Stanford
Environmental Research

2022 Year in Review

Stanford Woods Institute for the Environment

This report covers research by faculty, students, postdoctoral scholars and research staff from across Stanford's seven schools.

Above: As water resources from the Colorado River continue to dwindle, researchers at the Water in the West program found that many informal environmental water transactions sidestep formal legal processes, which could help states meet mandated reductions and relieve pressure on the environment. IMAGE CREDIT: ISTOCK / KOJI HIRANO

On the cover: Researchers from the Natural Capital Project found that the intersection of wildlife and built infrastructure creates tourism hotspots that can fuel green development. Here, a Geoffroy's spider monkey *(Ateles geoffroyi)* snacks on leaves in Corcovado National Park, Costa Rica. IMAGE CREDIT: DANIEL S. KARP

Table of Contents

Letter from Dean Arun Majumdar

At his inaugural address as Stanford's 11th president in the fall of 2016, President Marc Tessier-Lavigne asked a profound question: "Are we sufficiently advancing a purposeful university?"

In so doing, he inspired one of the finest institutions of higher learning in the world to reaffirm our commitment to being "a university that promotes and celebrates excellence not as an end in itself but as a means to magnify its benefit to society; a university that … discovers and applies knowledge for the benefit of humanity."

The Stanford community responded affirmatively and resoundingly with "Our Vision," the university-wide long-range plan focused on accelerating our purposeful impact in the world and, with it, the historic establishment of the Stanford Doerr School of Sustainability.

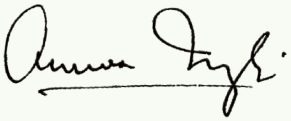
Prior to last fall, it had been 75 years since Stanford had established a new school on our campus. And while those nearly eight decades don't even register as a blip on the geologic time scale, the advancements in knowledge and technology and changes in society and culture over that time have been unprecedented.

Discoveries in science and public health saved countless millions of lives. Humans traveled to space and unlocked the secrets of the most minute particles. Creative endeavors in art, literature, and music inspired us to comprehend the world, and each other, in new ways.

Among those advancements and changes came a fuller and indisputable realization of the impact of humanity on the environment and the reality of climate change.

Sustainability is the defining challenge of our time and requires a response equal to the most impactful discoveries of the past century. This vision drove the founding of the Stanford Doerr School of Sustainability and inspires all that we do. By bringing together eminent scholars and thought leaders on the central questions related to sustainability, we build the networks of knowledge and action necessary to make real global impact. Truly, we are seeking to do no less than reimagine the capacity of higher education to deal with the immense challenges of climate and sustainability. To that end, we are rethinking the ways we teach, learn, do research, apply knowledge, and make an impact.

Fundamental to all our efforts is the transformative commitment to discovery chronicled in this report. Featuring research and scholarship from across the university, this collection proves how Stanford faculty, students, postdoctoral scholars, and research staff are building bridges spanning from knowledge to solutions to impact and putting our university at the forefront of creating the solutions for a livable and sustainable planet now and for the future.



Arun Majumdar

Chester Naramore Dean, Stanford Doerr School of Sustainability

Jay Precourt Professor of Mechanical Engineering & Energy Science and Engineering

Senior Fellow, Precourt Institute for Energy & Hoover Institution

Note From Director Chris Field

Throughout the pandemic, Stanford researchers were resourceful and resilient, advancing our understanding of a changing planet Earth, illuminating fundamental natural processes, connecting climate change impacts to human society and well-being, and developing innovative sustainability solutions.

I am thrilled to share with you a collection of research from 2022 that celebrates the breadth and depth of environment and sustainability expertise at Stanford. Researchers expanded our knowledge of ice sheets, corals, and gravity waves and the lifespan of methane in the atmosphere. New findings revealed how climate change is amplifying the risk of catastrophic wildfires, contributing to worsened air quality and severe health impacts across the country.

Other significant results documented negative impacts of human activity on environmental systems, focusing on microplastics, nitrogen oxides, and groundwater extraction. Highlighting the complex social and environmental dynamics related to the global ocean, scholars offered new frameworks and insights into justice, food security, and human rights in aquatic food systems.

Researchers also explored the potential for nature-based solutions through beaver dams, riverfront restoration, coastal conservation to protect against sea level rise, and the synergy of wildlife and built infrastructure to support tourism. They emphasized the broad scale of climate issues, from our personal responses to natural disasters to state and federal climate strategy. By bringing their expertise to collaborative partnerships, Stanford researchers are playing a role in scholarship, policy, and real-world impact.

On September 1, 2022, the Woods Institute joined the Stanford Doerr School of Sustainability. The launch of the school marks an exciting new chapter in Stanford's long-term commitment to environment and sustainability research, education, and impactful solutions at scale. The Woods community brings a wealth of experience to contribute to the school's ambition to advance climate and sustainability scholarship and to deliver solutions at scale. I look forward to sharing this journey as we work together to connect knowledge to action.

Christopher Field

Perry L. McCarty Director of the Stanford Woods Institute for the Environment

Research Awards for Environmental Solutions

In order to tackle immense environmental challenges, scientists, engineers, law experts, social scientists, and other scholars must take risks and enact bold, creative research plans. In 2022, the Stanford Woods Institute for the Environment awarded more than $1.5 million to 10 innovative projects in the form of Environmental Venture Projects (EVP) and Realizing Environmental Innovation Program (REIP) grants.

Since EVP began in 2004 and REIP began in 2015, the Stanford Woods Institute has awarded more than $20 million in grants to 132 research teams representing all seven of Stanford's schools and working in 36 different countries. These projects have gone on to receive more than $50 million in additional funding from other sources.

Environmental Venture Projects

The goal of EVP grants is to support interdisciplinary, high-risk research projects that identify and develop real-world solutions. The projects selected for 2022 will receive up to $200,000 over two years.

Developing new water purification technology

Water scarcity is one of the most rapidly intensifying environmental challenges. At current levels of consumption, potable water demand is expected to exceed supply by 40 percent in 2030. While water reuse is a potential solution, current approaches, such as reverse osmosis or thermal distillation, are either cost-prohibitive or require large energy inputs. This project aims to develop novel resin technologies for the removal and recovery of critical contaminants from wastewaters. Results will help decipher design considerations for selective binding of critical contaminants, generate novel resin technologies with unprecedented efficacy, and yield novel methods for resin development and screening.

Eric Appel (Materials Science and Engineering), Polly Fordyce (Bioengineering and Genetics), William Tarpeh (Chemical Engineering)

Upgrading housing infrastructure to improve health and minimize emissions

In low-income countries, housing improvements are linked to improved health. Yet, the production and transport of building materials are major contributors to global greenhouse gas emissions. Researchers will test whether "green" concrete floors made with an alternative cement mix can improve child health while minimizing greenhouse gas emissions in rural Bangladesh. They will also develop guidelines for green concrete floor installation in rural, low-income settings and model greenhouse gas emissions under scaled up implementation scenarios. The team will engage with nongovernmental organizations in Bangladesh to investigate opportunities to install green concrete floors at scale.

Jade Benjamin-Chung (Epidemiology and Population Health), Sarah Billington (Civil and Environmental Engineering), Ali Boehm (Civil and Environmental Engineering), Mike Lepech (Civil and Environmental Engineering)

A Great Egret *(Ardea alba)* takes flight from wetlands at Assateague Island National Seashore in Maryland. IMAGE CREDIT: MARY SWIFT / ISTOCK

A team of Stanford researchers is working to develop an alternative concrete mix that would produce fewer emissions and provide health benefits. IMAGE CREDIT: 5./15 WEST / ISTOCK

Understanding the threat of wildfire smoke-borne metals

Wildfires are contributing a rapidly increasing proportion of key air pollutants across the U.S., but their health effects remain poorly understood. Altered by fire, naturally occurring soil- and plant-borne metals, such as chromium, are transformed into a toxic state associated with deleterious health effects. Little is known about how fire intensity and soil type affect this process. Researchers will develop a set of geospatial tools that predicts the threat of toxic chromium generation and downstream exposure, and will determine solutions through mitigation strategies that limit exposure risk to first responders and local communities.

Marshall Burke (Earth System Science), Scott Fendorf (Earth System Science), Kari Nadeau (Medicine - Pediatrics)

Informing open ocean restoration through historical reconstruction

Restoring degraded ecosystems requires a comprehensive understanding of their pre-disturbance state. Ecosystem restoration on the open ocean has yet to be attempted. This project will combine biogeochemical, eDNA, and microscopic analyses of sediment cores to quantify the ecological regime shifts in the Southern Ocean, with a focus on the impact of Antarctic whaling – one of the greatest removals of animal biomass ever. The approach will quantify the pre-disturbance state of one of the most important open ocean ecosystems in the world, and provide a framework for restoration targets in similar ecosystems worldwide.

Jeremy Goldbogen (Oceans), Rob Dunbar (Oceans), Liz Hadly (Biology)

Accounting for wetland greenhouse gas emissions

Methane emissions from natural wetlands account for up to a third of global methane emissions, yet they remain poorly understood in part because current measurement technology is prohibitively expensive, limited in where it can be deployed and limited in how much spatial and temporal variability it can characterize. With recalibration, low-cost natural gas sensors can provide an accurate alternative. Using this approach, the researchers aim to develop an unprecedented network of 1,000 low-cost autonomous sensors for deployment in the tropics.

Alison Hoyt (Earth System Science), Debbie Senesky (Aeronautics and Astronautics)

Understanding how wildfires transform soil- and plant-borne metals into toxic substances could inform preventative strategies for first responders and local communities. IMAGE CREDIT: DANIIIELC / ISTOCK

A humpback whale *(Megaptera novaeangliae)* dives below the surface in Antarctic waters. Whaling in Antarctica in the early 20th century led to one of the greatest known removals of animal biomass in history.
IMAGE CREDIT: S_LEW / ISTOCK

Capturing and sequestering carbon dioxide in soils

Soils contain the largest reservoir of carbon at the Earth's surface. Soil respiration, or decomposition of soil carbon by microorganisms and respiration by roots, releases carbon dioxide at a rate about seven to eight times greater than fossil fuel burning. Soil-based carbon mitigation strategies have focused on reducing rates of decomposition or increasing soil acidity or alkalinity. However, the concentration of carbon dioxide in soil pores is typically 45-50 times greater than atmospheric levels. This project aims to design a strategy for soil carbon dioxide capture using low-cost, environmentally friendly sorbent materials.

Kate Maher (Earth System Science), Zhenan Bao (Chemical Engineering)

Mitigating water pollution

Water contaminants damage aquatic ecosystems and threaten human health. Nitrogen pollution affects over 70 percent of U.S. freshwater and coastal marine ecosystems, costing $2.2 billion each year in lost livelihoods, recreation, and remediation. Without accurate, localized measurements, we cannot adequately evaluate interventions or progress. However, current measurement techniques restrict remediation efforts to reactive, general responses rather than proactive, site-specific interventions. This project aims to advance remediation efforts by integrating newly developed nitrogen sensors with machine learning for adaptive sensor control and data analysis on the site, watershed, and eventually regional and national scales.

