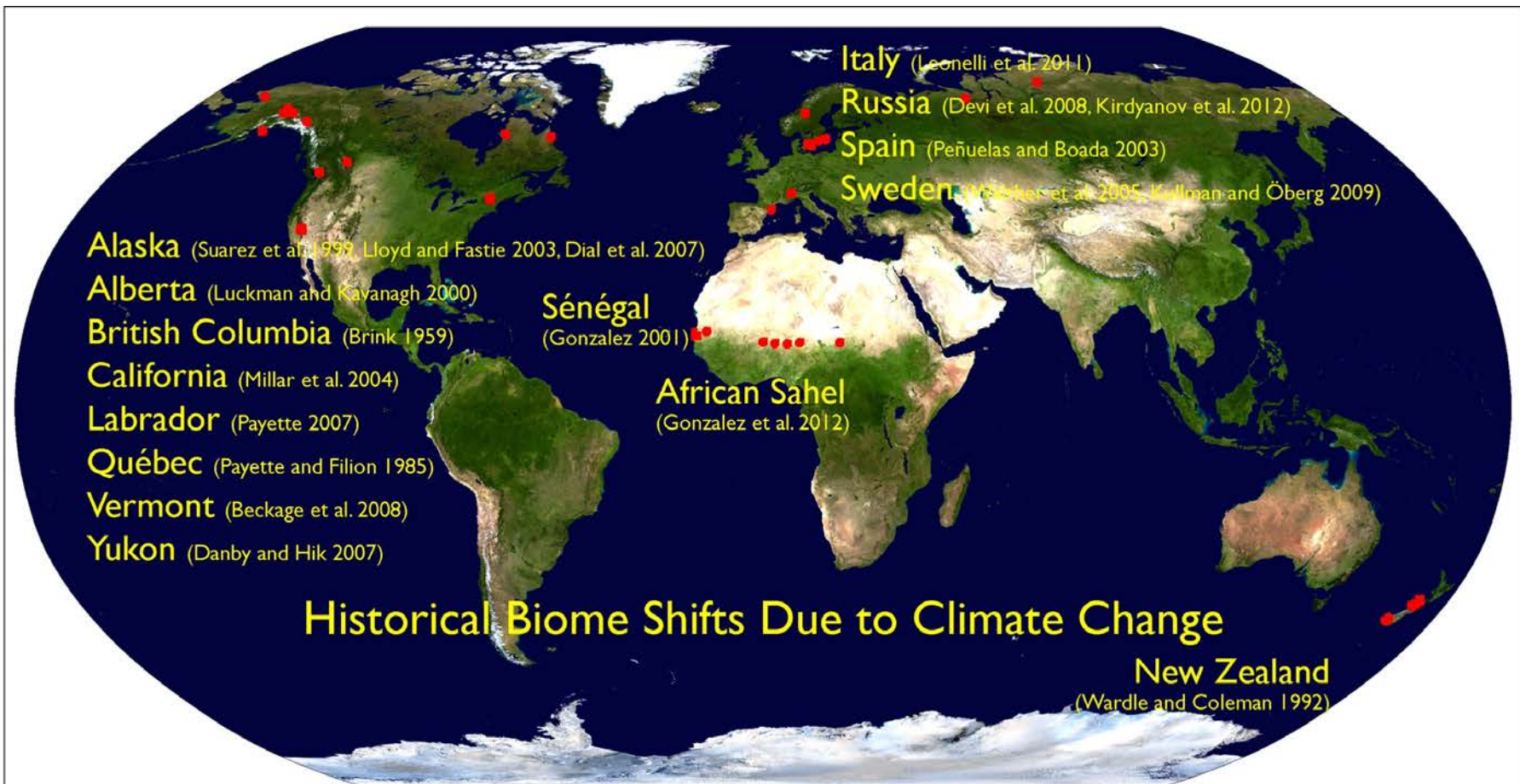
Yosemite National Park, California, USA
photo P. Gonzalez

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



Analysis: Gonzalez et al. 2010 Global Ecology and Biogeography,
Settele et al. 2014 Intergovernmental Panel on Climate Change
Satellite Image: National Aeronautics and Space Administration

Climate change has caused >400 species extirpations (local disappearances) globally, 1849-2012

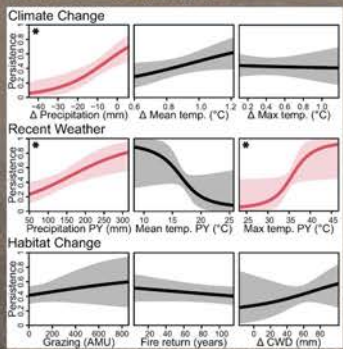
Wiens 2016 PLoS Biology
Beever et al. 2011 Global Change Biology
Intergovernmental Panel on Climate Change 2022



American pika (*Ochotona princeps*)
Extirpated from ten sites in the Great Basin, Nevada, Oregon, USA
photo U.S. National Park Service

Climate change reduced bird species richness 40% in Mojave Desert national parks, through increased aridity and physiological heat stress, 1908-2016

Iknayan and Beissinger 2018 Proceedings of the National Academy of Sciences of the USA
Riddell et al. 2019 Proceedings of the National Academy of Sciences of the USA



Iknayan and Beissinger 2018

Mojave National Preserve, California, USA
photo H. Chi

Climate change caused extirpation of five bird species in Perú, shifting habitat up and off a mountain ridge, 1985-2017

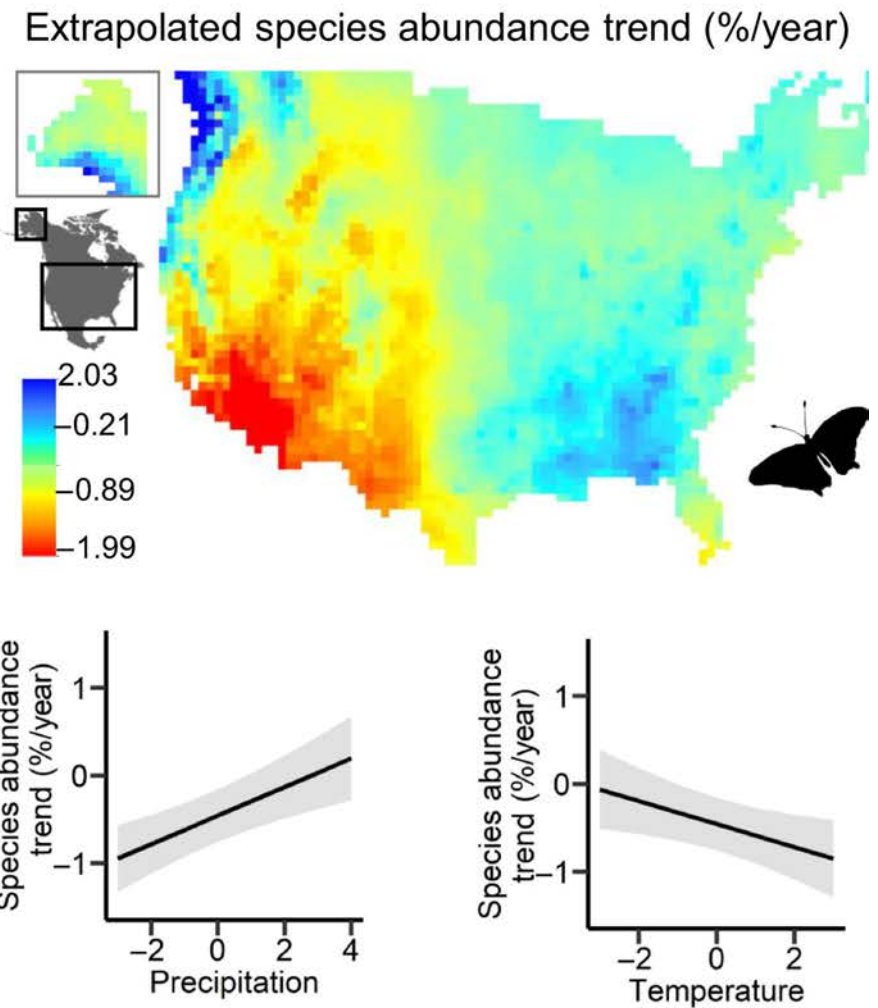
Freeman et al. 2018. Proceedings of the National Academy of Sciences of the USA



White-eared solitaire (*Entomodestes leucotis*)
disappeared from Cerro de Pantiacolla, Perú
photo in Perú Roger Ahlman

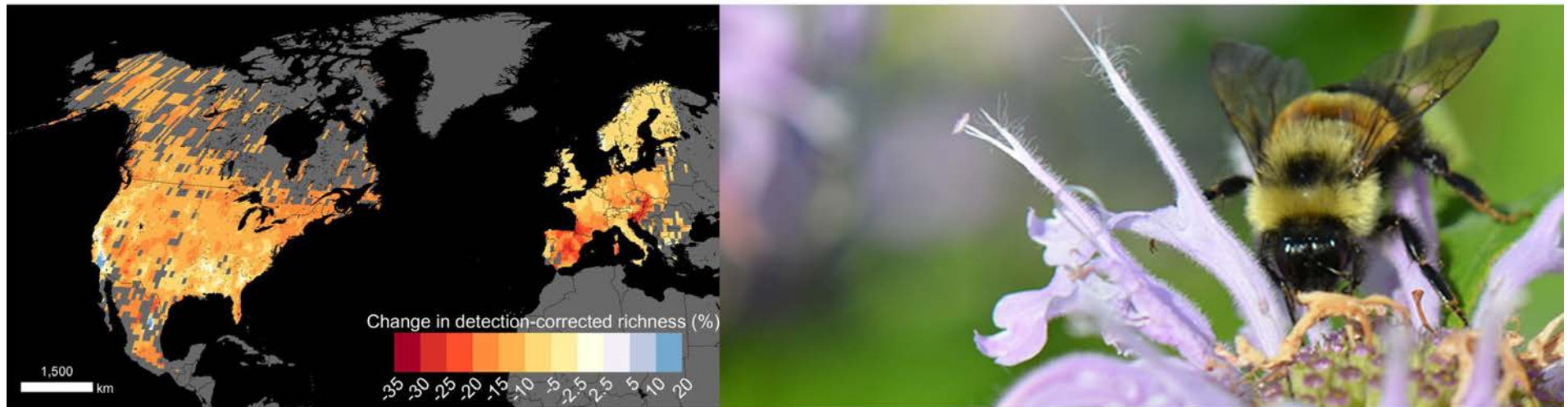
Climate change reduced butterfly species richness up to half in the southwestern U.S., 1993-2018

Crossley et al. 2021 Global Change Biology



Climate change reduced bumble bee species richness and abundance up to one-third in North America and Europe, 1901-2014

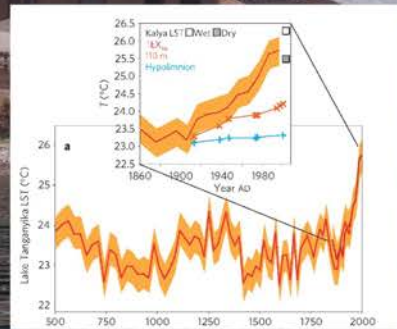
Soroye et al. 2020 Science



Rusty Patched Bumble Bee (*Bombus affinis*)
feeding on wild bergamot (*Monarda fistulosa*)
photo Kim Mitchell, U.S. Fish and Wildlife Service

Climate change has increased the water temperature of Lake Tanganyika to its highest in 1500 years, decreasing fish abundance more than half since 1850

Cohen et al. 2016 Proceedings of the National Academy of Sciences of the USA
Tierney et al. 2010 Nature Geoscience
Verburg et al. 2003 Science
O'Reilly et al. 2003 Nature



Water temperature
Tierney et al. 2010

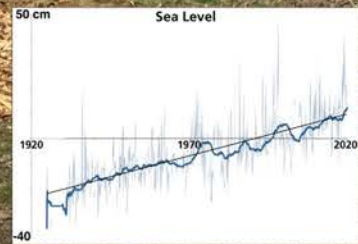


Migebuka (*Lucioides stappersii*)
Fish important in the diet and economy
photo Catherine O'Reilly

