Stanford

Environmental Research

2023 Year in Review

Stanford

Woods Institute for the Environment

The Stanford Environmental Research Year in Review is produced by the Stanford Woods Institute for the Environment and covers research by faculty, students, postdoctoral scholars, and research staff from across Stanford's seven schools.

Above: Researchers at the Natural Capital Project found over an 18-year study that diversified farms with ribbons or patches of forest offered a safe haven for Costa Rican birds. IMAGE CREDIT: GETTY IMAGES

On the cover: A wildflower superbloom in North Table Mountain Ecological Reserve in California sprouted after a series of winter storms in early 2023. IMAGE CREDIT: MADISON POBIS

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Letter from Dean Arun Majumdar

The world faces an unprecedented challenge.

We are confronted with creating a sustainable future amidst a $100 trillion global economy based predominantly on fossil fuels and a global population of 8 billion people growing to 10 billion by 2050.

In response, the world is embarking on the largest transition humanity has ever undertaken. And while nations, corporations, and organizations the world over have made commitments to reduce emissions, ambiguity and disagreement persist on how to navigate the path forward.

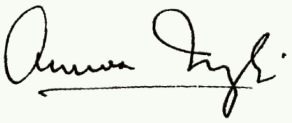
As a result, the greatest challenge of the 21st century also represents the greatest opportunity.

The world is seeking answers on how to achieve a future that cuts carbon, protects communities from climate extremes, and secures a prosperous planet for our children and grandchildren. Such outcomes require innovation and solutions with the metrics of speed and scale as our touchstones. We need to align technologies, policies, finance, and markets while pursuing an intense focus on communities, especially underserved communities, so that all can enjoy a prosperous and healthy future.

In short, the world is relying on linking knowledge to impact.

As demonstrated in the pages of this report, the Woods Institute for the Environment serves as Stanford's hub for interdisciplinary research on the environment, working to leverage the efforts of researchers from across the entire university community and foster collaborations and partnerships to address the planet's most pressing challenges. Truly, Woods Institute scholars are transforming knowledge into action and turning the century's gravest challenge into its most promising opportunity.

When the Stanford Doerr School of Sustainability launched in 2022, we laid out a bold vision for reimagining academia and its value to society. The Woods Institute represents a key pillar of that ambition. What is more, the transformative research featured in this report represents just a portion of the world-changing work being accomplished by the faculty, students, postdoctoral scholars, and research staff from across Stanford affiliated with the institute. Each day, their committed efforts bring us closer to the knowledge and solutions essential for a sustainable 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

Letter from Director Chris Field

It is both humbling and inspiring to witness the insights and accomplishments of Stanford researchers as they tackle complex issues at the intersection of climate, human and planetary health, nature-based climate solutions, and thriving ecosystems.

It is my pleasure to share with you a collection of research from 2023 that highlights some of the remarkable discoveries on environment and sustainability from across Stanford's seven schools. This publication underscores not only the diversity and ambition of Stanford research, but also the commitment to interdisciplinarity and practical solutions.

Much of this research sharpens our understanding of how climate change is precipitating critical losses to ecosystems, negatively impacting human health, and shortening the window of opportunity for system-level transformation. Yet, these sobering findings are balanced by broad progress on meaningful solutions. From pioneering advancements in groundwater measurements to innovative strategies for enhancing food system resilience on land and in the ocean, Stanford researchers are at the forefront of driving action in a rapidly changing world.

This year's selections demonstrate how Stanford environmental research is defined not only by its technical rigor but also its holistic approach, integrating cutting-edge technology with insights from social science and community engagement. The guiding principles of resilience and environmental justice are embedded in scholarship focused on flood adaptation, planned relocation, oil spill response, marine protected areas, open space management, and urban water markets.

Stanford experts authored a robust set of special reports on food security, sustainable infrastructure, and wildfire resilience. By bridging the gap between innovation and implementation, we are generating knowledge as well as empowering communities to enact solutions that address their unique environmental challenges.

I extend my heartfelt gratitude to the researchers, partners, and supporters who are advancing this vital mission.