William Tarpeh (Chemical Engineering), Kate Maher (Earth System Science), Fio Micheli (Oceans), Debbie Senesky (Aeronautics and Astronautics)

Monitoring urban neighborhoods to reduce inequities in wellbeing

Neighborhood environments play a significant role in shaping the well-being of individuals and communities, but empirical evidence is limited by a lack of data across neighborhoods, cities, and time. Drawing on innovations for monitoring urban environments, computer vision to identify visible neighborhood conditions from imagery, and survey methods, the researchers will collect real-time data in a major city and examine connections between the natural and visible attributes of urban environments and well-being. The researchers hope to work with local stakeholders to develop and test interventions that alter different features of the environment aimed at reducing inequality in well-being within cities.

Jackelyn Hwang (Sociology), Hae Young Noh (Civil and Environmental Engineering), Sarah Billington (Civil and Environmental Engineering)

Low-cost, environmentally friendly materials could help soils absorb atmospheric carbon dioxide. IMAGE CREDIT: MINTR / ISTOCK

People navigate a busy street corner in the Harlem neighborhood of New York City. IMAGE CREDIT: MICHELE VACCHIANO / ISTOCK

Stanford researchers are working to quantify the state of the Southern Ocean prior to Antarctic whaling in order to inform future conservation targets. IMAGE CREDIT: FILM / ISTOCK

Realizing Environmental Innovation Program

REIP grants are intended to forward solution-based projects from the discovery phase of research to the validation phase and adoption by end users. The projects selected for 2022 will receive up to $200,000 over two years:

Developing ocean-friendly sunscreens

Common sunscreens include chemicals and active ingredients that have detrimental effects on coral reefs and other aquatic life. The researchers have identified a set of naturally occurring viruses produced by bacteria that can absorb ultraviolet light. These materials are safe, structurally stable, completely biodegradable, inexpensive, and non-toxic to human cells or aquatic bacteria. This project aims to develop this technology for use in novel sunscreens that will protect against skin cancers without damaging oceans and reefs.

Paul Bollyky (Medicine – Infectious Diseases), Giulio De Leo (Oceans)

Mitigating lead and greenhouse gas emissions in EV battery recycling

Lead is toxic throughout the biosphere and, in humans, permanently reduces intelligence and leads to heart disease, stroke, kidney failure, and premature death. In South Asia, an estimated 400 million children are poisoned by lead. To mitigate a primary source of that lead — informal recycling of lead acid batteries from 3-wheeled electric vehicles (EVs) – the researchers have developed a business model for EV garage owners, EV drivers, battery manufacturers and a microfinance organization in Bangladesh. A randomized controlled trial will measure the model's effects on lead emissions, greenhouse gas emissions, profits, and livelihoods.

Erica Plambeck (Business), Steve Luby (Medicine – Infectious Diseases)

Improper recycling of batteries from electric vehicles contributes to emissions and lead poisoning in children in South Asia.
IMAGE CREDIT: ISTOCK

Transforming sulfur in wastewater into valuable materials

As fresh water supplies dwindle, particularly in arid regions, focus has intensified on developing technologies that convert wastewater to drinkable water. Membrane processes that use anaerobic or oxygen-free environments to filter wastewater show promise, but they produce sulfides that are toxic, corrosive, and malodorous.

An EVP-funded analysis published in *ACS ES&T Engineering* revealed how to optimize electrical processes for transforming sulfur pollution, and could help lead to affordable, renewable energy-powered wastewater treatment that creates drinkable water.

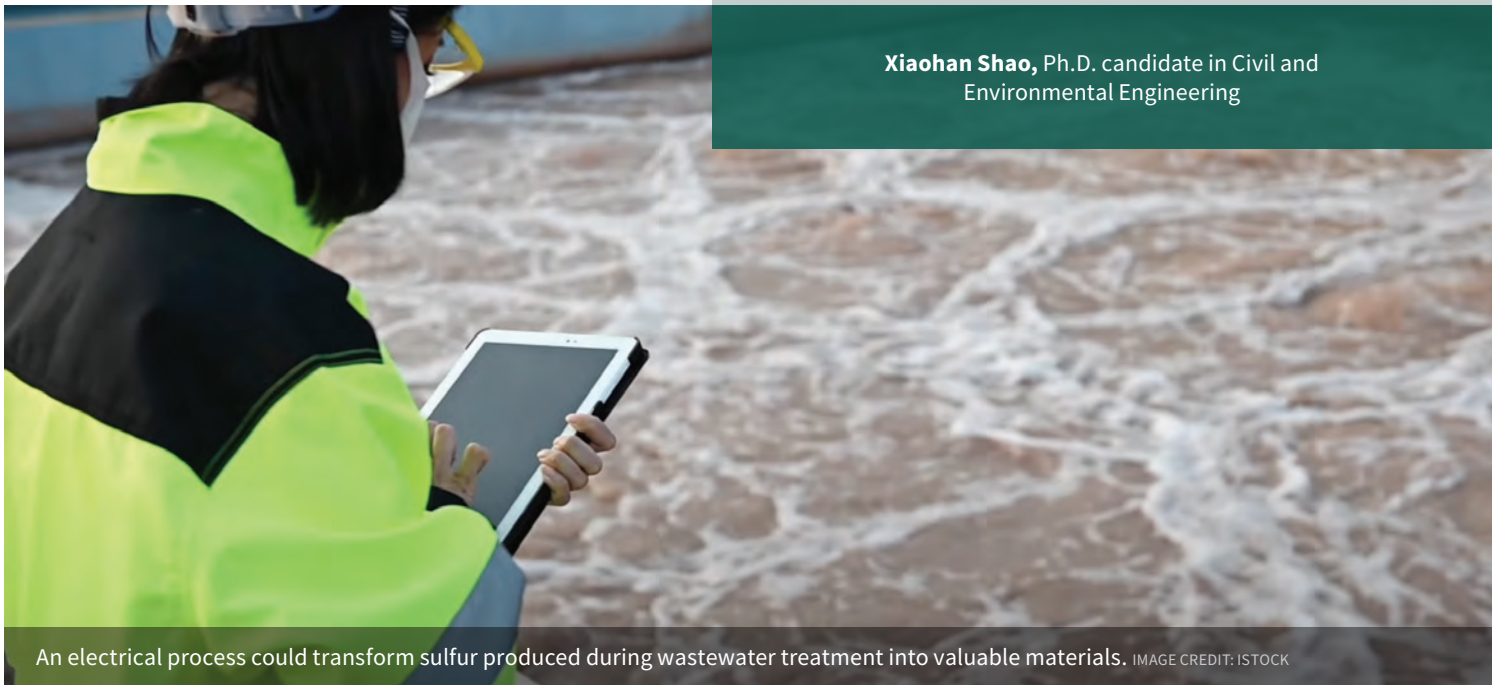
"We are always looking for ways to close the loop on chemical manufacturing processes," said study senior author Will Tarpeh, an assistant professor of chemical engineering at Stanford. "Sulfur is a key elemental cycle with room for improvements in efficiently converting sulfur pollutants into products like fertilizer and battery components."

The researchers used scanning electrochemical microscopy — a technique that facilitates microscopic snapshots of electrode surfaces while reactors are operating — to quantify the rates of each step of electrochemical sulfur oxidation along with the types and amounts of products formed. The study outlines a framework to inform the design of future electrochemical sulfide oxidation processes that balance energy input, pollutant removal, and resource recovery.

Read more…

Shao, X., Johnson, S. R., & Tarpeh, W. A. (2022). Quantifying and Characterizing Sulfide Oxidation to Inform Operation of Electrochemical Sulfur Recovery from Wastewater. *ACS ES&T Engineering*, *2*(5), 807-818. DOI:10.1021/acsestengg.1c00376

> "Hopefully, this study will help accelerate adoption of technology that mitigates pollution, recovers valuable resources and creates potable water all at the same time."
>
> **Xiaohan Shao,** Ph.D. candidate in Civil and Environmental Engineering



An electrical process could transform sulfur produced during wastewater treatment into valuable materials. IMAGE CREDIT: ISTOCK

Understanding how sunscreens damage coral

A common component of many sunscreens may hasten the demise of endangered coral reef ecosystems, according to a Stanford study published in *Science*.

Scientists have known for some time that oxybenzone, an organic compound found in many sunscreens, can damage corals. As a result, sunscreens with this compound have been banned in the U.S. Virgin Islands and Hawaii, the island nation of Palau, and Bonaire, an island municipality of the Netherlands, among other places. With funding from an EVP grant, a team of Stanford researchers characterized the chemical and biological mechanisms by which oxybenzone harms corals.

The findings showed that anemones and mushroom corals metabolized oxybenzone into damaging radicals when exposed to simulated sunlight. "It was strange to see that oxybenzone made sunlight toxic for corals – the opposite of what it is supposed to do," said William Mitch, a professor of civil and environmental engineering at Stanford. "The compound is good at absorbing light within the waveband we tested, which is why it's so common in sunscreens."

Many of the sunscreen components proposed as alternatives to oxybenzone share similar chemical structures and so could form similar phototoxic metabolites. This research could help inform whether these alternatives are truly safer for corals.

Read more…

Vuckovic, D., Tinoco, A., Ling, L., Renicke, C., Pringle, J., & Mitch, W. (2022). Conversion of oxybenzone sunscreen to phototoxic glucoside conjugates by sea anemones and corals. *Science*, *376*(6593), 644-648. DOI:10.1126/science.abn2600

A study by Stanford researchers revealed how a common component of many sunscreens may hasten the demise of corals. The findings could help guide the development of coral-safe sunscreens. IMAGE CREDIT: GETTY IMAGES

> “It would be a sad irony if ecotourism aimed at protecting coral reefs were actually exacerbating their decline. I hope that our research will help the development of sunscreens that are less likely to harm reefs.”

Djordje Vuckovic, Ph.D. candidate in Civil and Environmental Engineering

A freediver ascends along a vivid coral reef in the Red Sea, Egypt. IMAGE CREDIT: MIHTIANDER / ISTOCK

Traditional practices bolster food security in the Pacific Islands

The COVID-19 pandemic has disrupted supply chains and threatened food security around the globe, but for many communities, this disruption highlighted a solution close to home: bolstering local food production. A study published in *Marine Policy* found that rural communities in seven Pacific Island nations successfully weathered the initial impacts of COVID-19 by maintaining traditional food practices.

The study team at Stanford, which is supported by an EVP grant, collaborated with the Locally Managed Marine Area Network, the Ebiil Society, and numerous local researchers to collect 199 surveys in villages over the course of a year.

Traditional food practices include both local farming and sharing food along kinship lines and with any community members who may be in need, including the elderly, single mothers, widows, and new residents that have recently arrived from urban areas and therefore have not had time to cultivate crops. The study found that communities that shared food as a traditional practice were more food secure.

"It was inspiring to see Pacific Island communities, which are founded on solidarity, reciprocity and collective support, provide social support in these hard times," said lead author Caroline Ferguson, who completed this work while a Ph.D. student at the Emmett Interdisciplinary Program in Environment and Resources at Stanford.

The findings suggest that decision-makers should focus on bolstering sustainable local food production and practices to better position rural Pacific communities in the face of unprecedented global change.