Fishing village
Lake Tanganyika, Tanzania
photo Andrew Cohen

Climate change has raised global average sea level 20 cm, 1901-2018

Intergovernmental Panel on Climate Change 2021
Slangen et al. 2016 Nature Climate Change
Church and White 2011 Surveys in Geophysics



Sea level rise, 32 cm, 1924-2019, Washington, DC
data National Oceanic and Atmospheric Administration
analysis P. Gonzalez

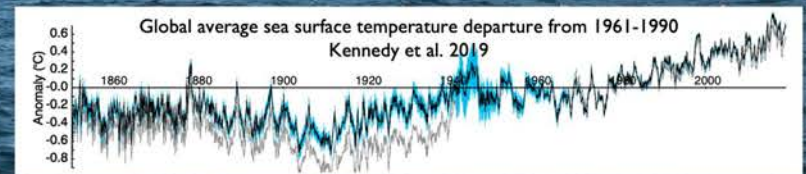
Tidal Basin, March 12, 2020
National Capital Parks, Washington, DC, USA
photo P. Gonzalez

Climate change has increased global sea surface temperature $0.9 \pm 0.1^\circ\text{C}$, 1900-2020

Intergovernmental Panel on Climate Change 2021
Kennedy et al. 2019 Journal of Geophysical Research: Atmospheres
Gleckler et al. 2012 Nature Climate Change



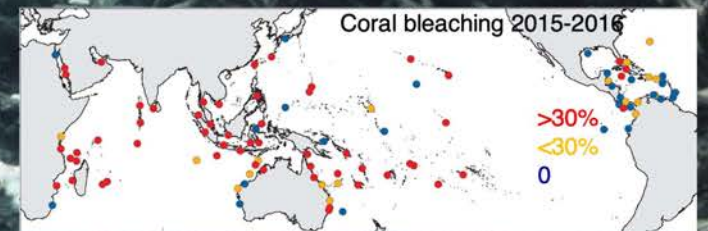
Anacapa Island, Pacific Ocean
Channel Islands National Park, California, USA
photo P. Gonzalez



Climate change has bleached coral reefs, causing coral mortality up to 50% in the Great Barrier Reef, through warmer waters

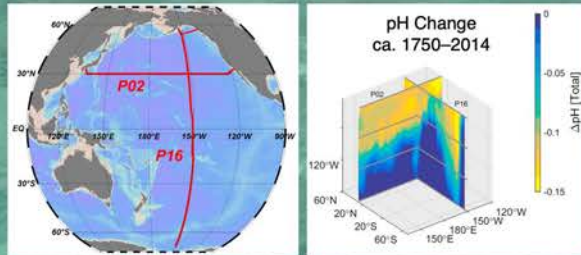
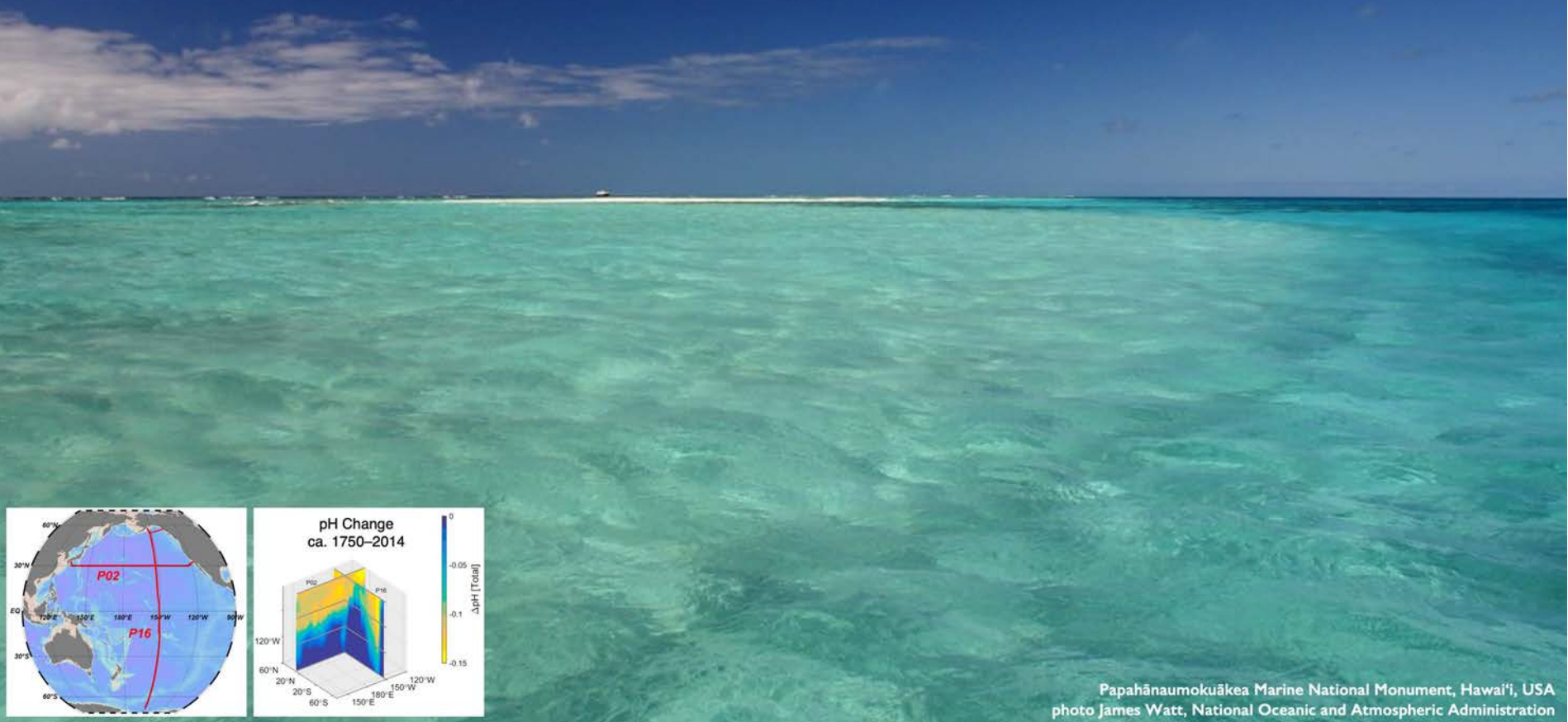
Hughes et al. 2018 Science
Hughes et al. 2018 Nature
Sully et al. 2019 Nature Communications
Intergovernmental Panel on Climate Change 2022

Great Barrier Reef, Australia
photo Christophe Bailhache, XL Catlin Seaview Survey



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

Carter et al. 2017 Global Biogeochemical Cycles
Intergovernmental Panel on Climate Change 2021



Papahānaumokuākea Marine National Monument, Hawai'i, USA
photo James Watt, National Oceanic and Atmospheric Administration

Ocean acidification has corroded or dissolved corals and shells of marine life around the world

Kroeker et al. 2013 *Global Change Biology*
Feely et al. 2016 *Estuarine, Coastal, and Shelf Science*
Bednaršek et al. 2017 *Scientific Reports*
Bednaršek et al. 2020 *Science of the Total Environment*
Intergovernmental Panel on Climate Change 2022

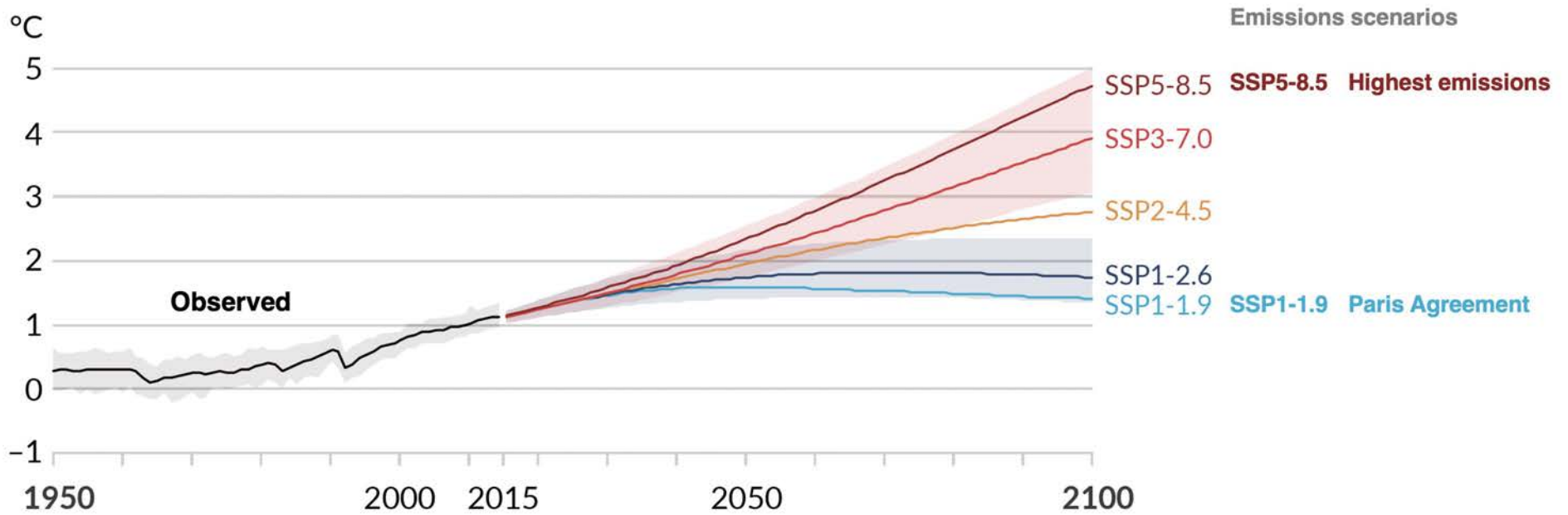


Omilu fish (Bluefin trevally, *Caranx melampygus*), cauliflower coral (*Pocillopora meandrina*), pohaku puna coral (*Porites lobata*)
Papahānaumokuākea Marine National Monument, Hawai'i, USA
photo James Watt, National Oceanic and Atmospheric Administration

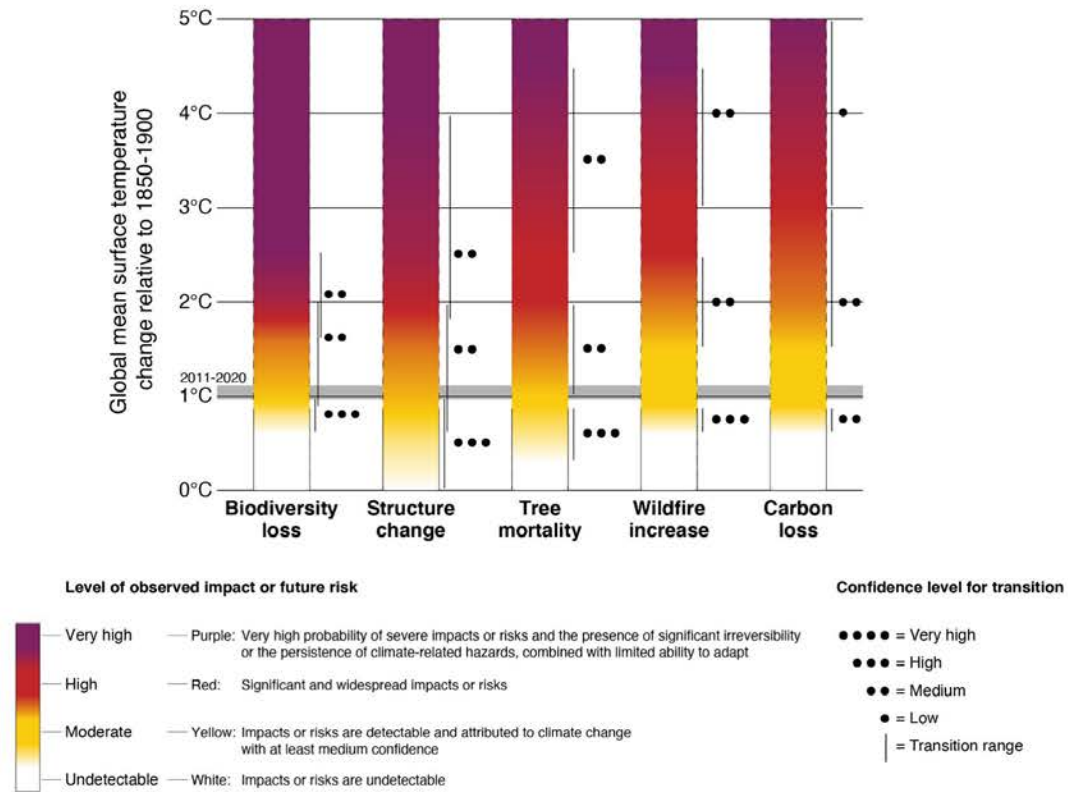
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Climate change projections