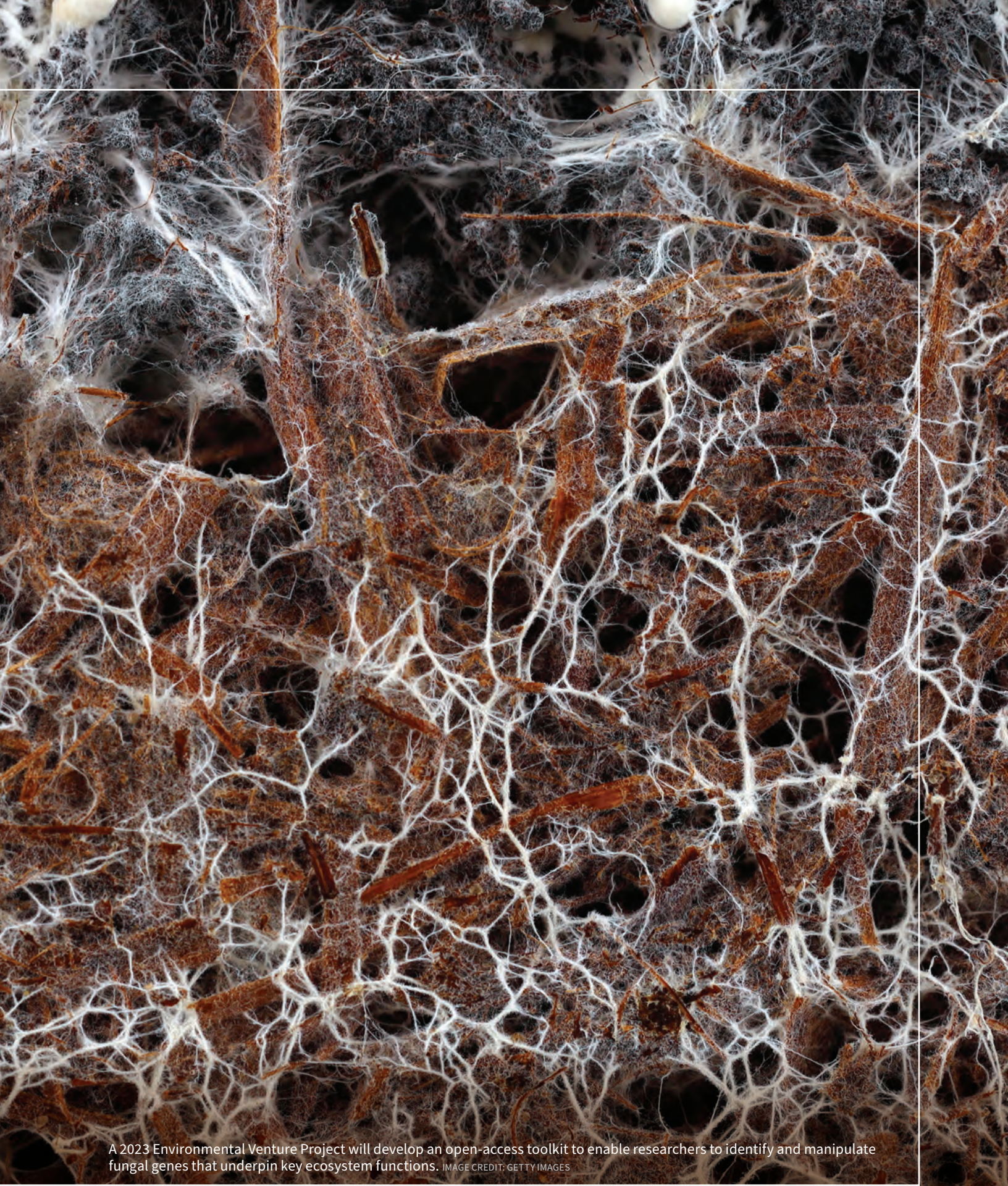
Christopher B. Field

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

Research Awards for Environmental Solutions

Interdisciplinary scholars from environmental and social science, medicine, engineering, business, education, and law must collaborate on bold and creative research plans to tackle immense environmental challenges. In continued support of this vision, the Stanford Woods Institute for the Environment awarded more than $3.75 million to 16 projects in the form of Environmental Venture Projects (EVP) and Realizing Environmental Innovation Program (REIP) grants in 2023.

Since EVP began in 2004 and REIP began in 2015, the Stanford Woods Institute has awarded more than $23 million in grants to 148 research teams representing all seven of Stanford's schools and working in 37 different countries. These projects have gone on to receive more than $50 million in additional funding from other sources.



A 2023 Environmental Venture Project will develop an open-access toolkit to enable researchers to identify and manipulate fungal genes that underpin key ecosystem functions. IMAGE CREDIT: GETTY IMAGES

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 2023 will receive up to $250,000 over two years.