Read more…

Ferguson, C. E., Tuxson, T., Mangubhai, S., Jupiter, S., Govan, H., Bonito, V., Alefaio, S., Anjiga, M., Booth, J., Boslogo, T., Boso, D., Brenier, A., Caginitoba, A., Ciriyawa, A., Fahai'ono, J. B., Fox, M., George, A., Eriksson, H., Hughes, A., Joseph, E., Kandannged, S., Kubunavanua, E., Loni, S., Meo, S., Micheli, F., Nagombi, E., Omaro, R., Ride, A., Sapul, A., Singeo, A., Stone, K., Tabunakawai-Vakalalabure, M., Tuivuna, M., Vieux, C., Vitukawalu, V., & Waide, M. (2022). Local practices and production confer resilience to rural Pacific food systems during the COVID-19 pandemic. *Marine Policy*, *137*, 104954. DOI:10.1016/j.marpol.2022.104954

> "By understanding how COVID-19 has impacted food systems from local to global scales, communities and governments can better prepare for future market disruptions, whether it's a sudden natural disaster or a more sustained impact like climate change."
>
> **Fiorenza Micheli,** co-director of the Stanford Center for Ocean Solutions

Two fishers glean sea cucumbers in Palau. IMAGE CREDIT: GEORGE STOYLE

Rethinking the time horizon of methane's climate impact

By focusing on the climate impact of methane over a 100-year timeframe, international climate negotiators have underestimated the importance of this short-lived greenhouse gas for achieving climate goals set out in the Paris Agreement, according to Stanford research published in *Environmental Research Letters*.

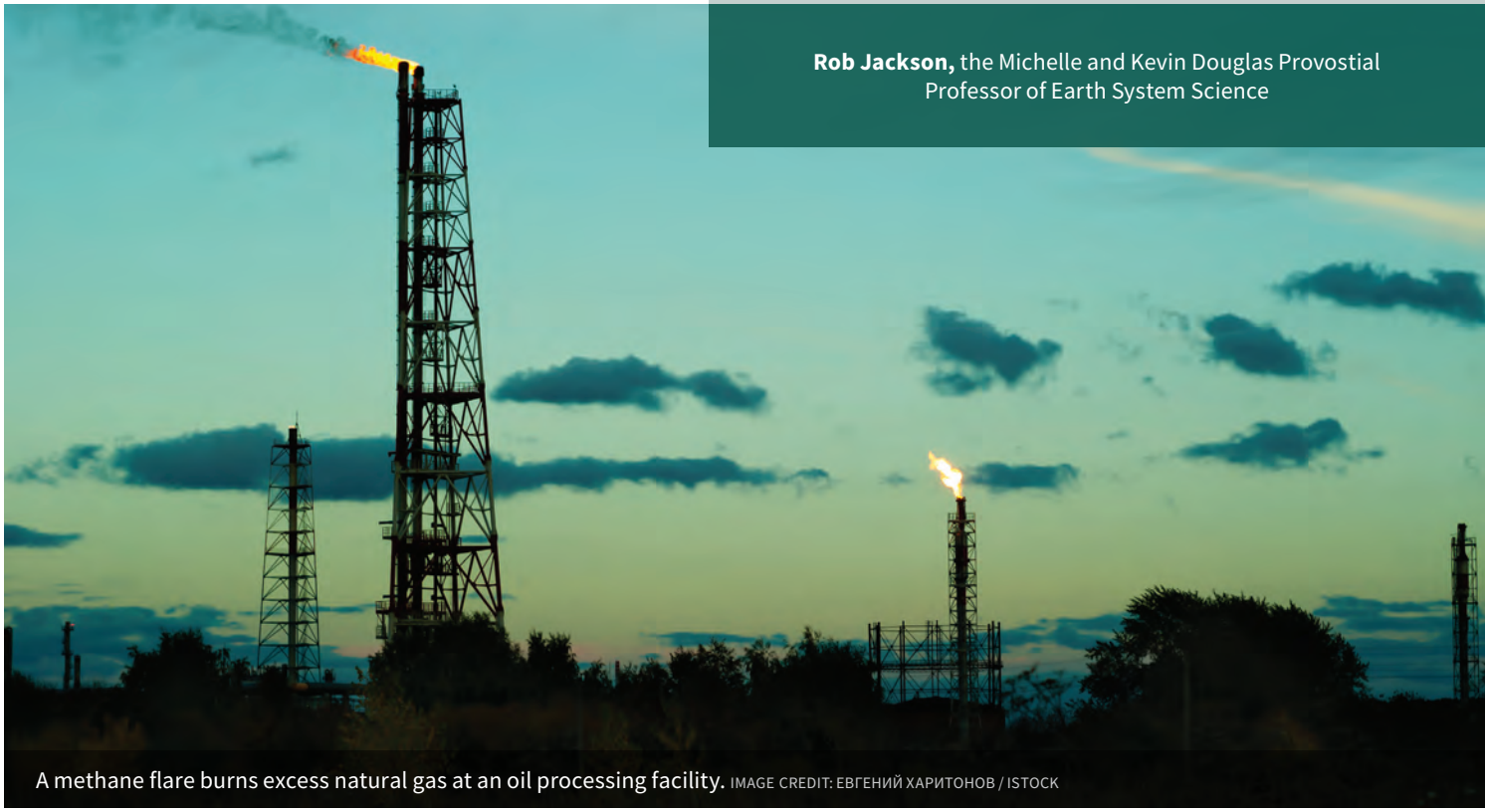
The lifetime of greenhouse gases — how long they remain in the atmosphere and impact climate — ranges widely, from thousands of years for carbon dioxide to just a few decades for methane. The 100-year timeframe currently used by negotiators serves as a convenient midpoint for comparing the impact of other greenhouse gases to carbon dioxide. However, the team's findings suggest this approach underestimates methane's importance up to 87 percent.

The study, which received funding from an EVP grant, proposes a 24-year timeframe that more accurately weights the impact of methane and incentivizes aggressive methane reduction plans.

Read more…

Abernethy, S. & Jackson, R. B. (2022). Global temperature goals should determine the time horizons for greenhouse gas emission metrics. *Environmental Research Letters*, *17*, 024019. DOI:10.1088/1748-9326/ac4940

> "We need to reduce emissions of carbon dioxide in all scenarios, near and far. The more aggressive the temperature goal is, however, the more important potent, shorter-lived greenhouse gases such as methane become."
>
> **Rob Jackson,** the Michelle and Kevin Douglas Provostial Professor of Earth System Science



A methane flare burns excess natural gas at an oil processing facility. IMAGE CREDIT: ЕВГЕНИЙ ХАРИТОНОВ / ISTOCK

Research Highlights

Alejandra Echeverri, a postdoctoral researcher with the Natural Capital Project, watches for birds in a Costa Rican forest. IMAGE CREDIT: MOLLIE CHAPMAN

Natural gas stoves contributing to climate change and health impacts

A Stanford study published in *Environmental Science & Technology* showed that methane leaking from natural gas-burning stoves inside U.S. homes has a climate impact comparable to the carbon dioxide emissions from about 500,000 gasoline-powered cars over a 20-year lifespan.

To better understand cooking appliances' potential climate and health impacts, the researchers measured methane and nitrogen oxides released in 53 homes in California. More than three-quarters of methane emissions occurred while stoves were off, suggesting that gas fittings and connections to the stove and in-home gas lines are responsible for most emissions, regardless of how much the stove is used.

Over one-third of U.S. households — more than 40 million homes — cook with gas. Unlike other gas appliances, such as space and water heaters that are usually placed away from living quarters, cooking appliances directly expose people to pollutants. This research adds to a growing discussion as legislators in numerous U.S. municipalities and at least one state — New York — weigh banning natural gas hookups from new construction in favor of transitioning to electric appliances.

Read more…

Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. (2022). Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, *56*(4), 2529-2539. DOI:10.1021/acs.est.1c04707

> "Surprisingly, there are very few measurements of how much natural gas escapes into the air from inside homes and buildings through leaks and incomplete combustion from appliances. It's probably the part of natural gas emissions we understand the least about, and it can have a big impact on both climate and indoor air quality."
>
> **Eric Lebel,** senior scientist at PSE Healthy Energy and former Ph.D. student in Earth System Science

More than 40 million homes in the U.S. have natural gas stoves, which produce methane emissions and create irritating pollutants.
IMAGE CREDIT: BILL OXFORD / GETTY IMAGES

Impact of climate change and air pollution on children's health

A review paper with Stanford co-authors, published in the *New England Journal of Medicine*, outlined pollution and climate change threats to children's health and called for better understanding and intervention from health professionals.

More than 90 percent of children under the age of 15 regularly breathe air so polluted it puts their health and development at serious risk, while vector-borne diseases and water scarcity — scourges exacerbated by global warming — affect more than one in four and more than one in three children, respectively.

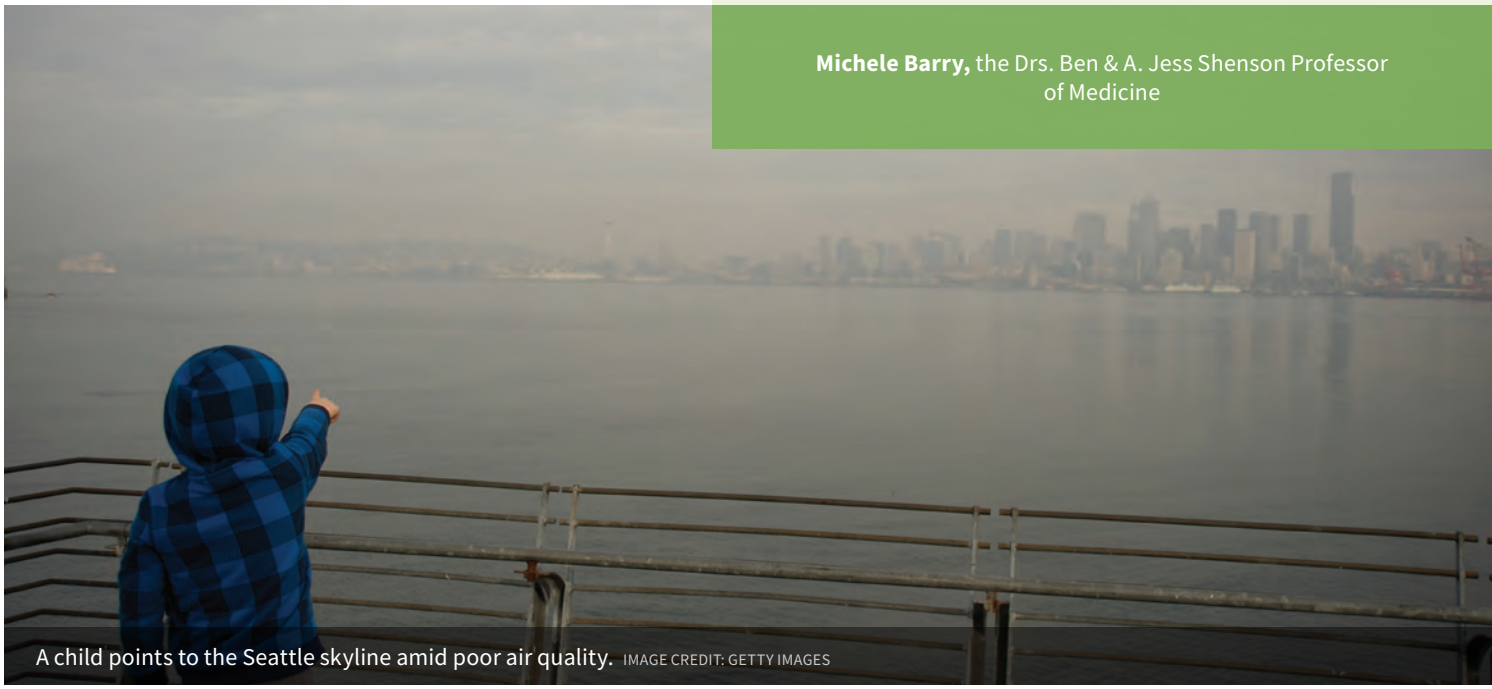
The burden of health impacts from climate change can be even greater for children from disadvantaged communities, where the intersection of environmental harm, poverty-related stress, and lack of access to health care can lead to worsened health effects and shortened lifespans.