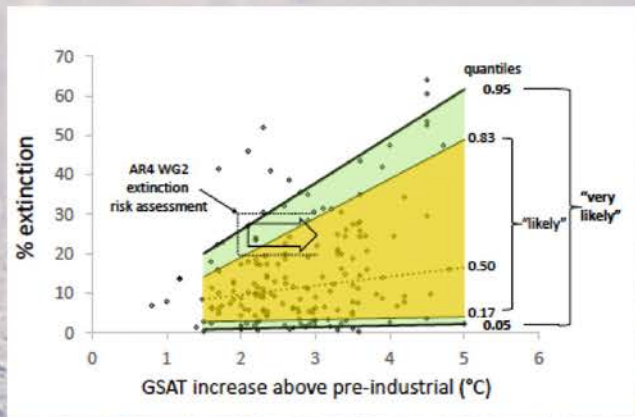


Climate change key risks to ecological integrity



Climate change at 4°C above pre-industrial could cause 30% more animal and plant extinctions than human habitat destruction and exploitation caused in 12 000 years

Intergovernmental Panel on Climate Change 2022



Polar bear (*Ursus maritimus*)
Listed as threatened due to climate change, under U.S. Endangered Species Act
Arctic National Wildlife Refuge, Alaska, USA
photo C. Donohue

Thirty-one species listed as threatened under the U.S. Endangered Species Act due to climate change



Rufa red knot (*Calidris canutus rufa*)
Delaware Seashore State Park, Delaware, USA
photo Jeff Holmes

Rufa red knot (*Calidris canutus rufa*)

Canada lynx (*Lynx canadensis*)

Corals (20 species)

Eastern black rail (*Laterallus jamaicensis jamaicensis*)

Emperor penguin (*Aptenodytes forsteri*)

Gunnison sagegrouse (*Centrocercus minimus*)

'I'iwi bird (*Drepanis coccinea*)

Meltwater lednian stonefly (*Lednia tumana*)

Polar bear (*Ursus maritimus*)

Ringed seal (*Phoca hispida*)

Western glacier stonefly (*Zapada glacier*)

U.S. Fish and Wildlife Service
U.S. National Marine Fisheries Service

Climate change at 4.3°C could reduce the emperor penguin population 90% by melting sea ice

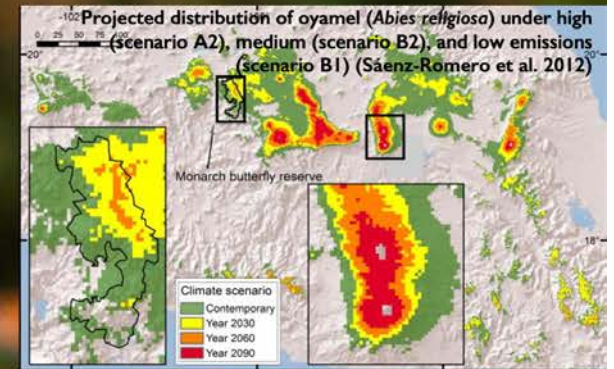
Jenouvrier et al. 2021 *Global Change Biology*
Trathan et al. 2020 *Biological Conservation*
Jenouvrier et al. 2019 *Global Change Biology*



Emperor penguin (*Aptenodytes forsteri*)
Mount Erebus, Antarctica
photo Laura Gerwin, National Science Foundation

Climate change increases risk to the Monarch butterfly of upslope shifts and loss of oyamel fir habitat in México

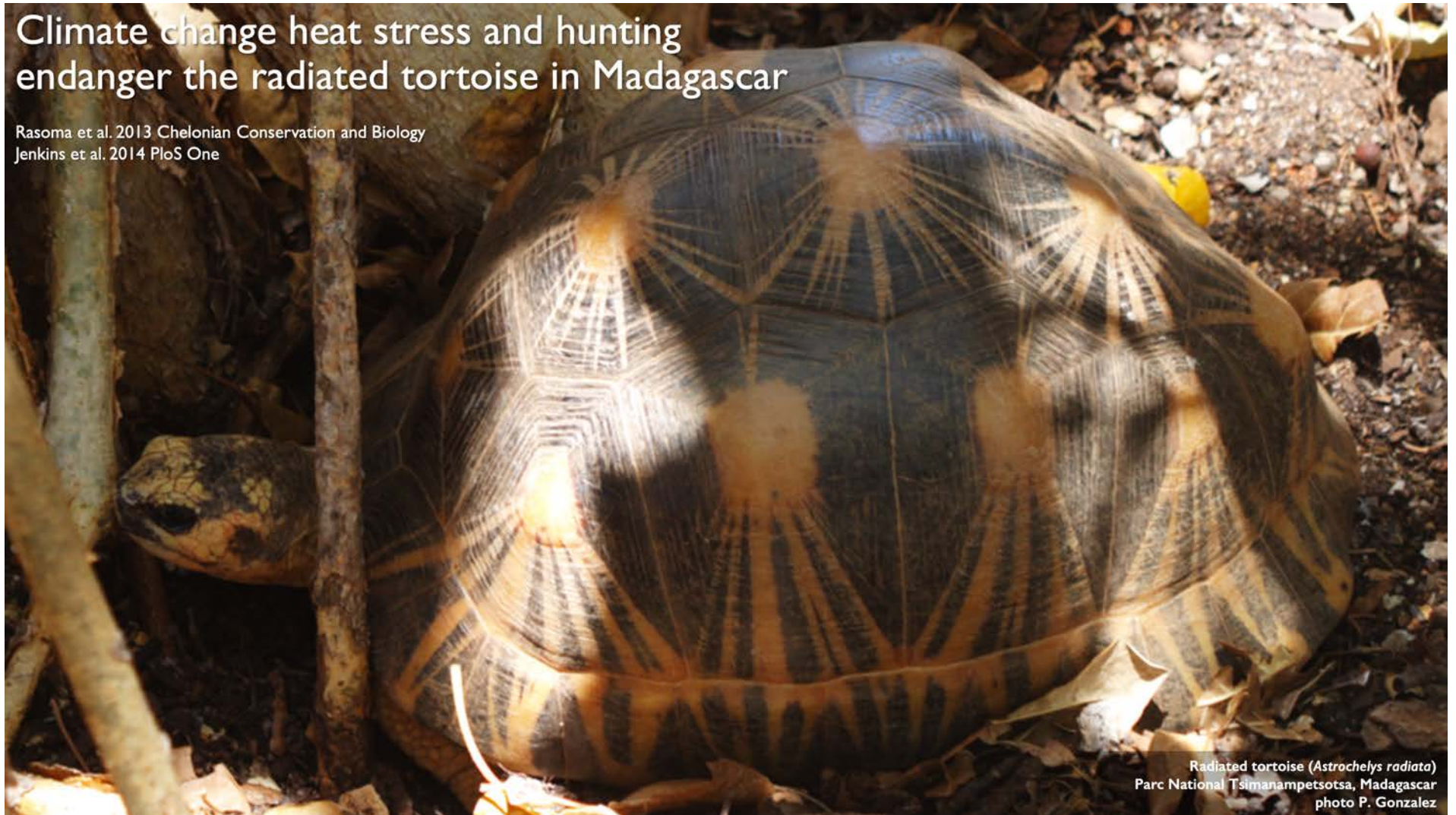
Sáenz-Romero et al. 2012 Forest Ecology and Management
Sáenz-Romero et al. 2020 Canadian Journal of Forest Research
Gomez-Pineda et al. 2020 Ecological Applications
Brower et al. 2009 Insect Conservation and Diversity



Monarch butterflies (*Danaus plexippus*) in oyamel trees (*Abies religiosa*)
Reserva de la Biosfera Mariposa Monarca, México
photo Richard Ellis

Climate change heat stress and hunting endanger the radiated tortoise in Madagascar

Rasoma et al. 2013 *Chelonian Conservation and Biology*
Jenkins et al. 2014 *PloS One*



Radiated tortoise (*Astrochelys radiata*)
Parc National Tsimanampetsotsa, Madagascar
photo P. Gonzalez

Ocean acidification under the highest human carbon dioxide emissions scenario could cause net dissolving of coral reefs globally before 2100

Intergovernmental Panel on Climate Change 2022
Intergovernmental Panel on Climate Change 2021
Eyre et al. 2018 Science Advances
Langdon et al. 2018 Limnology and Oceanography



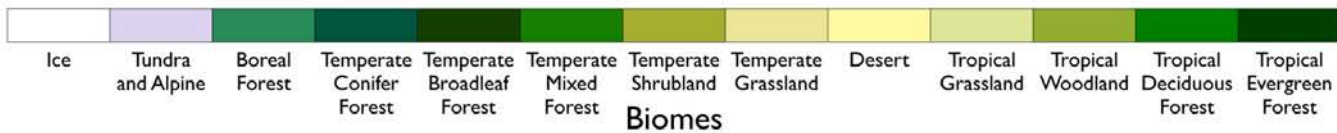
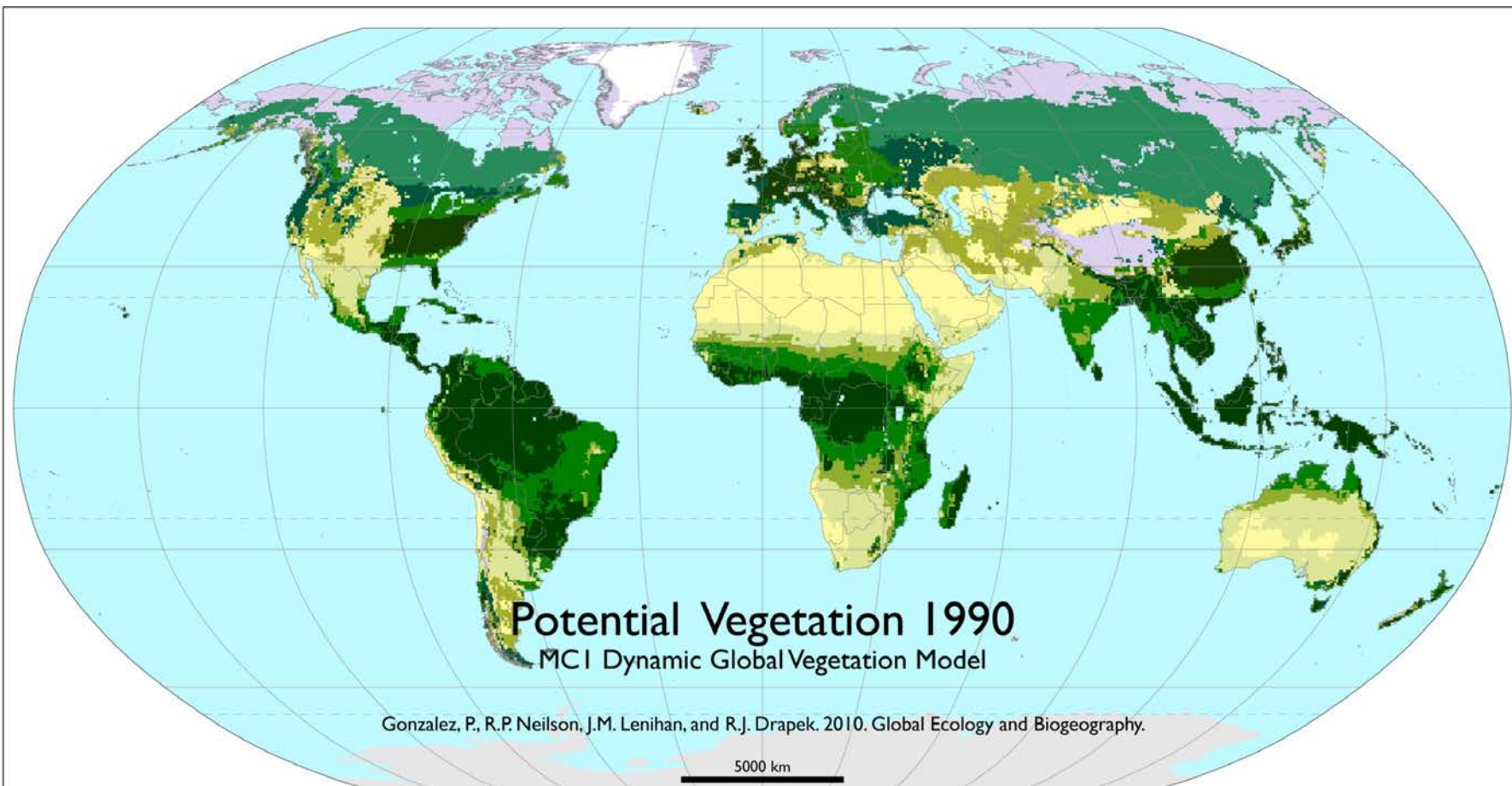
Coral reef, St. Croix, Virgin Islands, USA
photo National Oceanic and Atmospheric Administration