Disease early warning: A rapid approach for wastewater-based epidemiology

Wastewater-based epidemiology can monitor population-level infection, provide early warnings about outbreaks, and help control disease spread. However, current methods to identify bacteria are slow, costly, and not suitable for high-throughput screening of diverse bacterial species. This project will develop a new platform combined with machine learning models to detect a wide range of pathogenic bacteria in wastewater and identify their antibiotic susceptibility. The approach could be expanded to correlate bacterial pathogens with other infectious diseases and environmental contaminants, and scaled to detect bacterial pathogens in a broader range of environmental samples.

Jennifer Dionne (Materials Science and Engineering)
Alexandria Boehm (Civil and Environmental Engineering)

Plastic to food: Converting polyethylene into palm oil

Less than 5% of all U.S. plastic waste generated is recycled. Meanwhile, as the demand for palm oil grows, rainforests are being cleared for new oil palm crops. This project will address both environmental challenges simultaneously by developing a new technology to convert polyethylene — by far the most discarded plastic — into palm oil. The approach could add value to the plastic waste management chain while sourcing palm oil through a less destructive route.

Matteo Cargnello (Chemical Engineering)
Jennifer Cochran (Bioengineering)

A wastewater treatment plant as seen from above. Stanford researchers are developing an approach to test wastewater for bacterial pathogens. IMAGE CREDIT: GETTY IMAGES

A 2023 EVP team aims to address plastic waste and deforestation for palm oil by developing new recycling technology. IMAGE CREDIT: GETTY IMAGES

Cost-effective methane monitoring

Methane is a potent greenhouse gas emitted by natural resources, such as wetlands, and human sources, such as landfills and agriculture. The extent of the problem is not well understood because of a lack of effective monitoring. This project will develop low-cost sensors that can monitor methane emissions across wide spatial scales in less than a second.

Leo Hollberg (Physics)
Alison Hoyt (Earth System Science)

Empowering youth in frontline communities through climate data

While data on environmental conditions, such as air quality, temperature and traffic patterns can provide insight on how communities experience climate change, frontline communities often lack access to such data. In partnership with Climate Resilient Communities, a community-based organization, this project will conduct out-of-school learning experiences to equip cohorts of youth with the skills to map environmental impacts and disseminate these maps, fostering collective awareness and advocacy. The researchers also aim to design a toolkit with curriculum, technology, and social support to position youth as changemakers who can leverage environmental data to inform their communities.

Victor Lee (Education)
Nicole Ardoin (Social Sciences)
Jenny Suckale (Geophysics)

Adaptive drought management in a changing climate

In many water-stressed regions, water security is simultaneously threatened by increased drought frequency, long-term drying trends, and increasing water demand. This project will develop a new approach to drought management that will help planners identify when to adapt hydrological indicators most useful for drought management, enact short-term drought responses, and invest in long-term water supply infrastructure. It will provide guidance on the water governance reform needed to support adaptive management. The team will partner with local researchers, water managers, and policymakers in Chile to apply the approach to the Maipo river basin, which supplies water to the city of Santiago and is facing its fourteenth consecutive year of drought.

Sarah Fletcher (Civil and Environmental Engineering)
Alexandra Konings (Earth System Science)
Bruce Cain (Political Science)

An interdisciplinary team of Stanford researchers is piloting a novel approach to data science education and access in collaboration with local youth climate action communities.
IMAGE CREDIT: MARC CALLEJA LOPEZ / GETTY IMAGES

The Mapocho River runs through downtown Santiago, Chile.
IMAGE CREDIT: TIFON IMAGES / GETTY IMAGES

Strengthening community advocacy for natural flood solutions

The impact of Hurricane Harvey on Houston – especially low-income communities of color – was a stark reminder of the growing problem of urban flooding and the inadequate protection that current flood control and mitigation provides. This project will provide insight into the utility and public demand for nature-based solutions in Houston. The researchers will work with a community-based organization to quantify the value of restoring and conserving wetlands hydrologically connected to marginalized communities. Surveys of marginalized communities will assess knowledge and support of such natural flood solutions. Communities will be able to use the project's results to advocate for green alternatives to address urban flooding.