The researchers offered practical advice for health professionals to incorporate environmental health into primary care, including encouraging pediatricians to proactively engage parents in conversation about air pollution and engaging with community health workers and networks to build awareness.

Read more…

Agache, I., Sampath, V., Aguilera, J., Akdis, C. A., Akdis, M., Barry, M., Bouagnon, A., Chinthrajah, S., Collins, W., Dulitzki, C., Erny, B., Gomez, J., Goshua, A., Jutel, M., Kizer, K. W., Kline, O., LaBeaud, A. D., Pali-Schöll, I., Perrett, K. P., Peters, R. L., Plaza, M. P., Prunicki, M., Sack, T., Salas, R. N., Sindher, S. B., Sokolow, S. H., Thiel, C., Veidis, E., Wray, B. D., Traidl-Hoffman, C., Witt, C., & Nadeau, K. C. (2022). Climate change and global health: A call to more research and more action. *Allergy*, 77(5), 1389-1407. DOI:10.1111/all.15229

> "Research increasingly shows us the toll that climate change is taking on human health — particularly the health of children, who are more vulnerable to its impacts. Swift global action is needed to mitigate and prepare for future climate events, including more forceful policies and individual and collective action."
>
> **Michele Barry,** the Drs. Ben & A. Jess Shenson Professor of Medicine



A child points to the Seattle skyline amid poor air quality. IMAGE CREDIT: GETTY IMAGES

Double-hazard wildfire zones amplifying the effects of climate change

Climate change is not necessarily increasing wildfire hazard uniformly across the American West due to the interplay of at least a dozen plant and soil traits, according to a Stanford study.

The analysis, published in *Nature Ecology & Evolution*, showed that the combination of highly sensitive, tinder-dry plants and a faster-than-average increase in atmospheric dryness creates "double-hazard" zones. These regions of overlap are more likely to amplify the effect of climate change and increase the acreage of burned areas.

In order to account for the wide range of factors that affect the moisture content of vegetation, the researchers created a new metric of plant-water sensitivity. The authors used artificial intelligence, statistical analysis, and microwave remote sensing data to show that this measure of local vulnerability to drying out in the face of limited rainfall and an arid atmosphere is tightly linked to increases in areas burned by wildfire with a drying climate in forests and shrublands.

The findings underscore how unevenly climate change is amplifying the risks of catastrophic wildfires for the millions of people living where vulnerable homes have been built in or next to wildlands.

Read more…

Rao, K., Williams, A. P., Diffenbaugh, N. S., Yebra, M., & Konings, A. G. (2022). Plant-water sensitivity regulates wildfire vulnerability. Nature Ecology & Evolution, *6*, 332-229. DOI:10.1038/s41559-021-01654-2

> "This redoubles the need to be thinking about what we can do to reduce wildfire impacts in the wildland-urban interface in general, including for this subgroup of people who are in the most vulnerable locations."
>
> **Alexandra Konings,** assistant professor of Earth System Science

The Almeda Fire destroyed thousands of homes in Southern Oregon in September 2020. IMAGE CREDIT: ARBOURSABROAD / SHUTTERSTOCK

Wildfire smoke unraveling decades of air quality gains

Wildfire smoke now exposes millions of Americans each year to dangerous levels of fine particulate matter, lofting enough soot across parts of the West in recent years to erase much of the air quality gains made over the last two decades, according to Stanford research published in *Environmental Science & Technology*.

The study focused on a type of particle pollution known as PM2.5, which can lodge deep in our lungs and even get into our bloodstream. Using statistical modeling and artificial intelligence techniques, the researchers estimated concentrations of PM2.5 specifically from wildfire smoke in regions across the U.S. from 2006 to 2020.

The finding showed that more than eight million people live in areas experiencing unhealthy air at least one day per year, measured as a day with PM2.5 concentrations from wildfire smoke reaching at least 100 micrograms per cubic meter – a 27-fold increase from a decade ago.

In order to understand the impacts of wildfire smoke on society, the Stanford team trained a machine learning model with satellite data to accurately predict PM2.5 concentrations from wildfire smoke in areas that don't have pollution monitors.

The Stanford model can help researchers better understand societal impacts from wildfire smoke pollution, including severe smoke events, which are becoming more common as climate change extends wildfire season, accelerates fire frequency, and expands burn areas.

Read more…

Childs, M. L., Li, J., Wen, J., Heft-Neal, S., Driscoll, A., Wang, S., Gould, C. F., Qiu, M., Burney, & Burke, M. (2022). Daily Local-Level Estimates of Ambient Wildfire Smoke PM2.5 for the Contiguous US. *Environmental Science & Technology*, *56*(19), 13607-13621. DOI:10.1021/acs.est.2c02934

> "It's important for regulators to understand what's causing changes in air quality, and to think about how we might amend existing regulations to account for the fact that wildfires are more and more important in determining air quality."
>
> **Marshall Burke,** associate professor of Earth System Science

A Stanford study showed people are being exposed to more days with wildfire smoke, and more people are experiencing at least one day of the most extreme levels of pollution from fine particulate matter from smoke. IMAGE CREDIT: E4C / GETTY IMAGES

Personal experience affects responses to climate-related disasters

Two Stanford-led studies revealed that personal experiences are among key variables in pushing people to take or accept protective measures against climate-related disasters like flood insurance and planned power shutoffs.

A survey published in *Energy Research & Social Science* shows that people with more personal experiences in terms of health and exposure to wildfire hazards, such as poor air quality, were more likely to worry about such risks. In turn, they were more likely to support power shutoffs. However, people who were worried about possible negative impacts from shutoffs were less likely to support them.

A survey of Florida and Texas residents, published in *Environmental Research Letters*, found that negative experiences of hurricanes, hurricane risk appraisal and hurricane adaptation appraisal were all positively associated with adaptation behaviors, such as using hurricane forecasts when making travel plans, identifying shelters and putting together emergency kits.

Taken together, the hurricanes and wildfires surveys make clear that effective adaptation requires a better understanding of how people appraise risks and worry about the threat of extreme events given their personal experience, their concerns about possible interventions and, ultimately, the origins of support for interventions. Both papers' findings could inform public communications and policy to help vulnerable communities protect themselves from these and other extreme events.

Read more…

Wong-Parodi, G. & Garfin, D. R. (2022). Hurricane adaptation behaviors in Texas and Florida: exploring the roles of negative personal experience and subjective attribution to climate change. *Environmental Research Letters*, *17*, 034033. DOI:10.1088/1748-9326/ac4858

Wong-Parodi, G. (2022). Support for public safety power shutoffs in California: Wildfire-related perceived exposure and negative outcomes, prior and current health, risk appraisal and worry. *Energy Research & Social Science*, 88, 102495. DOI:10.1016/j.erss.2022.102495

Family members travel by boat to their home in Barataria, Louisiana, after it flooded during Hurricane Ida in 2021.
IMAGE CREDIT: BRANDON BELL / ISTOCK

> "As catastrophic wildfires, hurricanes and other events increase in frequency, they are having severe emotional, social and economic consequences on people's lives. It is imperative that we design ways to mitigate those impacts with an eye toward empowering vulnerable communities."

Gabrielle Wong-Parodi, assistant professor of Earth System Science

Benefits of riverfront forest restoration

Forested areas adjacent to rivers and streams absorb harmful pollutants in runoff, keeping them out of waterways. A Stanford-led study published in *Ecosystem Services* analyzed the benefits of riparian protection policy in Costa Rica and found that restoring these relatively narrow strips of riverfront forests could substantially improve regional water quality and carbon storage.

Software simulations found that reforestation of 10-meter-wide strips of riparian buffer would heavily boost retention of phosphorus, nitrogen, and sediment. Expanded forest cover would also increase carbon sequestration, and reforestation would be most impactful in steep, erosion-prone, and intensively fertilized landscapes.

The research explored how increases in water quality would reach those who rely on rivers the most, and found that riverfront reforestation policies could have huge impacts in areas of Costa Rica where large numbers of people are directly dependent on rivers for drinking water.

Read more…

Langhans, K. E., Schmitt, R. J., Chaplin-Kramer, R., Anderson, C. B., Bolaños, C. V., Cabezas, F. V., Dirzo, R., Goldstein, J.A., Horangic, T., Granados, C.M., Powell, T.M., Smith, J.R., Quesada, I.A., Quesada, A.U., Vargas, R.M., Wolny, S., & Daily, G. C. (2022). Modeling multiple ecosystem services and beneficiaries of riparian reforestation in Costa Rica. Ecosystem Services, *57*, 101470. DOI:10.1016/j.ecoser.2022.101470

> “Forests around rivers are key places to target for restoration because they provide huge benefits with very little impediment to productive land. A small investment could have a really big impact on the health of people and ecosystems.”
>
> **Kelley Langhans,** Ph.D. student in Biology at the Natural Capital Project

Costa Rican naturalist and Stanford research collaborator Dunia Villalobos examines a river in Las Cruces, Costa Rica.
IMAGE CREDIT: REBECCA CHAPLIN-KRAMER

Wildlife and infrastructure maximize tourism in Costa Rica

Wildlife and built infrastructure may seem at odds, but protecting nature can keep valuable tourism revenue flowing, according to a study published in *Proceedings of the National Academy of Sciences*. Government leaders in Costa Rica worked with researchers from the Stanford-based Natural Capital Project to understand how nature supports the country's most visited and valuable tourist destinations.

The researchers combined data from NASA satellites and social media posts to measure wildlife and understand tourism patterns in the country. By overlaying popular social media locations with NASA imagery and biodiversity data, the researchers were able to pinpoint where roads, hotels, water bodies and wildlife intersected to create tourism hotspots.

"These findings show just how important wildlife is — especially when paired with infrastructure — for a thriving tourist economy," said Alejandra Echeverri, co-lead author on the paper and a postdoctoral researcher at the Natural Capital Project.

Country leaders in Costa Rica plan to create a nationwide accounting system that tracks the value of their abundant natural assets, including the benefits that nature provides to the tourism industry. Each year, the government will be able to view new satellite images that show development and emerging tourism trends to adapt their national plans.