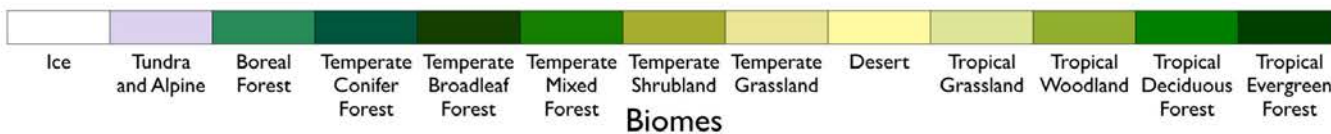
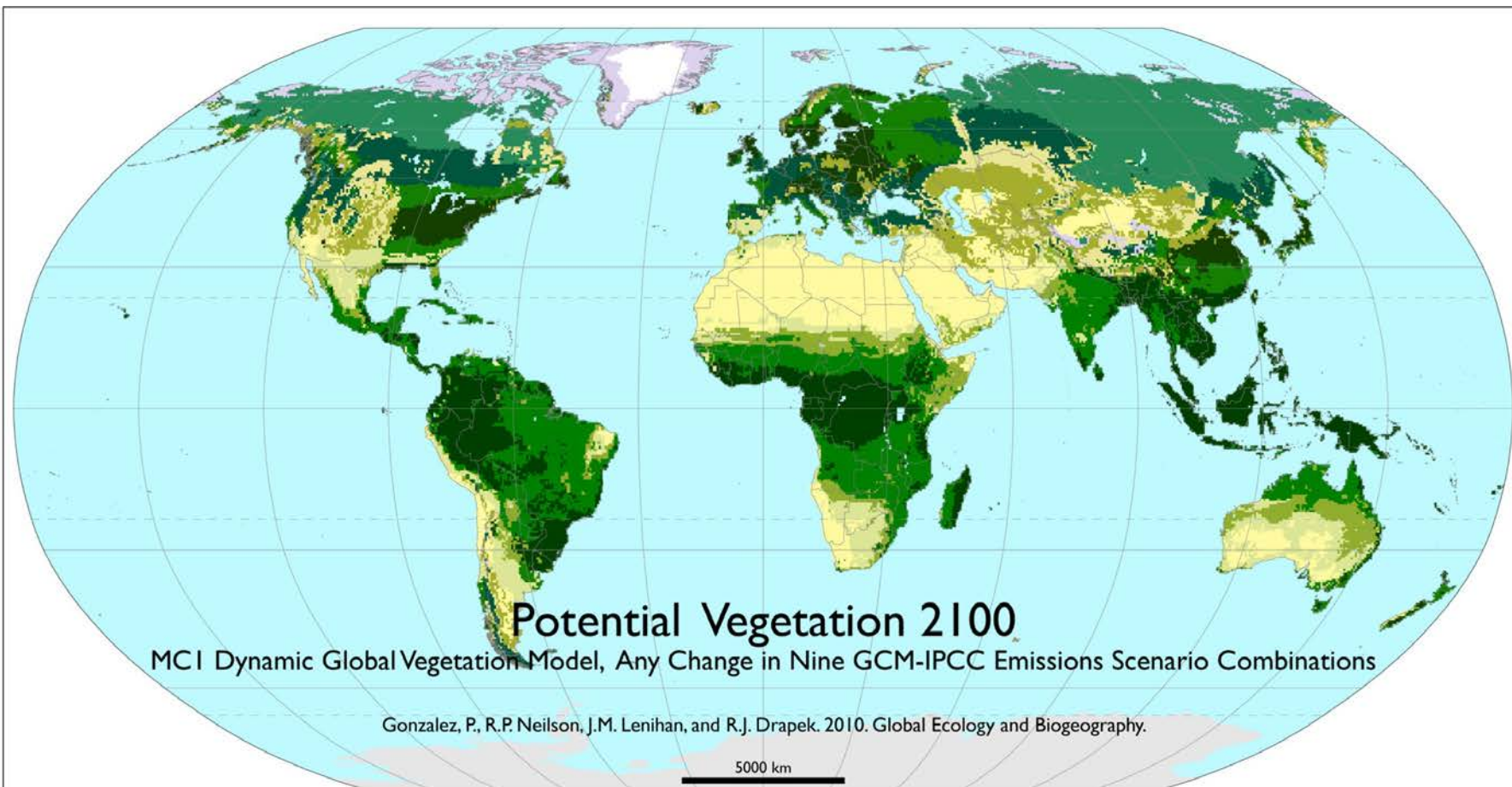
Climate change at 4°C could raise global sea level 0.6–1.0 m from 2014 to 2100, inundating all or parts of many small island nations

Intergovernmental Panel on Climate Change 2021
Sabunas et al. 2021 Frontiers in Built Environment
Andrew et al. 2019 PLoS One



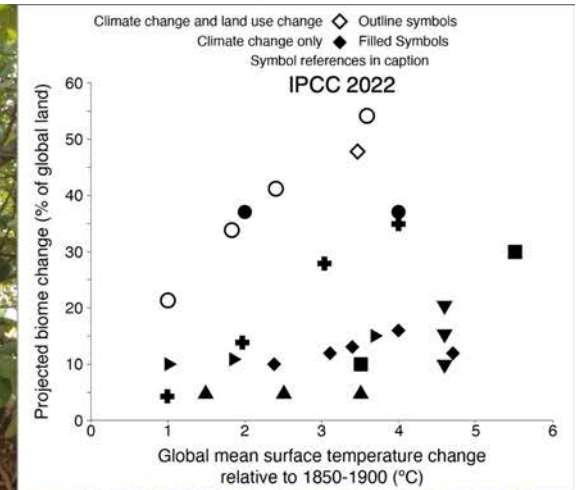
Kiribati
photo Herve Damlamian





Climate change and land use change increase risks of biome shifts on 5–50% of global land

Intergovernmental Panel on Climate Change 2022
Eigenbrod et al. 2015 Global Change Biology
Gonzalez et al. 2010 Global Ecology and Biogeography



Tropical woodlands at high risk of biome shifts due to climate change
Fig tree (*Ficus sp.*), Kanha National Park, India
photo: P. Gonzalez

Climate change under high emissions increases risks of mortality of up to a half of the trees in conifer forests of the southwest U.S.

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

Climate change increases the risk of mortality of coast redwood trees from reduction of fog, with heating of 2.5°C reducing suitable range by half

Sillett et al. 2022 Forest Ecology and Management

Francis et al. 2020 Ecography

Carroll et al. 2018 Dendrochronologia

Fernández et al. 2015 Global Change Biology

Johnstone and Dawson 2010 Proceedings of the National Academy of Sciences

Coast redwood trees (*Sequoia sempervirens*)
Tallest living beings on Earth

Muir Woods National Monument, California, USA, photo P. Gonzalez

Climate change increases the risk of mortality of bristlecone pine trees from bark beetle infestations

Bentz et al. 2022 Forest Ecology and Management



Bristlecone pine trees (*Pinus longaeva*)
Oldest living beings on Earth
Inyo National Forest, California, USA, photo P. Gonzalez

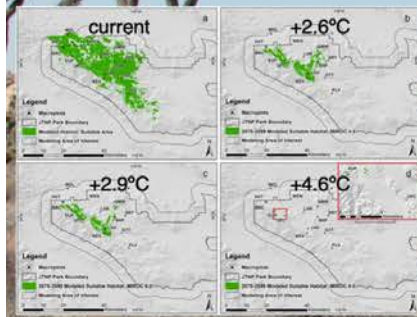
Climate change increases risk of the loss of Joshua trees from Joshua Tree National Park

Sweet et al. 2019 *Ecography*

Barrows and Murphy-Mariscal 2012 *Biological Conservation*

Cole et al. 2011 *Ecological Applications*

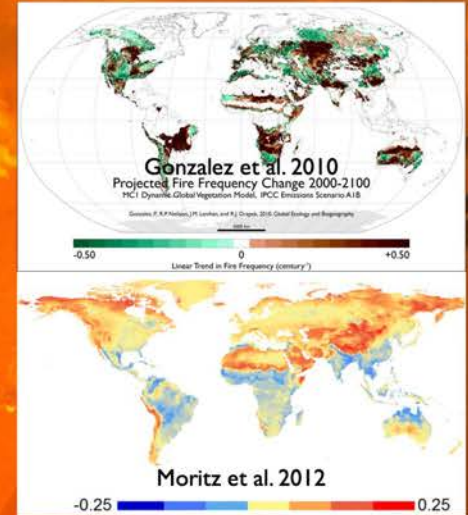
Dole et al. 2003 *Global and Planetary Change*



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

Climate change at 4°C could increase burned area 50-70% globally and increase fire frequencies across one to two-thirds of global land

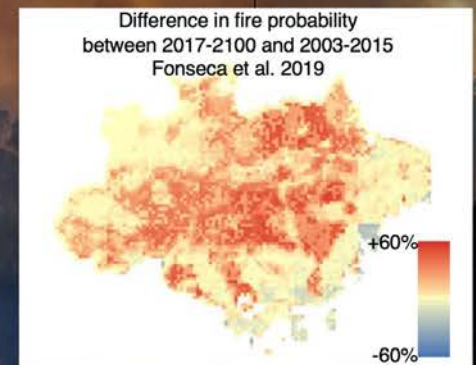
Intergovernmental Panel on Climate Change 2022
Senande-Rivera et al. 2022 Nature Communications
Kloster and Lasslop 2017 Global and Planetary Change
Knorr et al. 2016 Nature Climate Change
Moritz et al. 2012 Ecosphere
Gonzalez et al. 2010 Global Ecology and Biogeography



Lake Conjola, New South Wales, Australia, December 31, 2019
photo Matthew Abbott, New York Times

Climate change at 4°C and continued deforestation could double burned area in Amazon rainforest

Brando et al. 2020 Science Advances
Fonseca et al. 2019 Global Change Biology
Le Page et al. 2017 Earth System Dynamics



Fire in Amazon rainforest, August 15, 2020
north of Novo Progresso, Pará, Brazil
photo Carl de Souza, Agence France Presse

Climate change and deforestation fires could convert up to half of Amazon forest to grassland, releasing 1-3 years of 2019 global carbon emissions