Elliott White Jr. (Earth System Science)
Khalid Osman (Civil and Environmental Engineering)

Investigating environmental connections to high levels of kidney disease in California's Central Valley

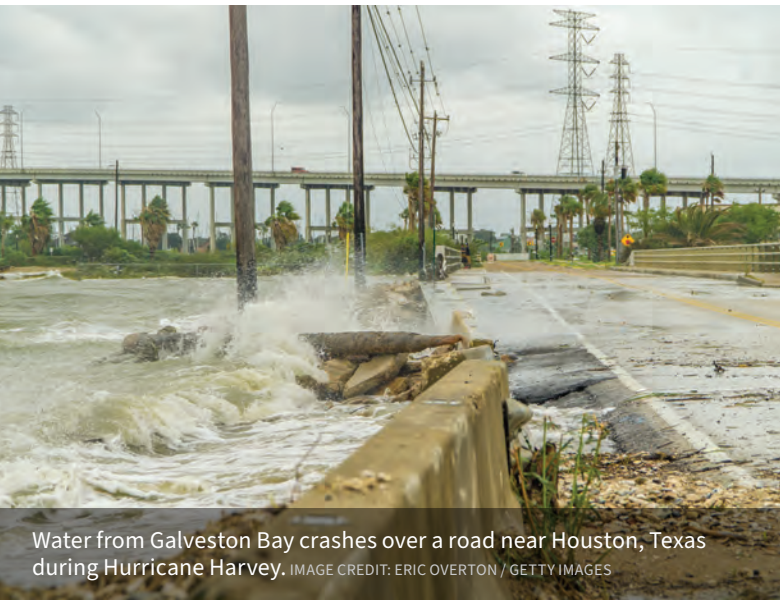
California's Central Valley has one of the highest rates of end-stage kidney disease in the U.S. This project focuses on young to middle-aged people undergoing dialysis in the region to ascertain occupation, residence, and health care access history. The survey data will be linked to existing state resources on pesticide use and water quality. The researchers plan to investigate whether agriculture work or groundwater contamination increase risk for undefined end-stage kidney disease.

Shuchi Anand (Medicine – Nephrology)
Manjula Tamura (Medicine – Nephrology)

Understanding ocean production of an important greenhouse gas

Microbial processes in oxygen-deficient ocean zones produce large amounts of nitrous oxide, a potent greenhouse gas. Existing measurements and models suggest that the eastern tropical south Pacific Ocean is an important region for nitrous oxide flux, and may increase its output of the gas in the future as a result of global change, including ocean deoxygenation. To better predict the future trajectory of nitrous oxide emissions, this project will conduct experiments at sea to characterize the effects of oxygen manipulation on microbial nitrous oxide production rates and mechanisms.

Karen Casciotti (Earth System Science)
Christopher Francis (Earth System Science)



Water from Galveston Bay crashes over a road near Houston, Texas during Hurricane Harvey. IMAGE CREDIT: ERIC OVERTON / GETTY IMAGES

A school of sardines swims in the Pacific Ocean, where Stanford researchers are investigating nitrous oxide flux from marine microbes. IMAGE CREDIT: IZANBAR / GETTY IMAGES

Harnessing plant-microbial partnerships to address major sustainability challenges

Partnerships between plant roots and fungi play a key role in the photosynthetic capacity, carbon budget and environmental tolerances of plant communities. These partnerships could be harnessed to address major challenges, such as climate mitigation and food security, but technical barriers limit the realization of this potential. This project will develop an open-access toolkit to enable researchers to identify and manipulate fungal genes that underpin key ecosystem functions. Resulting investigations could have wide reaching implications for the sustainability of natural and managed plant systems.

Kabir Peay (Biology)
Jennifer Brophy (Bioengineering)

A data-driven approach to redirect hospital fabrics from landfills could reduce waste and improve welfare for vulnerable communities in Brazil.
IMAGE CREDIT: GETTY IMAGES

Self-fertilizing plants: Toward a new era in agriculture and ecosystem management

Nitrogen fertilizer is essential for a robust crop yield, but its production, use, and cost drives massive amounts of carbon emissions, die-offs in lakes and ponds, and other challenges. This project will build a platform to enable the rapid development and study of enzymes that fix atmospheric nitrogen (nitrogenases), which can be optimized to enable different types of algae or plants to produce their own fertilizer. With this technology, self-fertilizing plants could reduce energy and nutrient leaching into water systems and also address global inequality by enabling more robust yields in locations where it is difficult to use chemical fertilizers.

Jennifer Brophy (Bioengineering)
Ellen Yeh (Pathology)

Disrupting hospital waste streams: Redirecting used fabric from landfills

In Brazil, most hospital textiles are incinerated or sent to landfill. This project will engineer a traceable, data-driven system to identify and predict waste patterns and adequately and efficiently redirect hospitals' textile waste to upcycling in a decentralized network. A new interactive digital tool that leverages modeling software will allow users to visualize and map the value provided by upcycling ecosystem services, combining sustainable waste interventions and economic welfare for vulnerable communities.