Read more…

Echeverri, A., Smith, Jeffrey, R., MacArthur-Waltz, D., & Daily, G. C. (2022). Biodiversity and infrastructure interact to drive tourism to and within Costa Rica. *Proceedings of the National Academy of Sciences*, *119*(11), e2107662119. DOI:10.1073/pnas.2107662119

The Great Kiskadee *(Pitangus sulphuratus)* is one of the many common backyard birds in Costa Rica that draws tourists each year.
IMAGE CREDIT: DANIEL S. KARP

Gretchen Daily, faculty director of the Natural Capital Project, and Jeffrey Smith, birdwatching in Guanacaste, Costa Rica.
IMAGE CREDIT: DANIEL S. KARP

> “While the balance between expanding tourism and protecting the natural assets that attract visitors needs to be handled carefully — especially considering the ruinous effects of overdevelopment — this research demonstrates how tourism can be a major driver toward green development in countries around the world.”

Gretchen Daily, the Bing Professor of Environmental Science, co-founder and faculty director of the Natural Capital Project

A green iguana *(Iguana iguana)* resting on a branch in a Costa Rican rainforest. IMAGE CREDIT: DANIEL S. KARP

Revealing the extent of labor abuse and illegal fishing

Given limited surveillance and enforcement capacity, the high seas — or the waters beyond a country's jurisdiction — have long provided a safe haven for illegal, unreported and unregulated (IUU) fishing. Every year, millions of tons of fish are caught illegally. Vessels engaged in IUU fishing often also have labor abuses on board, including subjecting workers to forced labor, debt bondage and poor working conditions.

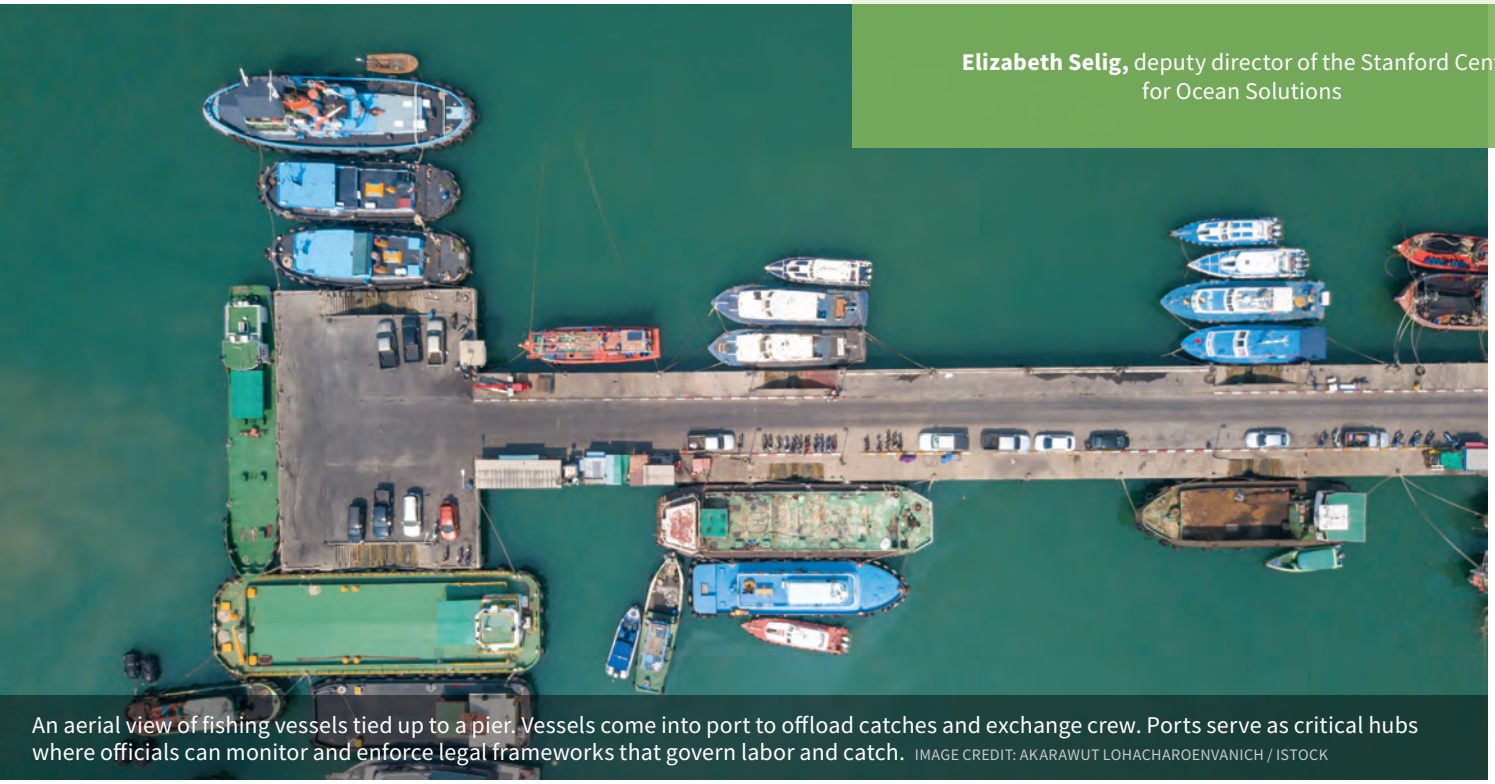
A Stanford University-led paper published in *Nature Communications* identifies the regions and ports at highest risk for labor abuse and illegal fishing and indicates two main risk factors: the country that a vessel is registered to, also known as its "flag state," and the type of fishing gear the vessel carries onboard.

Using an online survey of experts, the researchers also found that labor abuse and IUU fishing are globally pervasive: Of more than 750 ports assessed around the world, more than half are associated with risk of one or both practices. However, in addition to revealing the global extent of these risks, the study also highlights potential pathways to reduce these risks through actions at port that detect and respond to labor abuse and deter the landing of illegally caught fish.

Read more…

Selig, E. R., Nakayama, S., Wabnitz, C. C. C., Österblom, H., Spijkers, J., Miller, N. A., Bebbington, J., & Decker Sparks, J. L. (2022). Revealing global risks of labor abuse and illegal, unreported, and unregulated fishing. *Nature Communications*, *13*, 1612. DOI:10.1038/s41467-022-28916-2

> "Surveillance on the high seas is innately challenging, so these data provide a critical first step in helping stakeholders understand where to look deeper."
>
> **Elizabeth Selig,** deputy director of the Stanford Center for Ocean Solutions



An aerial view of fishing vessels tied up to a pier. Vessels come into port to offload catches and exchange crew. Ports serve as critical hubs where officials can monitor and enforce legal frameworks that govern labor and catch. IMAGE CREDIT: AKARAWUT LOHACHAROENVANICH / ISTOCK

Supporting justice across aquatic food systems

Marine and freshwater foods, or blue foods, are a vital source of micronutrients and income, sustaining livelihoods for up to 800 million people worldwide. However, a study of 195 countries revealed that despite generating more than $424 billion globally, the benefits of the aquatic foods sector are distributed unequally and contribute to ongoing injustices.

Published in the journal *Nature Food*, the paper was produced as one of six scientific papers for the Blue Food Assessment, an international joint initiative co-led by the Stanford Center for Ocean Solutions. It found the aquatic food sector supports both welfare-based benefits, in the form of jobs and affordable nutrition, as well as wealth-based benefits, in the form of revenues generated through increased production, trade, and consumption. However, social, economic, and political barriers tend to exclude countries most in need of welfare-generating benefits.

The research suggested that policies based on principles of justice and human rights, with inclusive decision-making processes that account for drivers of injustice, could support more just outcomes for aquatic food systems.

Read more…

Hicks, C. C., Gephart, J. A., Koehn, J. Z., Nakayama, S., Payne, H. J., Allison, E. H., Belhbib, D., Cao, L., Cohen, P. J., Fanzo, J., Fluet-Chouinard, E., Gelcic, S., Golden, C. D., Gorospe, K. D., Isaacs, M., Kuempel, C. D., Lee, K. N., MacNeil, M. A., Maire, E., Njuki, J., Rao, N., Sumaila, U. R., Selig, E. R., Thilsted, S. H., Wabnitz, C. C. C., & Naylor, R. L. (2022). Rights and representation support justice across aquatic food systems. *Nature Food*, *3*, 851-861. DOI:10.1038/s43016-022-00618-4

> “Our global food systems are currently highly unequal. Analyzing barriers to participation in the blue food sector is a key step in understanding how policies can steer towards more just blue food systems.”
>
> **Zach Koehn,** early career fellow at the Stanford Center for Ocean Solutions

Aquatic foods, also known as blue foods, provide income for up to 800 million people worldwide. A Stanford study revealed that the benefits of the aquatic food sector are unequally distributed. IMAGE CREDIT: FIRDAUS ROSLAN / UNSPLASH

Nature-based solutions protect against sea level rise

Rising sea levels are threatening lives and infrastructure around the world. Research published in *Urban Sustainability* showed that nature-based solutions, such as conserving marshlands and restoring beaches, can protect against sea-level rise as effectively as concrete seawalls. Conservation and restoration projects could even deliver up to eight times the benefits of traditional solutions while providing the same level of flood protection.

Researchers from the Stanford-based Natural Capital Project worked with San Mateo County and the San Francisco Estuary Institute to evaluate three scenarios under which the county could adapt to sea level rise. The study combined scenario modeling using the Natural Capital Project's free, open source tool, InVEST, with input from stakeholder workshops. By engaging with government and other stakeholders throughout the research process, researchers hoped that the findings would be helpful to decision-makers throughout the county.

Modeling revealed that the nature-based solutions being implemented today would result in six times more stormwater pollution reduction than a scenario using traditional concrete seawalls. Additional nature-based projects could result in eight times more stormwater pollution reduction than traditional approaches.

Read more…

Guerry, A. D., Silver, J., Beagle, J., Wyatt, K., Arkema, K., Lowe, J., Hamel, P., Griffin, R., Wolny, S., Plane, E., Griswold, M., Papendick, H., & Sharma, J. (2022). Protection and restoration of coastal habitats yield multiple benefits for urban residents as sea levels rise. *npj Urban Sustainability*, *2*, 13. DOI: 10.1038/s42949-022-00056-y

> "Our models show how communities can reap more benefits as they invest more in nature."
>
> **Anne Guerry,** chief strategy officer and lead scientist at the Natural Capital Project

Aerial view of a mobile home park in Pacifica, a coastal city in California's San Mateo County. IMAGE CREDIT: GETTY IMAGES

Whales ingest large amounts of microplastics

A Stanford-led study published in *Nature Communications* found that whales are ingesting massive amounts of microplastics via the prey they eat.

The study focused on blue, fin, and humpback whales and their consumption of plastic fragments no bigger than a few grains of sand, commonly called microplastics. Nearly all the microplastics whales consume come from their prey, not from the enormous volumes of seawater that these whales gulp when lunging to capture swarms of krill and small fish.

This troubling discovery suggests whales may not be getting the nutrition needed to thrive, according to lead study author Shirel Kahane-Rapport, who worked on the research as a Ph.D. student in the Goldbogen Lab at Stanford. The results represent an important first step toward understanding potential effects of microplastics on whales and other large filter-feeding animals.