Intergovernmental Panel on Climate Change 2022

Assis et al. 2022 Science Advances

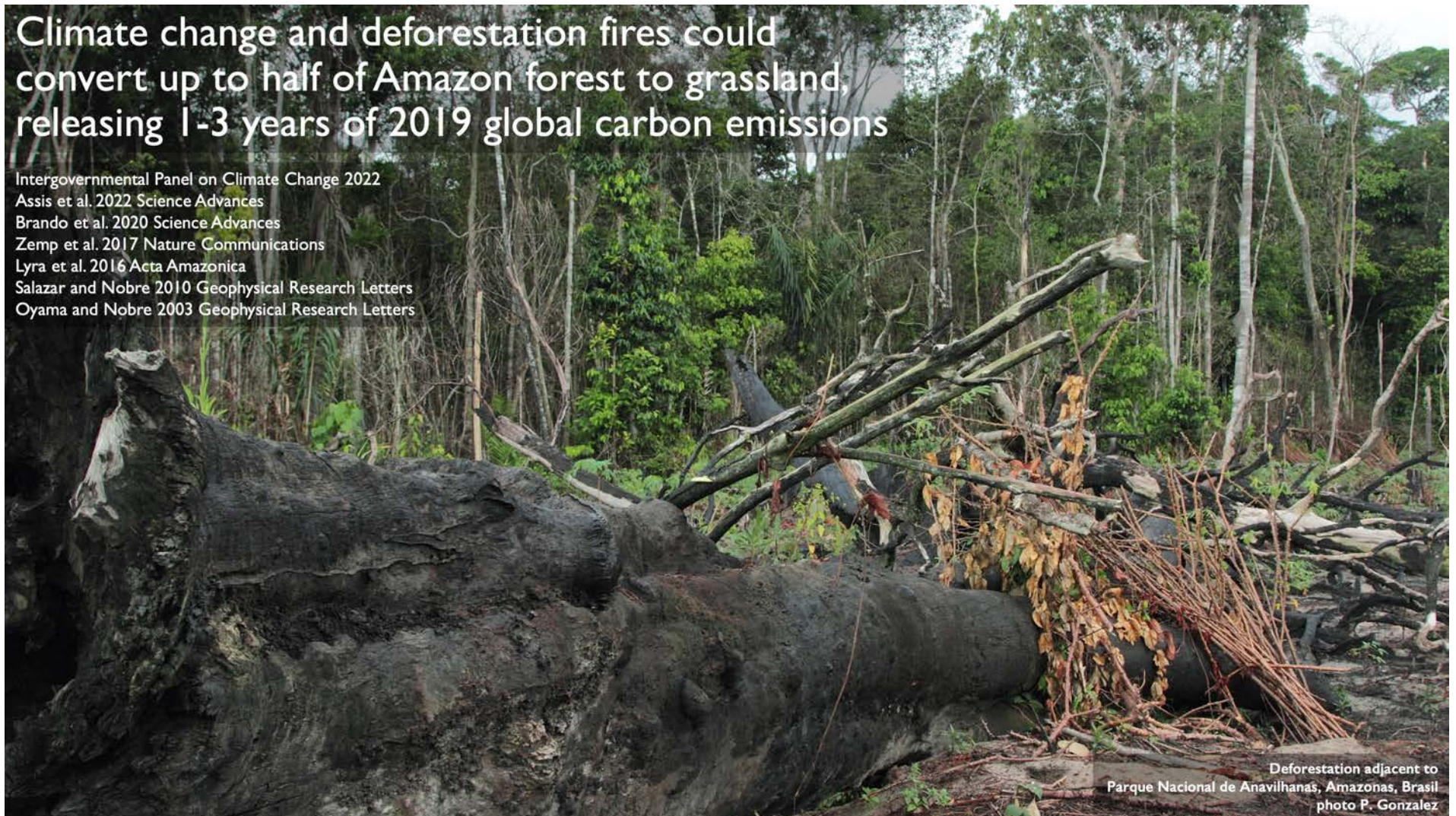
Brando et al. 2020 Science Advances

Zemp et al. 2017 Nature Communications

Lyra et al. 2016 Acta Amazonica

Salazar and Nobre 2010 Geophysical Research Letters

Oyama and Nobre 2003 Geophysical Research Letters



Deforestation adjacent to
Parque Nacional de Anavilhanas, Amazonas, Brasil
photo P. Gonzalez

Climate change of 4°C could cause fires and thaw permafrost across extensive areas of the Arctic, releasing up to 15 years of 2019 global carbon emissions

Intergovernmental Panel on Climate Change 2022

Intergovernmental Panel on Climate Change 2021

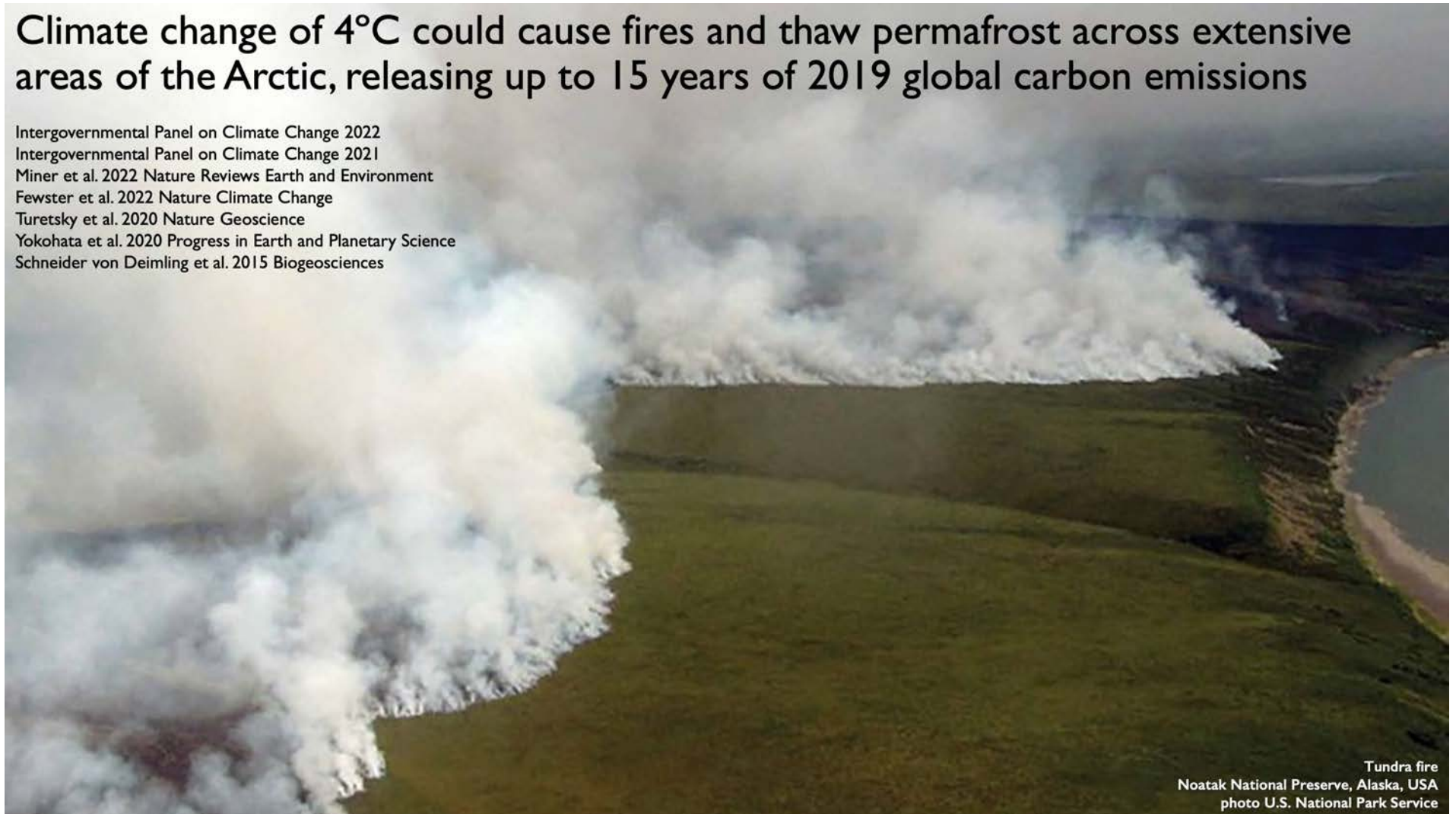
Miner et al. 2022 Nature Reviews Earth and Environment

Fewster et al. 2022 Nature Climate Change

Turetsky et al. 2020 Nature Geoscience

Yokohata et al. 2020 Progress in Earth and Planetary Science

Schneider von Deimling et al. 2015 Biogeosciences



Tundra fire
Noatak National Preserve, Alaska, USA
photo U.S. National Park Service

Human-Caused Climate Change Impacts on Biodiversity and Solutions for the Future

1. Human cause of climate change
2. Observed changes
3. Future risks
4. **Adaptation**
5. Carbon solutions

Conserving climate change refugia in Joshua Tree National Park, California

Sweet et al. 2019 Ecosphere
Barrows et al. 2014 Biodiversity and Conservation
Intergovernmental Panel on Climate Change 2022



Upgrading U.S. policies from suppression of all fire to restoration of natural fire could reduce catastrophic wildfire under climate change, carbon loss, and costs

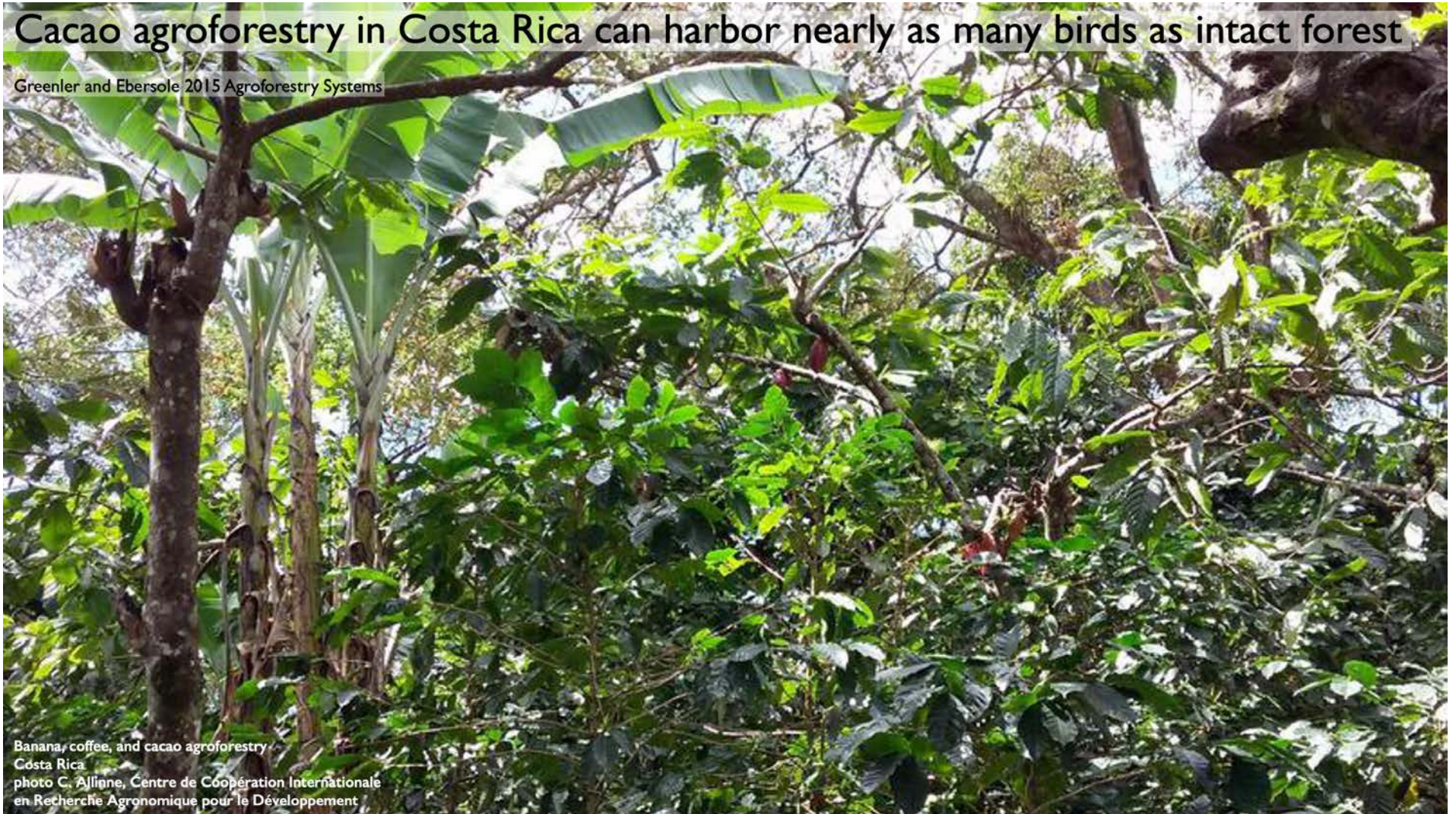
Hessburg et al. 2022 *Frontiers in Ecology and the Environment*
International Association of Wildland Fire 2022 Position Statement
Prichard et al. 2021 *Ecological Applications*
Stephens et al. 2020 *Frontiers in Ecology and the Environment*
Gonzalez 2020 Day One Project
Parks et al. 2015 *Ecological Applications*
North et al. 2015 *Science*
Stephens et al. 2013 *Science*