Read more…

Humpback whales *(Megaptera novaeangliae)* lunge feed in Monterey Bay. Stanford research showed whales are ingesting plastic in larger quantities than previously thought, and nearly all comes from their prey, not from the enormous volumes of seawater the whales gulp when feeding.

IMAGE CREDIT: CHASE DEKKER WILD-LIFE IMAGES / GETTY IMAGES

Kahane-Rapport, S. R., Czapanskiy, M. F., Fahlbusch, J. A., Friedlaender, A. S. , Calambokidis, J., Hazen, E. L., Goldbogen, J. A., & Savoca, M. S. (2022). Field measurements reveal exposure risk to microplastic ingestion by filter-feeding megafauna. *Nature Communications*, *13*, 6327. DOI:10.1038/s41467-022-33334-5

> “Large filter feeders like baleen whales evolved to process and filter vast amounts of the ocean, so they represent sentinels of environmental change, including pollution like microplastics.”
>
> **Jeremy Goldbogen,** associate professor of Oceans

Students and postdoctoral scholars aboard Stanford’s research boat R/V *Dauphin* lower an echosounder into the ocean off the coast of Big Sur to measure whale prey abundance and distribution. IMAGE CREDIT: JAMES FAHLBUSCH

Beaver dams improve water quality

Beaver dams in the mountain watersheds of the American West may counter water quality degradation worsened by climate change, according to a Stanford study published in *Nature Communications*.

A Stanford study showed that beaver dams redirect water through riparian zones that act like filters, straining out excess nutrients and contaminants before re-entering the main channel. IMAGE CREDIT: ISTOCK

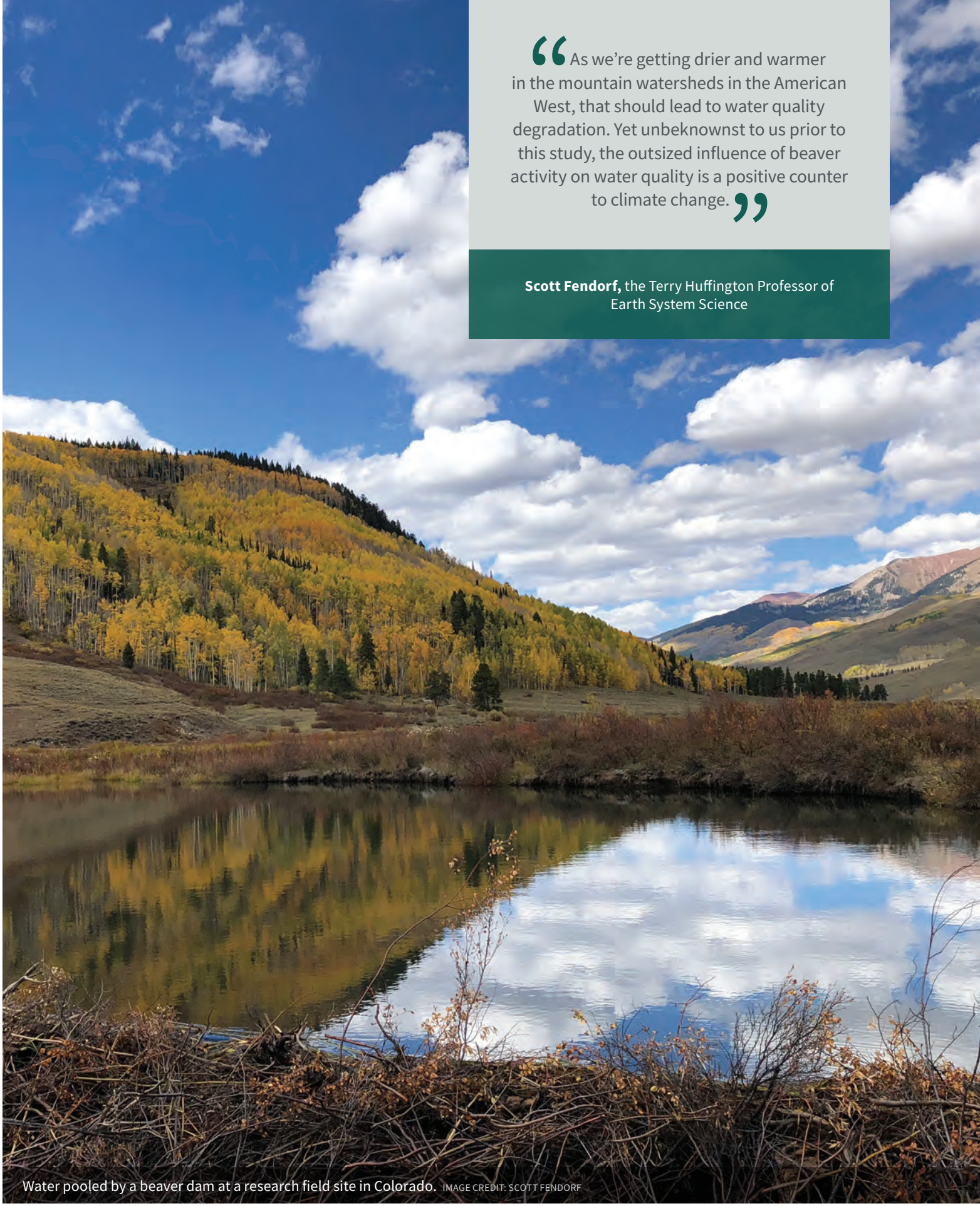
During periods of drought, as less water flows through rivers and streams, concentrations of contaminants and excess nutrients rise. Beaver dams improve water quality by raising upstream water levels and diverting water into surrounding soils and secondary waterways. These zones act like filters, straining out excess nutrients and contaminants before water re-enters the main channel downstream.

The study revealed that dams can have a far greater effect on water quality than climate-driven, seasonal extremes in precipitation. This influence may prove to be a particularly important counteractive force, as the same hot, arid conditions that lessen water quality have contributed to a resurgence of beaver populations and an explosion of dam building.

Read more…

Dewey, C., Fox, P. M., Bouskill, N. J., Dwivedi, D., Nico, P., & Fendorf, S. (2022). Beaver dams overshadow climate extremes in controlling riparian hydrology and water quality. *Nature Communications*, *13*, 6509. DOI:10.1038/s41467-022-34022-0

Lead study author Christian Dewey stands next to a beaver dam at the Colorado field site. IMAGE CREDIT: SCOTT FENDORF



> “As we’re getting drier and warmer in the mountain watersheds in the American West, that should lead to water quality degradation. Yet unbeknownst to us prior to this study, the outsized influence of beaver activity on water quality is a positive counter to climate change.”

Scott Fendorf, the Terry Huffington Professor of Earth System Science

Water pooled by a beaver dam at a research field site in Colorado. IMAGE CREDIT: SCOTT FENDORF

Air pollution decreases crop yields

A Stanford-led study published in *Science Advances* used satellite images to reveal for the first time that removing nitrogen oxides — a common air pollutant found in car exhaust and industrial emissions — could lead to dramatic gains in crop yields.

Nitrogen oxides, or NOx, can directly damage crop cells and indirectly affect them through their role as precursors to formation of ozone and particulate matter aerosols, which scatter sunlight away from crops. The researchers combined satellite measures of crop greenness and nitrogen dioxide levels to understand the impact on crop productivity across several regions. Based on their observations, they estimated that reducing NOx emissions could lead to substantial crop yield gains, especially in seasons and locations where NOx likely drives ozone formation.

"The actions you would take to reduce NOx, such as vehicle electrification, overlap closely with the types of energy transformations needed to slow climate change and improve local air quality for human health," said study co-author Jennifer Burney, an associate professor of environmental science at the University of California, San Diego. "The main take-home from this study is that the agricultural benefits of these actions could be really substantial, enough to help ease the challenge of feeding a growing population."

Read more…

Lobell, D. B., Di Tommaso, S., & Burney, J. A. (2022). Globally ubiquitous negative effects of nitrogen dioxide on crop growth. *Science Advances*, *8*(22). DOI:10.1126/sciadv.abm9909

> "Nitrogen oxides are invisible to humans, but new satellites have been able to map them with incredibly high precision. Since we can also measure crop production from space, this opened up the chance to rapidly improve our knowledge of how these gases affect agriculture in different regions."
>
> **David Lobell,** the Gloria and Richard Kushel Director of Stanford's Center on Food Security and the Environment

Stanford researchers found that reducing emissions of nitrogen oxides could lead to substantial crop yield gains. IMAGE CREDIT: LAMYAI / ISTOCK

Dams can provide needed water storage for food security

Many regions struggle with a mismatch between the timing of water availability and irrigation needs. Two-thirds of global cropland depends on rainfall, and farmers often make up for its absence by using non-sustainable water resources, such as non-renewable groundwater, or impeding environmental flows. There is an urgent need to explore water storage solutions that could help to feed our growing global population. A study published in *Proceedings of the National Academy of Sciences* found that dammed reservoirs could store more than 50 percent of the water needed to irrigate crops without depleting water stocks or encroaching on nature.

Researchers estimated that the full potential of storage-fed irrigation could feed about 1.15 billion people. If all 3,700 existing potential dam sites were built and partially used for irrigation, the world's dams could supply enough water storage to irrigate crops for about 641 million people or 55 percent of the total.

However, large reservoirs are only part of the solution. The researchers urge strategic planning approaches to minimize the socio-environmental consequences of future irrigation dams, which can include fragmentation of rivers, fish migration, and sediment transport, along with displacement of people.

Read more…

Schmitt, R. J., Rosa, L., & Daily, G. C. (2022). Global expansion of sustainable irrigation limited by water storage. *Proceedings of the National Academy of Sciences*, *119*(47), e2214291119. DOI: 10.1073/pnas.2214291119

> "Our research illuminates the crucial role of water storage for ensuring food security in the future."
>
> **Rafael Schmitt,** lead scientist at the Stanford Natural Capital Project

The Seli'š Ksanka Qlispe' Dam in Montana provides water for hydroelectricity, recreation, and irrigation. IMAGE CREDIT: BORONG TSAI / ISTOCK

Framework for designing affordable, sustainable urban neighborhoods

Urban areas account for more than two-thirds of global energy consumption and carbon dioxide emissions, according to United Nations estimates. Their water sources are increasingly stressed by global warming and burgeoning populations. A solution lies in coordinating the design of systems that supply power, water and wastewater treatment. Unlike traditionally large, centralized plants with segregated functions, this local, integrated arrangement can make it possible to achieve a variety of efficiencies.

A Stanford analysis published in *Frontiers in Sustainable Cities* presented a first-of-its-kind framework to design the most efficient building mix for an urban district along with systems that supply wastewater treatment, cooling, heating and electricity.

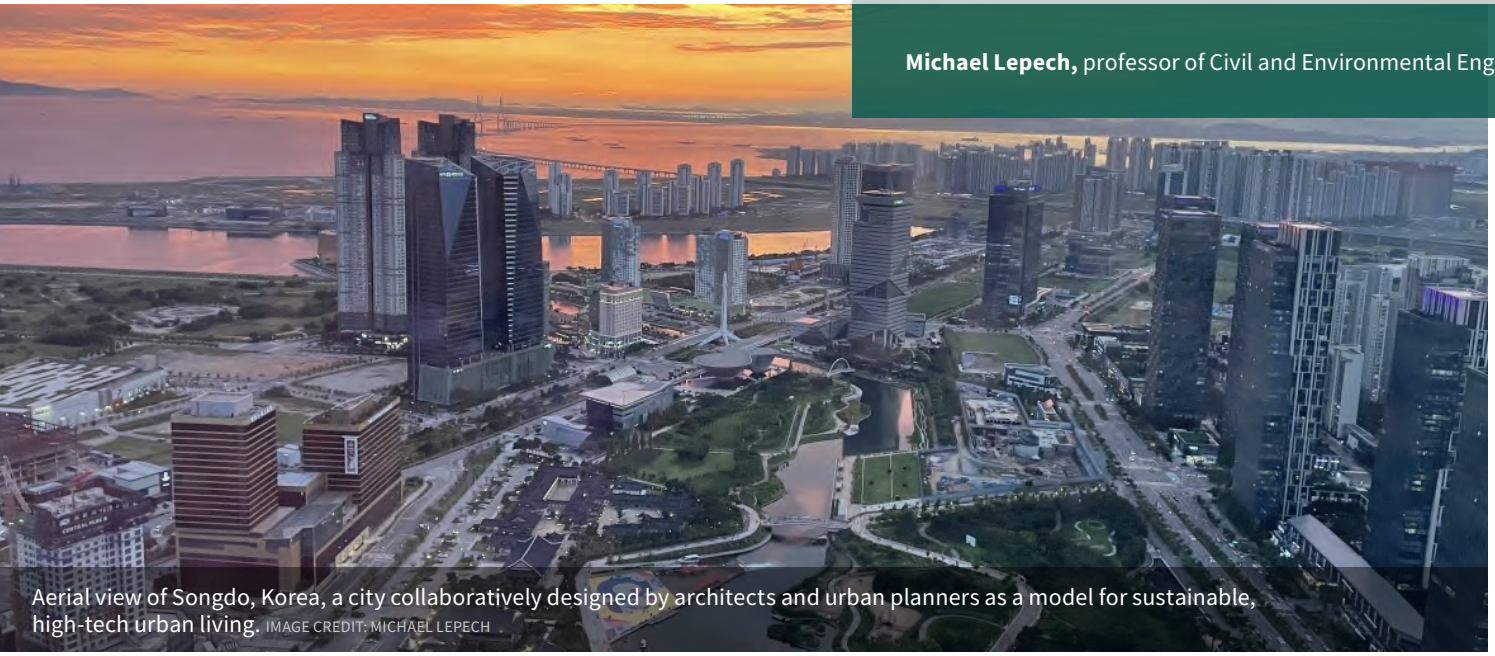
The analysis found that fully integrating power and water systems with building mixes resulted in a 75 percent reduction in social, environmental and economic damage from carbon emissions, and a 20 percent reduction in lifecycle equipment costs compared to traditional segregated systems.

The approach proposed in this study is expected to inform urban planners and infrastructure designers of a range of optimal configurations for designing a neighborhood. The findings could help policymakers across the U.S. spend billions of dollars in new federal infrastructure funding more wisely.

Read more…

Kalehbasti, P. R., Lepech, M. D., & Criddle, C. S. (2022). Integrated Design and Optimization of Water-Energy Nexus: Combining Wastewater Treatment and Energy System. *Frontiers in Sustainable Cities, 4*, 856996. DOI:10.3389/frsc.2022.856996

> "It is exciting to see that by integrating existing infrastructure with new urban technologies, and optimizing their performance in unison, we can discover new, substantial pathways toward global carbon reduction."
>
> **Michael Lepech,** professor of Civil and Environmental Engineering



Aerial view of Songdo, Korea, a city collaboratively designed by architects and urban planners as a model for sustainable, high-tech urban living. IMAGE CREDIT: MICHAEL LEPECH

Accounting for gravity waves with artificial intelligence

Gravity waves are ubiquitous atmospheric ripples that emerge when air is forced upward by wind blowing over, for instance, a thunderstorm or mountain. Atmospheric scientists have long understood gravity waves help to drive the overall circulation of the atmosphere, and influence storm tracks and the polar vortex – the swirl of bitter cold air near Earth's poles that occasionally wobbles and brings extreme winter weather to parts of the United States, Europe, and Asia.

In a study published in *Geophysical Research Letters*, Stanford researchers used artificial intelligence to create more realistic estimates of gravity waves, which will contribute to more robust and accurate global climate models.

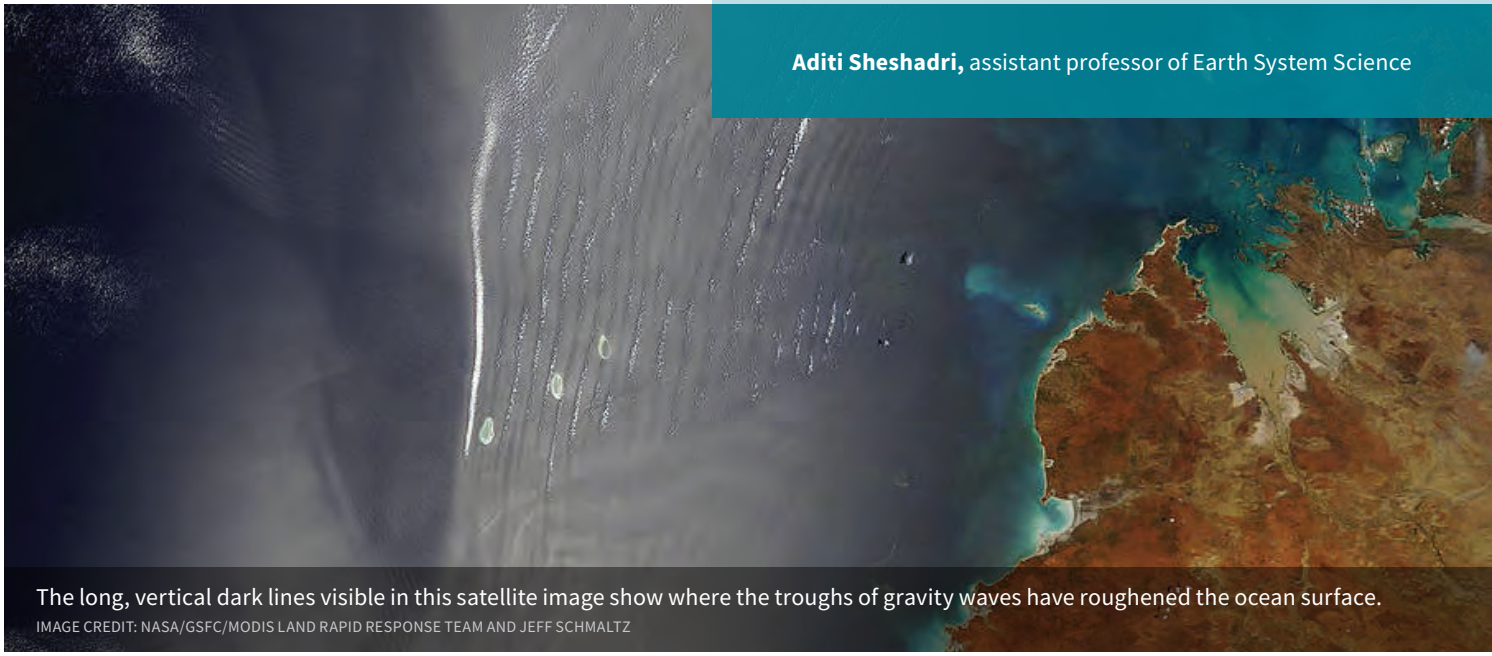
Since gravity waves are too small and short-lived to appear in climate models designed to cover the whole planet, scientists rely on simplified equations known as "parameterizations" to create an approximation for the ripples without bogging down computation. But even small changes in the approximations built into gravity wave parameterizations can lead to very different regional climate projections.

The researchers developed an AI-driven model, dubbed WaveNet, that can accurately emulate how dissipating gravity waves accelerate and decelerate atmospheric winds. The results are a promising first step towards developing fully data-driven gravity wave parameterizations – and increasing confidence in projections that help communities prepare for future climate impacts.

Read more…

Espinosa, Z. I., Sheshadri, A., Cain, G. R., Gerber, E. P., & DallaSanta, K. J. (2022). Machine Learning Gravity Wave Parameterization Generalizes to Capture the QBO and Response to Increased CO_2. *Geophysical Research Letters*, *49*(8), e2022GL098174. DOI: 10.1029/2022GL098174

> "Including a more physical representation of gravity waves in climate models should ultimately lead to more accurate climate projections, particularly at a regional scale."
>
> **Aditi Sheshadri,** assistant professor of Earth System Science



The long, vertical dark lines visible in this satellite image show where the troughs of gravity waves have roughened the ocean surface.
IMAGE CREDIT: NASA/GSFC/MODIS LAND RAPID RESPONSE TEAM AND JEFF SCHMALTZ

Thawing at the base of the Antarctic ice sheet

Sea level rise projections could be missing a crucial component of ice sheet loss in Antarctica, according to a Stanford-led study published in *Nature Communications*. The study identified a process that could trigger or accelerate ice sheet mass loss: thawing of the bed, known as basal thaw, at the interface of land and the miles-thick ice sheet above it.

Using numerical models that simulated ice sheet loss in a 100-year period, the researchers found that triggering basal thaw led to mass loss in regions that are not usually associated with instability and sea level contributions at that time scale.

The study shows that measuring, understanding, and modeling the temperature at the base of ice sheets is important for understanding future sea level rise because there is uncertainty about the contribution from processes that can shift the behavior of massive ice sheets like Greenland and Antarctica.

Read more…

Dawson, E.J., Schroeder, D.M., Chu, W., Mantelli, E., & Seroussi, H. (2022). Ice mass loss sensitivity to the Antarctic ice sheet basal thermal state. *Nature Communications*, *13*, 4957. DOI:10.1038/s41467-022-32632-2

> "When you consider the recent theoretical work showing that thermal processes at the bed can be easy to activate — even spontaneous — it makes near-term thawing of the ice-sheet bed seem like a far easier switch to flip than we'd thought."
>
> **Dustin Schroeder,** associate professor of Geophysics and Electrical Engineering

An iceberg in the Weddell Sea, Antarctica. IMAGE CREDIT: 66 NORTH / UNSPLASH

Groundwater depletion and sinking California farmland

Groundwater pumping in California's Central Valley depletes aquifers and causes the floor of the arid valley to sink. A Stanford-led remote sensing study, published in *Water Resources Research*, revealed that land subsidence will likely continue for years to come.

Researchers combined satellite-based subsidence data, private well logs, and water level measurements to simulate sinking. The study's results suggest thick clays throughout the valley will continue to compact for decades to centuries even if water levels in the region's aquifers stabilize. The land's subsidence will slow only if deposits to groundwater basins – from rainfall and runoff or managed aquifer recharge projects – begin to outpace withdrawals.