Andy Lamebear lights a prescribed burn
Yurok Reservation, California, USA
photo Matt Mais, Yurok Tribe

Cacao agroforestry in Costa Rica can harbor nearly as many birds as intact forest

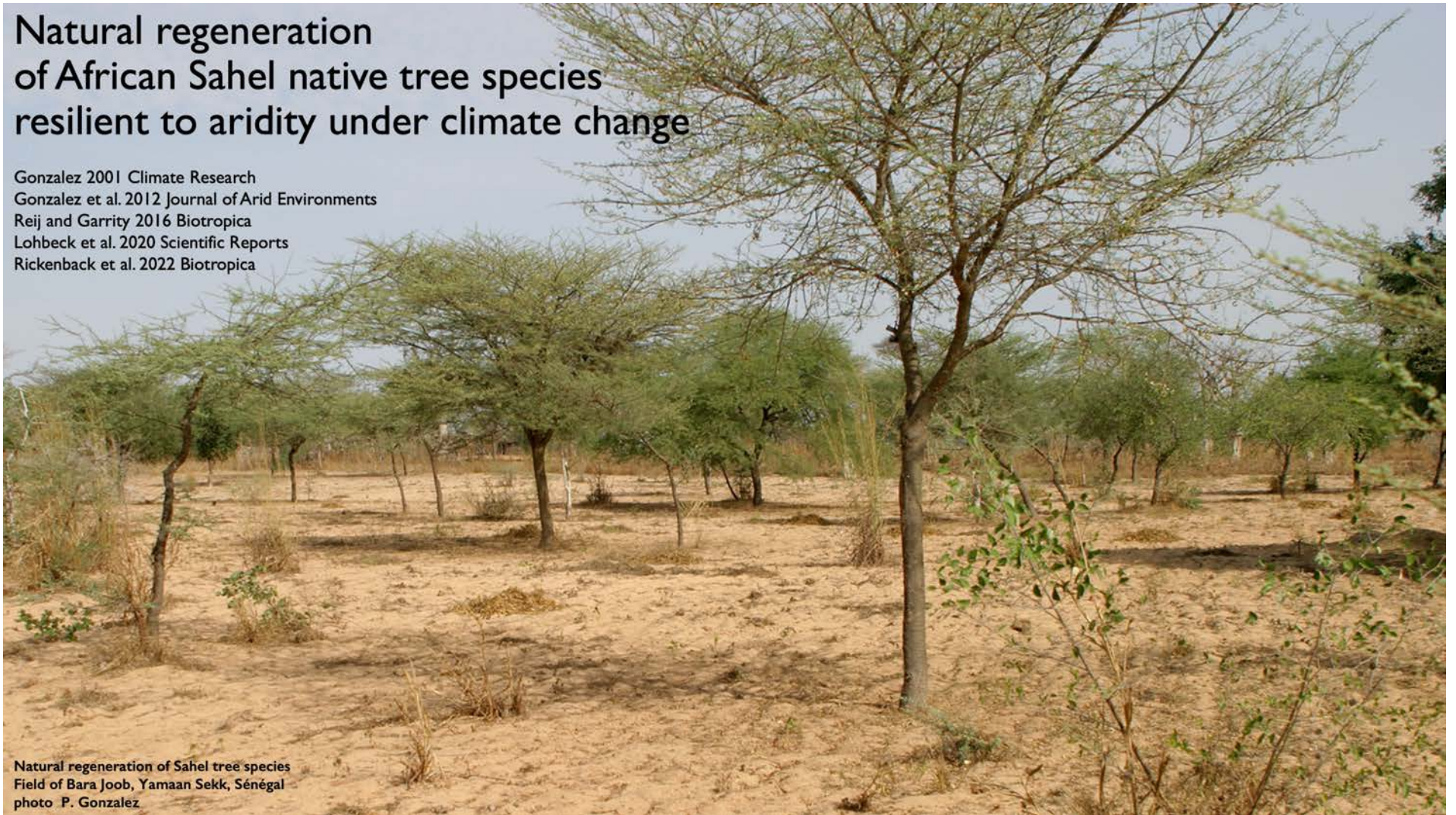
Greenler and Ebersole 2015 Agroforestry Systems



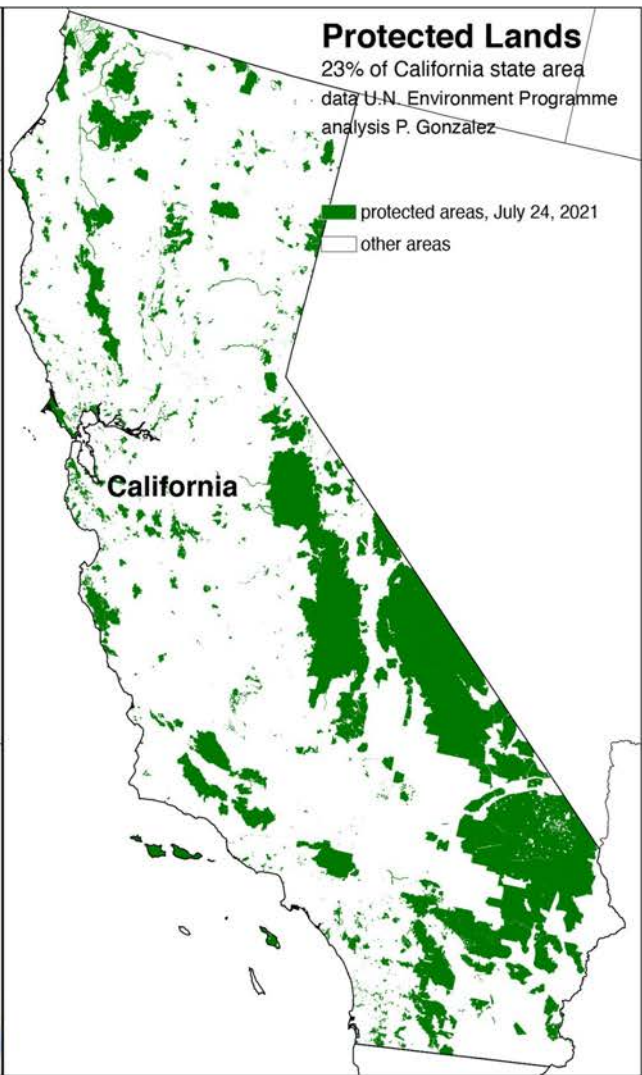
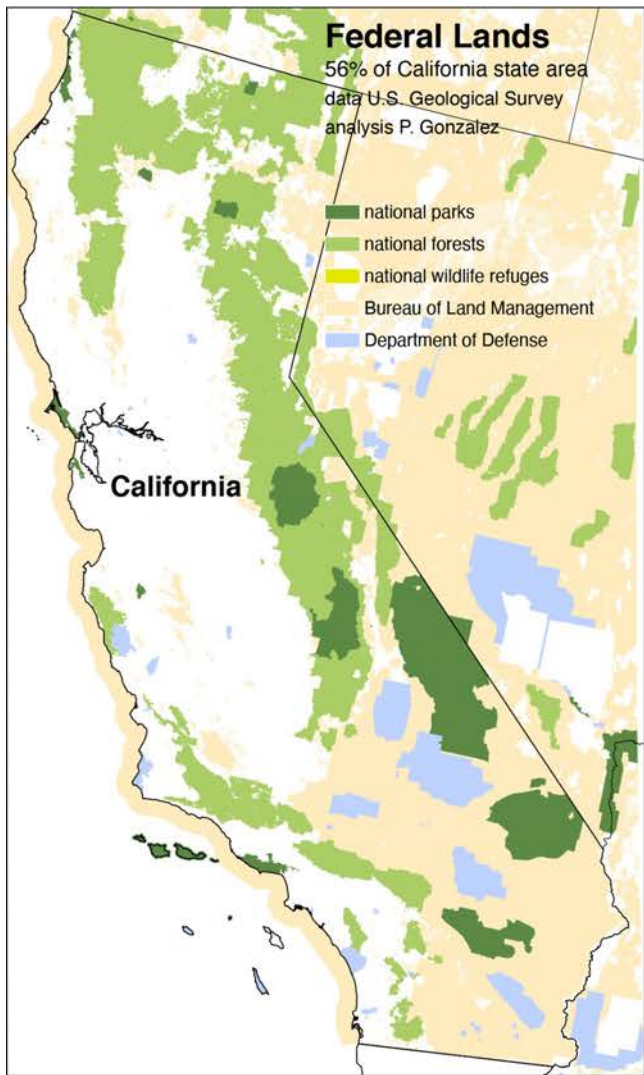
Banana, coffee, and cacao agroforestry
Costa Rica
photo C. Alligne, Centre de Coopération Internationale
en Recherche Agronomique pour le Développement

Natural regeneration of African Sahel native tree species resilient to aridity under climate change

Gonzalez 2001 Climate Research
Gonzalez et al. 2012 Journal of Arid Environments
Reij and Garrity 2016 Biotropica
Lohbeck et al. 2020 Scientific Reports
Rickenback et al. 2022 Biotropica



Natural regeneration of Sahel tree species
Field of Bara Joob, Yamaan Sekk, Sénégal
photo P. Gonzalez



Upgrading conservation management of U.S. federal lands could double protection without purchasing new land

	USA	California
Federal land	28%	56%
Protected 2022	13%	24%
Target 2030	30%	30%

Analyses
Patrick Gonzalez, University of California, Berkeley

Policies – 30 x 30 Goal
U.N. Convention on Biological Diversity, 2021
U.S. Executive Order 14008, January 27, 2021
California Executive Order N-82-20, October 7, 2020

Human-Caused Climate Change Impacts on Biodiversity and Solutions for the Future

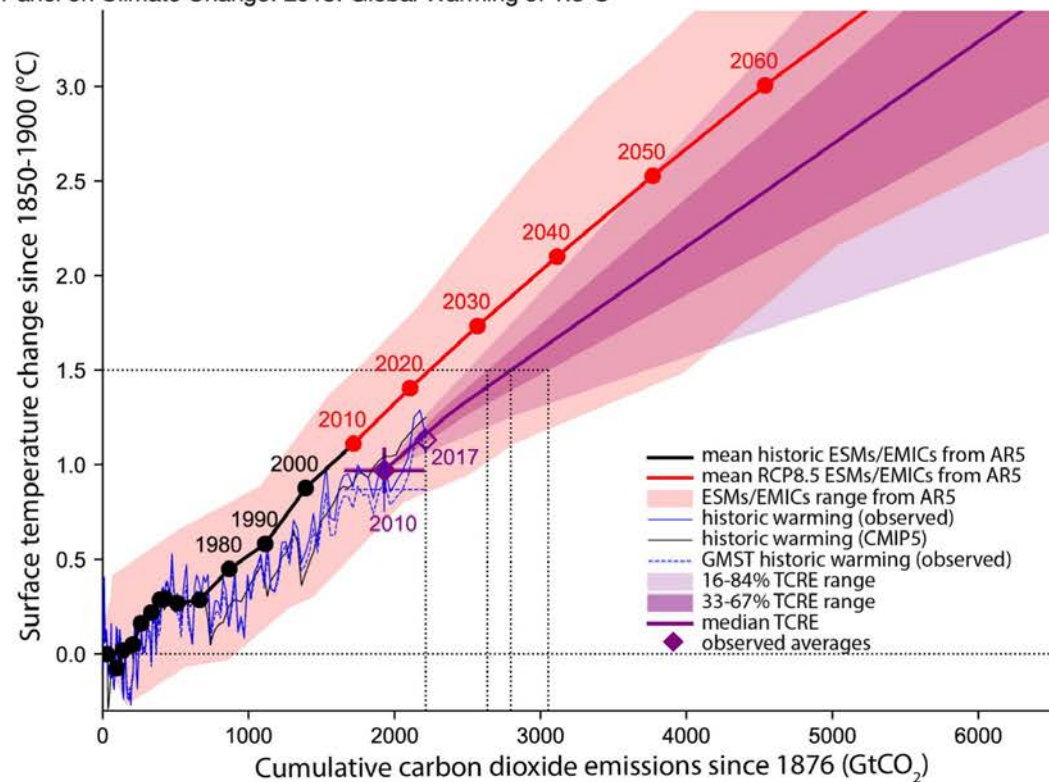
1. Human cause of climate change
2. Observed changes
3. Future risks
4. Adaptation
5. Carbon solutions

Global temperature increase may exceed 1.5° by 2032-2034 at 2010-2019 emissions

Intergovernmental Panel on Climate Change. 2021. Climate Change 2021: The Physical Science
 Intergovernmental Intergovernmental Panel on Climate Change. 2018. Global Warming of 1.5°C

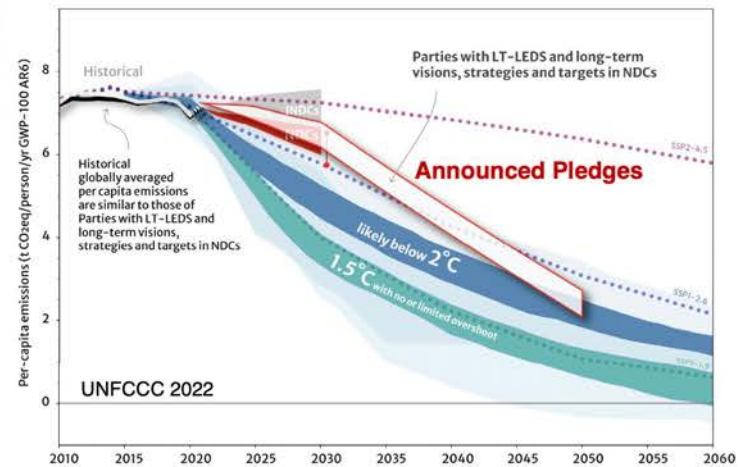
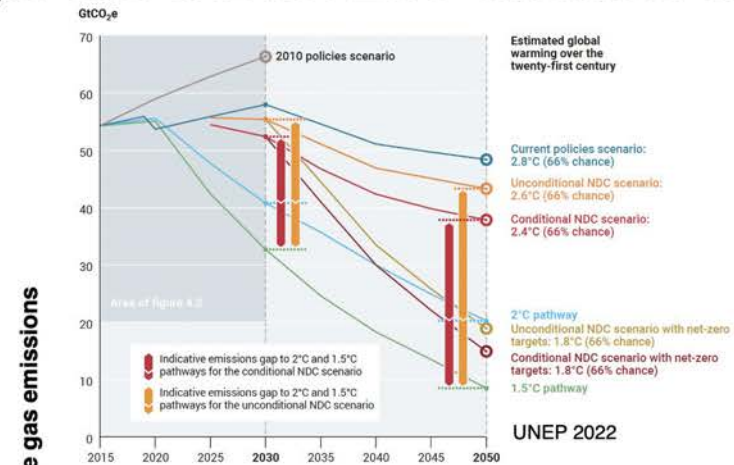
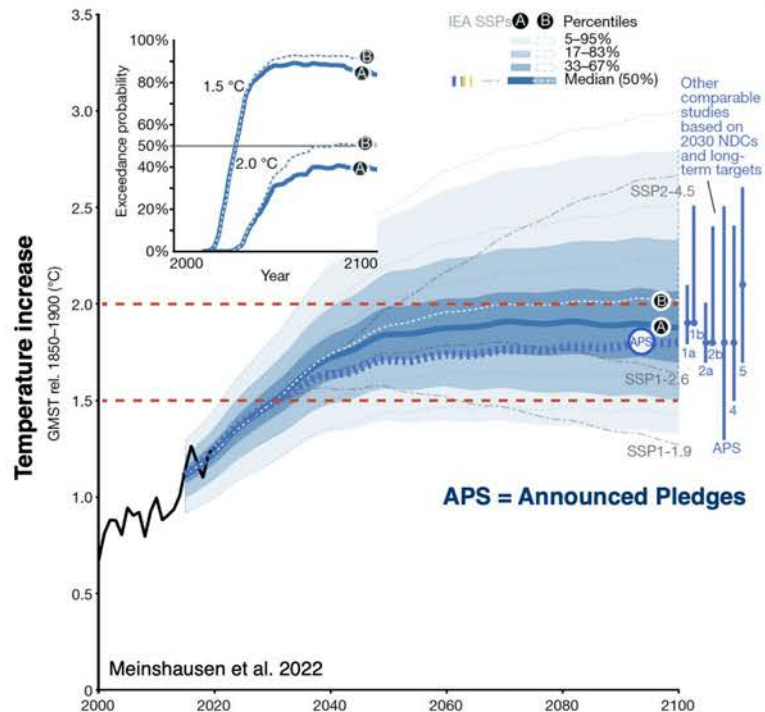
Remaining budget starting January 1, 2020
 140 ± 60 Gt Carbon
 (510 ± 220 Gt CO₂)

Emissions 1876-2019
 685 ± 75 Gt Carbon
 (2500 ± 275 Gt CO₂)



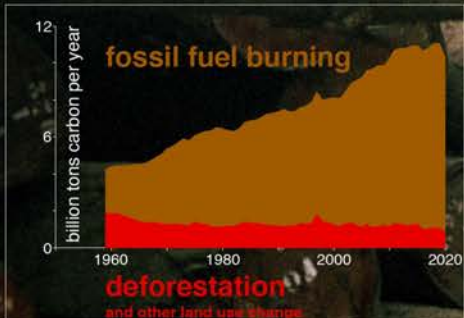
Limiting climate change to 1.8°C attainable with complete implementation of all Paris Agreement national greenhouse gas cuts and net-zero emissions targets but current policies lead to 2.8°C increase

U.N. Framework Convention on Climate Change, Long-Term Low-Emissions report, October 26, 2022
 U.N. Environment Programme, Emissions Gap Report, October 27, 2022
 Meinshausen et al., Nature, April 14, 2022



Halting deforestation could cut global carbon emissions 10% and reduce climate change

Friedlingstein et al. 2022 Earth System Science Data
U.N. Framework Convention on Climate Change, Reducing Emissions from Deforestation and Degradation and through improved forest management (REDD+) 2013



	2011-2022	billion tons carbon per year
Fossil fuels		9.5 ± 0.5
Deforestation		1.1 ± 0.7

Congo rainforest, Gabon
photo Patrick González

National parks and other protected areas effectively reduced deforestation in those areas 72%, saving 86 000 km² of forest, 2000-2012

Shah et al. 2021 Environmental Research Letters

Goncalves-Souza et al. 2021 Science Advances

Graham et al. 2021 Scientific Reports

Pauly et al. 2022 Scientific Reports

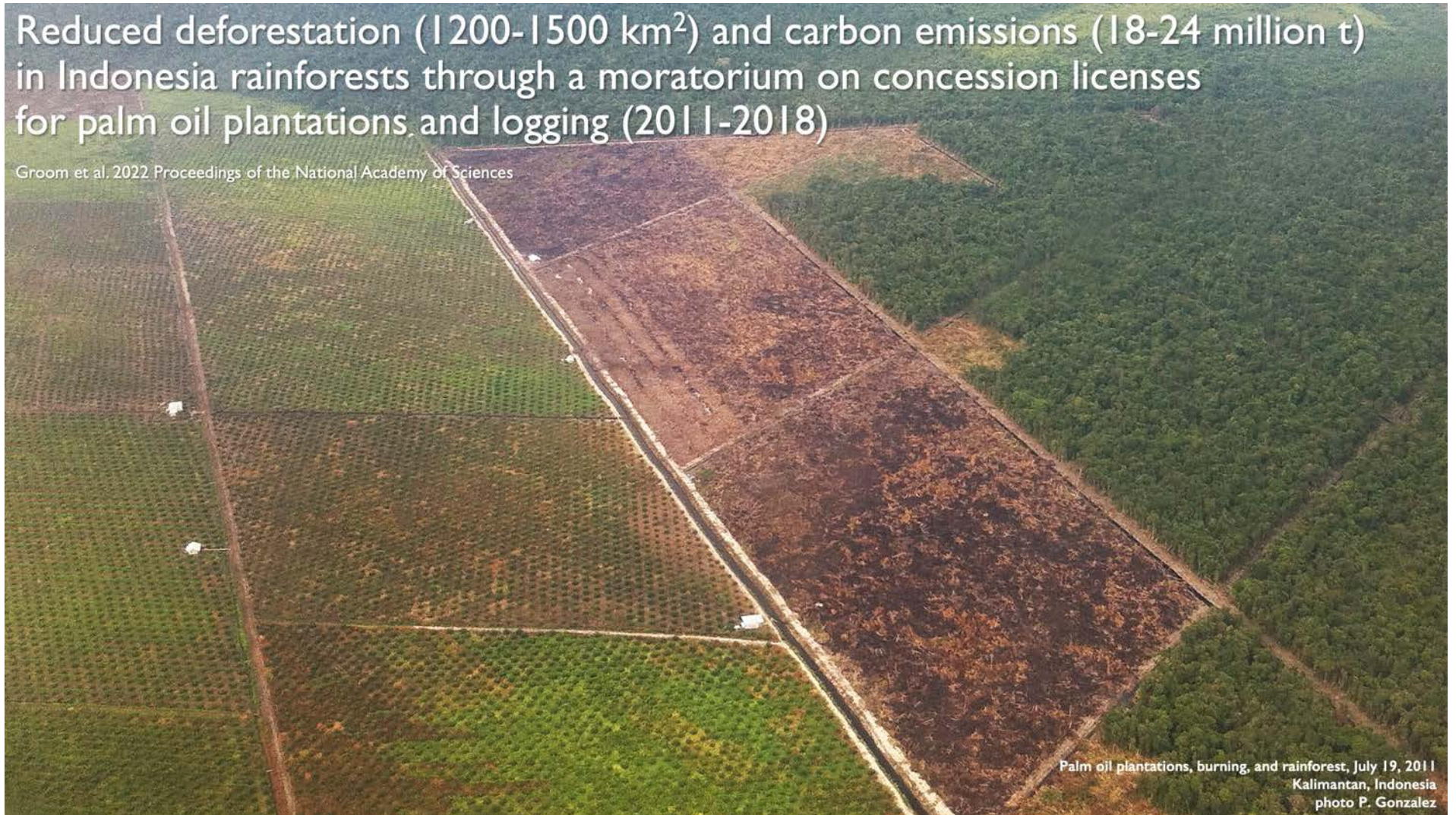
Gonzalez et al. 2014 Forest Ecology and Management

Adeney et al. 2009 PLoS One

Amazon rainforest
Parque Nacional Yanachaga-Chemillén, Perú
photo P. Gonzalez

Reduced deforestation (1200-1500 km²) and carbon emissions (18-24 million t) in Indonesia rainforests through a moratorium on concession licenses for palm oil plantations and logging (2011-2018)

Groom et al. 2022 Proceedings of the National Academy of Sciences



Palm oil plantations, burning, and rainforest, July 19, 2011
Kalimantan, Indonesia
photo P. Gonzalez

If U.S. passenger cars and light trucks were a separate country, they would be the 8th largest carbon polluter in the world

World Resources Institute 2022 Climate Watch
U.S. Environmental Protection Agency 2022 Inventory of U.S. Greenhouse Gas Emissions