The results are likely representative of subsiding regions throughout the San Joaquin Valley.

The methodology and findings can be used to understand aquifer systems worldwide and craft sustainable management plans.

Read more…

Lees, M., Knight, R., & Smith, R. (2022). Development and application of a 1D compaction model to understand 65 years of subsidence in the San Joaquin Valley. *Water Resources Research*, *58*(6), e2021WR031390. DOI:10.1029/2021WR031390

> "The modeling carried out in this study, if done in areas throughout the state, would provide the scientific basis needed to inform sustainable management. A range of possible actions to mitigate subsidence could be rigorously assessed."
>
> **Rosemary Knight,** the George L. Harrington Professor of Geophysics

A wheat field receives water from a pumping system tapped into an irrigation canal in the southern region of the San Joaquin Valley, near Bakersfield, California. IMAGE CREDIT: JOHN CHACON / CALIFORNIA DEPARTMENT OF WATER RESOURCES

Informal environmental water markets for addressing shortages

As the Colorado River and its primary storage reservoirs fall to historic lows, fragile ecosystems that depend on the river are threatened. Environmental water transactions — when owners of water rights are paid to leave water in the river — could provide a solution. However, states have been slow to enact laws that enable these transactions. A Stanford study, published in *Environmental Research Letters*, found that informal environmental water transactions have decoupled market activity from water law across Colorado River basin states, sidestepping formal legal processes to conserve water and restore freshwater ecosystems.

The researchers studied water transactions in five Colorado River Basin states between 2014 and 2020 to better understand how — and how frequently — they actually occur. They found that substantial numbers of environmental water transactions have taken place, including in states with more restrictive laws. Furthermore, 95 percent of the water transactions recorded during the study period occurred outside of the states' formal legal processes.

The conclusions of the study point to a solution that could simultaneously help states meet mandated reductions and relieve pressure on the environment.

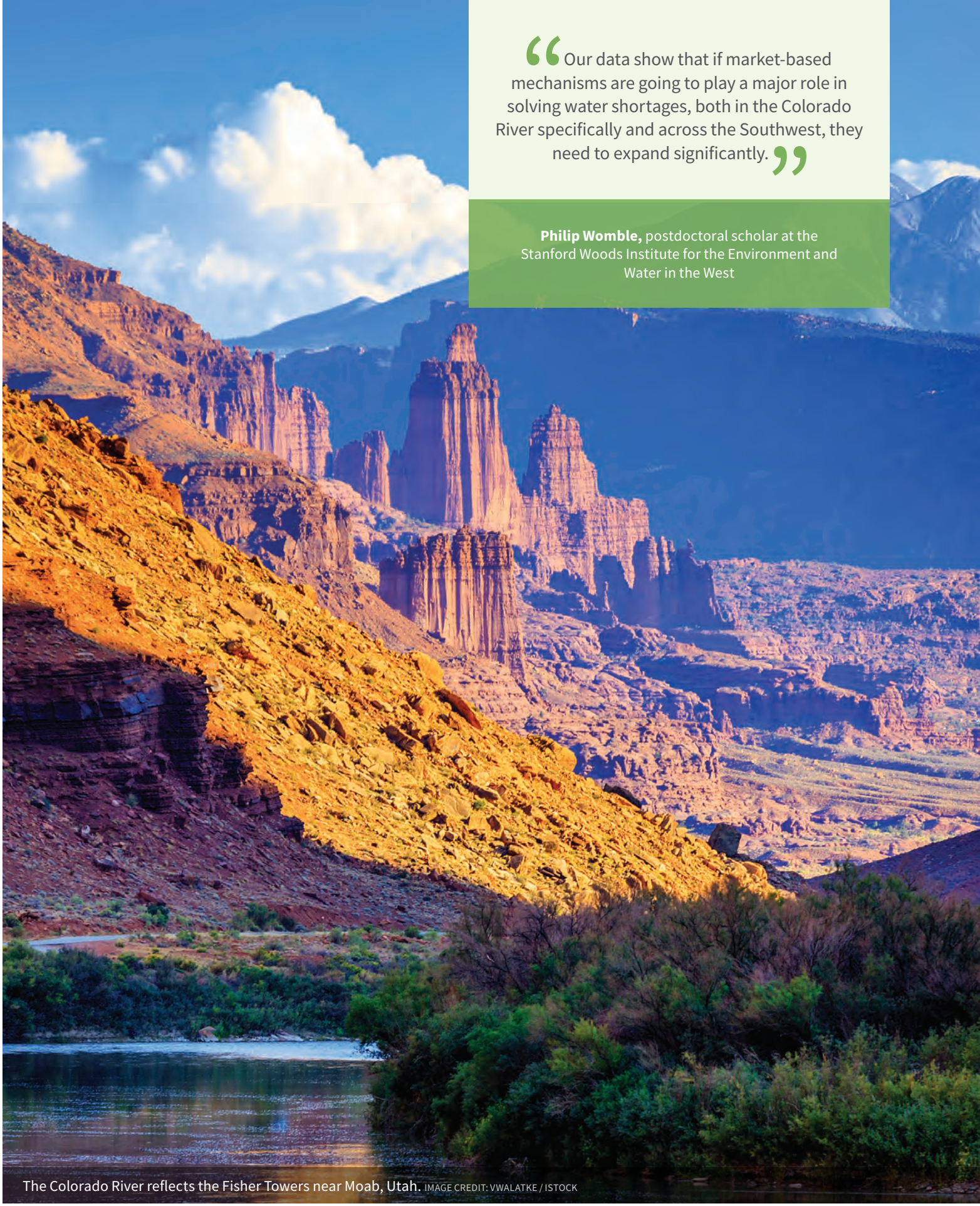
And yet while promising, the team's analysis determined that at least $86–89 million annually in new investment is required to significantly delay or stave off future curtailment of critical water users in the Upper Colorado River basin.

Read more…

Womble, P., Townsend, A., & Szeptycki, L. F. (2022). Decoupling environmental water markets from water law. *Environmental Research Letters*, *17*, 065007. DOI:10.1088/1748-9326/ac6d6d

Lake Powell is one of the primary reservoirs that provide Colorado river water to surrounding states, tribes, and ecosystems. IMAGE CREDIT: BRIGITTE WERNER / PIXABAY

The Colorado River, which has fallen to historic lows in recent years, runs through Glenwood Canyon in Colorado. IMAGE CREDIT: SERGE YATUNIN / ISTOCK



> “Our data show that if market-based mechanisms are going to play a major role in solving water shortages, both in the Colorado River specifically and across the Southwest, they need to expand significantly.”

Philip Womble, postdoctoral scholar at the Stanford Woods Institute for the Environment and Water in the West

The Colorado River reflects the Fisher Towers near Moab, Utah. IMAGE CREDIT: VWALATKE / ISTOCK

Special Reports

Stanford scholars co-authored two special reports in 2021. They covered federal policies for climate resilience and nature-based solutions in state climate policy. For a searchable listing of published special reports and research briefs, visit: woods.stanford.edu/research/publications

Nature-based solutions, such as restoring mountain meadows and reintroducing beavers, show promise for addressing the American West's water and climate challenges.

IMAGE CREDIT: SEAN XU / ISTOCK

SPECIAL REPORT

Forging New Ground: Implementing a Climate Resilience Agenda Across the U.S. Federal Government

Stanford Woods Institute for the Environment

This position paper provided a White House insider's view of the architecture that the Biden administration is putting in place to help communities be more resilient in the face of the most serious climate impacts, namely wildfire, drought, floods, extreme heat, and coastal impacts. The report was authored by David Hayes, a visiting lecturer at Stanford Law School who previously served as Special Assistant to President Biden for Climate Policy. The paper urges the Biden administration to work with Congress to institutionalize and expand the administration's climate resilience agenda, in close partnership with state, tribal, and local leaders.

Read more…

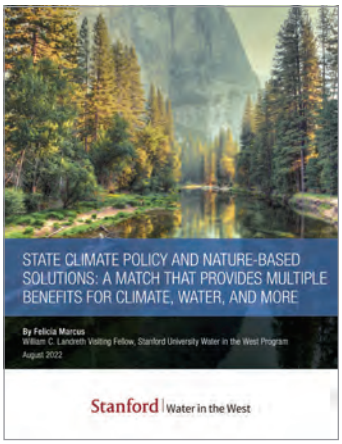
SPECIAL REPORT

State Climate Policy and Nature-Based Solutions: A Match That Provides Multiple Benefits for Climate, Water, and More

Water in the West

This special report examined how states are turning to nature in their efforts to combat climate change. It was authored by Felicia Marcus, an attorney and water policy expert and the William C. Landreth Visiting Fellow at Stanford's Water in the West program. Nature-based solutions, such as ecological forest management, meadow restoration, and "regenerative" agricultural practices, can yield multiple benefits for people and ecosystems. Those benefits include climate emissions reduction and sequestration; protection of people, ecosystems, and public health; improvements in the quantity, quality, and timing of water supplies; maintenance and restoration of biodiversity; and more. The report outlines barriers to meeting those potential benefits and provides recommendations to accelerate the implementation of nature-based solutions with water benefits in state climate policies.

Read more…



Notes

Stanford faculty, students, postdoctoral scholars, and research staff authored more than 700 peer-reviewed publications in 2022 related to the environment and sustainability. View the full listing of publications at:

stanford.io/3BqWmav

More than 280 faculty members and academic staff perform significant research related to the environment and sustainability at Stanford. For a searchable listing of them, with filters for topic areas and academic departments, visit:

woods.stanford.edu/people/faculty-researchers

The Stanford Environmental Research Year in Review is produced by the Stanford Woods Institute for the Environment.

woods.stanford.edu/research/stanford-environmental-research-year-review

About Us

The Stanford Woods Institute for the Environment is part of the Stanford Doerr School of Sustainability. Since 2004 the Woods Institute has worked to produce breakthrough environmental solutions that protect and nurture our planet so it can meet the vital needs of people today and of generations to come. Drawing on the ingenuity, passion and pioneering spirit of Stanford University, Woods pursues this mission through research by Stanford's exceptional faculty and students, convening global experts, developing environmental leaders and linking knowledge to action. Learn more:

woods.stanford.edu

Editorial Staff

Editor
Madison Pobis

Contributing Writers/Editors
Brennecke Gale
Rob Jordan
Alexandra May Smith
Christine Black

Graphic Design
John Verducci/Studio EM

Stanford researchers found that a process known as basal thaw could trigger mass Antarctic ice sheet loss, contributing to sea level rise. IMAGE CREDIT: MLENNY/GETTY IMAGES

Stanford Woods Institute for the Environment | Stanford Doerr School of Sustainability

For more information visit: **woods.stanford.edu**

Stanford Woods Institute for the Environment
Stanford University
Jerry Yang & Akiko Yamazaki Environment & Energy Building - MC 4205
473 Via Ortega, Stanford, CA 94305

Phone: 650.736.8668
Fax: 650.725.3402
environment@stanford.edu

The Stanford Environmental Research Year in Review is produced by the Stanford Woods Institute for the Environment. To view a full listing of publications and previous reports, please visit: woods.stanford.edu/research/stanford-environmental-research-year-review