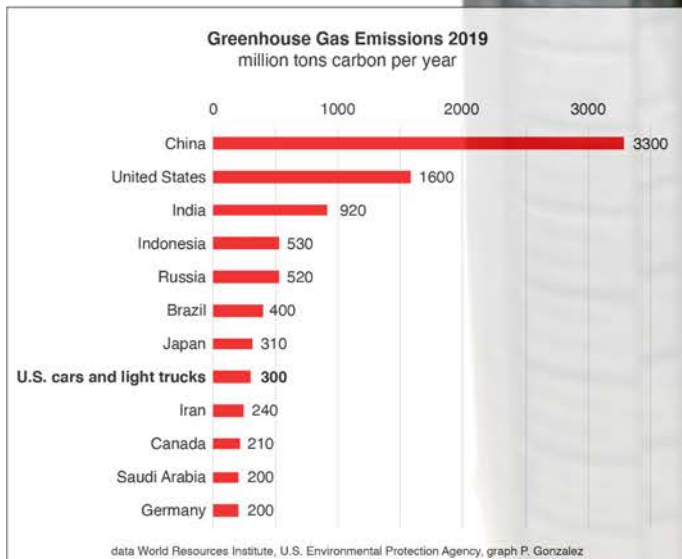


photo P. Gonzalez

Walking, biking, and public transit can cut personal transportation carbon pollution up to 99%

Intergovernmental Panel on Climate Change 2021
Bonilla-Alicea et al. 2020 Journal of Industrial Ecology
Knobloch et al. 2020 Nature Sustainability
Nordelöf et al. 2019 Transportation Research Part D
Chester and Horvath 2009 Environmental Research Letters
U.S. Federal Transit Administration 2009

Life cycle emissions (fuel, production, disposal)
grams carbon per passenger per kilometer

Walking	<1
Bicycle	1-3
Bus	10-25
Rail	5-25
Car	90-130



Ohlone Greenway
and Bay Area Rapid Transit (BART)
Albany, California, USA
photo P. Gonzalez

Global adoption of a plant-rich, meat-free diet could cut global greenhouse gas emissions 40%

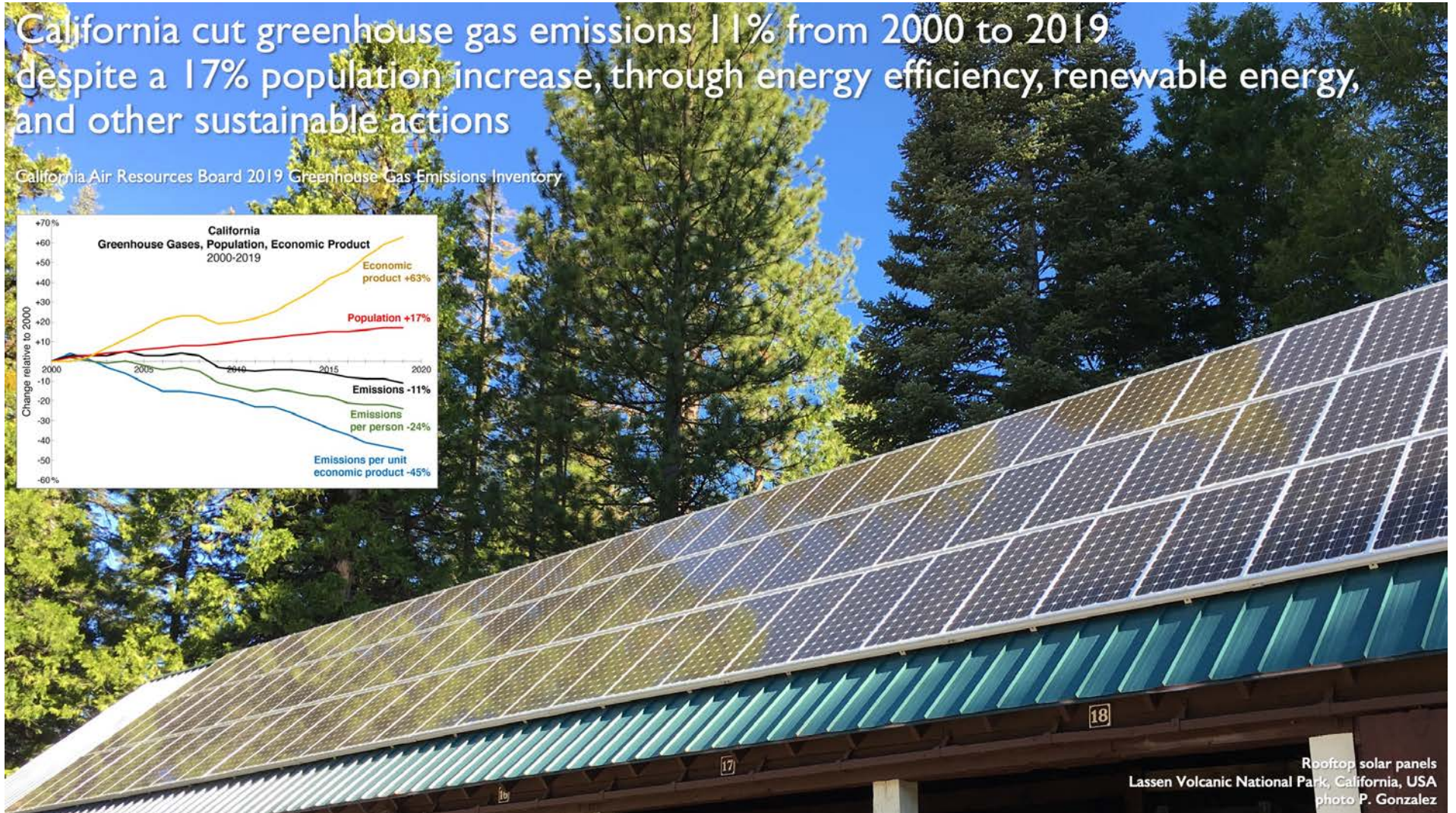
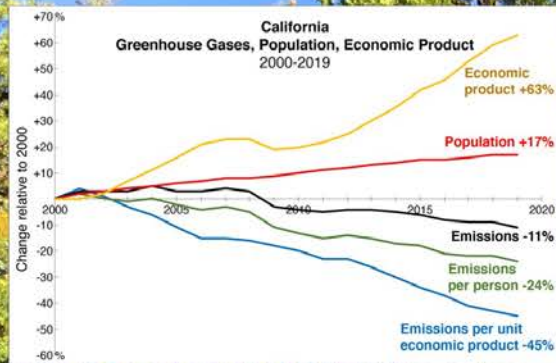
Eisen and Brown 2022 PLoS Climate
Intergovernmental Panel on Climate Change 2022 Mitigation
Castaldi et al. 2022 Scientific Reports
Costa et al. 2022 Scientific Reports
Clark et al. 2020 Science Advances
Springmann et al. 2018 Nature

Beef cattle feedlot
photo Texas A & M University



California cut greenhouse gas emissions 11% from 2000 to 2019 despite a 17% population increase, through energy efficiency, renewable energy, and other sustainable actions

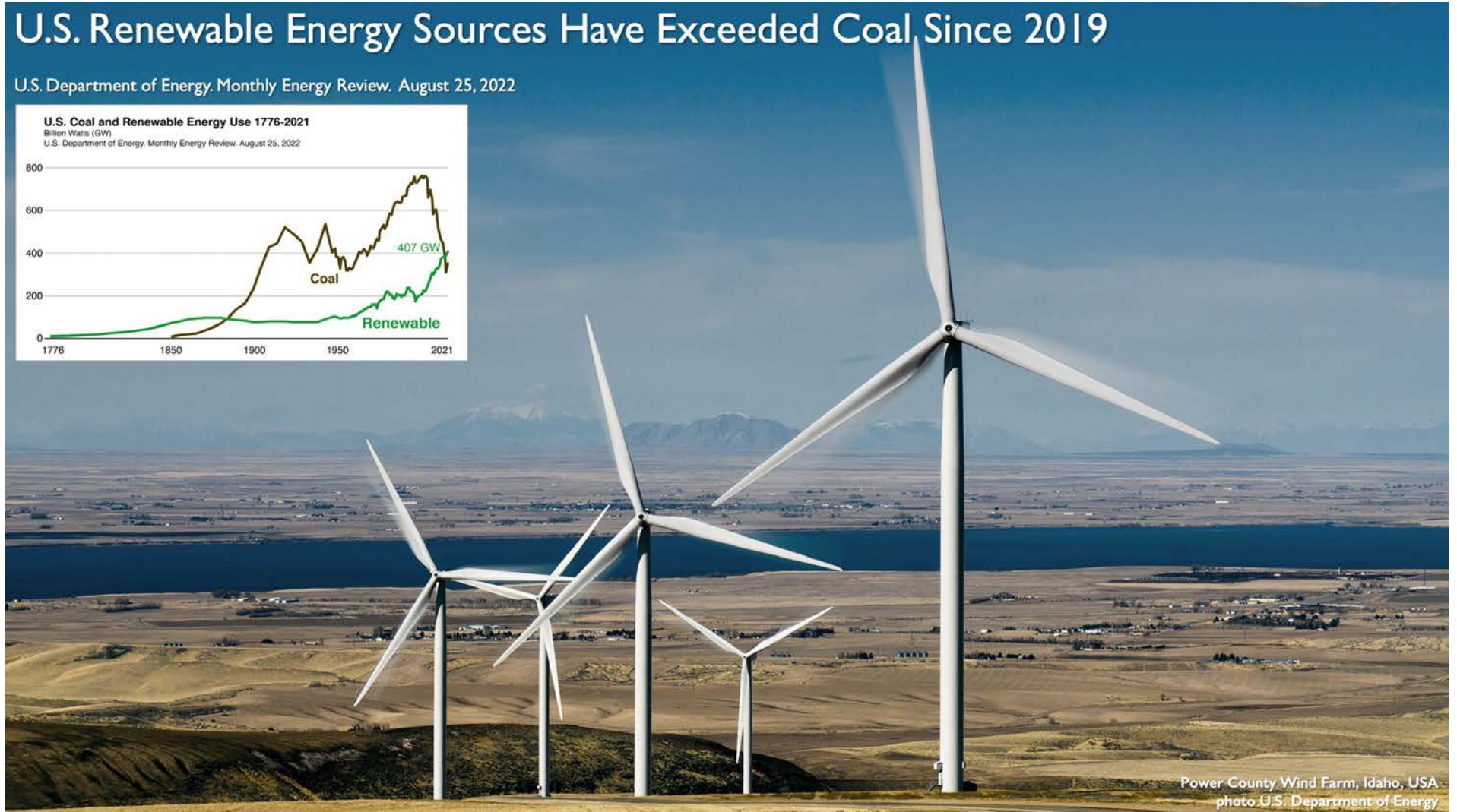
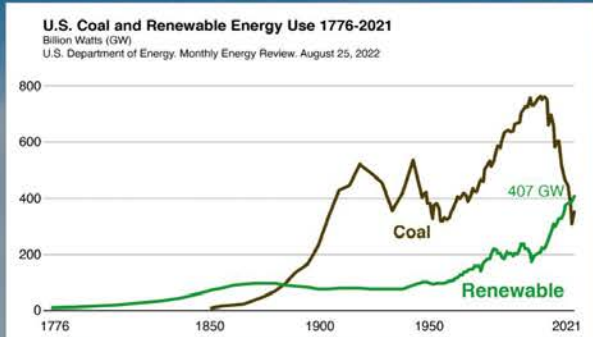
California Air Resources Board 2019 Greenhouse Gas Emissions Inventory



Rooftop solar panels
Lassen Volcanic National Park, California, USA
photo P. Gonzalez

U.S. Renewable Energy Sources Have Exceeded Coal Since 2019

U.S. Department of Energy. Monthly Energy Review. August 25, 2022



Power County Wind Farm, Idaho, USA
photo U.S. Department of Energy

Limiting temperature increase to 1.5° to 2°C attainable with concerted action by governments, companies, individuals, using existing technologies and behaviors

Intergovernmental Panel on Climate Change. 2022. Climate Change 2022: Mitigation