Robson Capasso (Medicine - Otolaryngology - Head & Neck Surgery)
Tulio Valdez (Medicine - Otolaryngology - Head & Neck Surgery)

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 2023 will receive up to $500,000 over two years:

Combating deforestation linked to human trafficking

In the Brazilian Amazon, forced labor drives some illegal deforestation. This project will expand a remote detection model developed in collaboration with Brazilian law enforcement to find illegal labor camps suspected of human trafficking. The researchers will leverage powerful new data streams reporting environmental law violations and monitoring deforestation, land development, and road construction. The project, a partnership with the Brazilian Federal Labor Prosecution Office, has the potential to profoundly enhance the capabilities of front-line law enforcement to stop human trafficking and illegal deforestation in the Amazon.

Michael Baiocchi (Medicine - Epidemiology and Population Health)
Grant Miller (Health Policy)

Improving nutrition, food security, and livelihoods with blue foods

Indonesia is a major producer of blue foods — animals, plants, and algae harvested from freshwater and marine environments — and has one of the largest populations of people dependent on blue foods. This project will collaborate with Indonesian government ministries, civil society organizations, and businesses to co-design research and solutions that can help Indonesia capitalize on the potential of blue foods to improve nutrition, food security, and livelihoods for populations that have historically been marginalized.

Jim Leape (Center for Ocean Solutions)
David Cohen (Center for Human Rights and International Justice)

Symmetrical rows of charcoal kilns visible on satellite imagery could help Stanford researchers identify potentially illegal deforestation and trafficking operations in the Amazon. IMAGE CREDIT: ALBERTO CHAGAS / GETTY IMAGES

Carbon- and energy-efficient water reuse for irrigation

Domestic wastewater can be a resource for water, energy, and nutrients. Conventional wastewater treatment systems have high energy consumption and a large carbon footprint, primarily due to nitrous oxide emissions from aeration of organic matter and ammonium. By contrast, strictly anaerobic processes produce methane, a valuable energy resource, and also produces a nutrient-rich effluent that can offset the need for imported water and fertilizer for irrigation. This project will show proof-of-concept for efficient and sustainable water reuse through anaerobic treatment with ultrafine membranes.

Craig Criddle (Civil and Environmental Engineering)
Richard Luthy (Civil and Environmental Engineering)

Ultrafine membranes could help purify wastewater for agricultural irrigation. IMAGE CREDIT: PIXDELUXE / GETTY IMAGES

Recovering resources from wastewater affordably and sustainably

Re-envisioning wastewater facilities as resource recovery facilities is critical to decarbonizing our water supply and supporting a circular water and nutrient economy. But recovering biogas, potable water, and nutrients from traditional treatment processes is expected to increase electricity requirements of the plant by four times, and has been shown to increase emissions. A promising alternative lies in coordinated operation of battery, wastewater, and compressed biogas storage via an "integrated energy management system" which can reduce electricity costs by 17% and minimize harmful biogas flaring. Through demonstration studies, this project will extend the approach to account for potable water reuse, air stripping for ammonia recovery, and compressed air storage.

Meagan Mauter (Civil and Environmental Engineering)
Will Tarpeh (Chemical Engineering)
Inês Azevedo (Energy Science Engineering)

Using social input to identify carbon reduction pathways

This project aims to scale a program for optimizing the identification of realistic scenarios for rewiring diagrams that describe energy flow in the U.S. and the associated carbon dioxide emissions to achieve a 50% global warming gas reduction from 2005 levels by 2030. The researchers will analyze how changes in components of the system affect each other, and include in their model different categories of social input — assessments and opinions provided by experts, lay persons, government, and other stakeholders. The result is a ranked order of potential pathways for achieving the desired global warming gas reduction. The optimization program will be publicly available online.

Lambertus Hesselink (Electrical Engineering)
Hamdi Tchelepi (Energy Science Engineering)

Recyclable and nontoxic powder uses sunlight to disinfect drinking water

At least two billion people worldwide routinely drink water contaminated with disease-causing microbes. A team of Stanford researchers and engineers demonstrated that a new low-cost, harmless metallic powder can kill thousands of waterborne bacteria per second when exposed to ordinary sunlight. Their results were published in a study in *Nature Water.*

Conventional water-treatment technologies include chemicals, which can produce toxic byproducts, and ultraviolet light, which takes a relatively long time to disinfect and requires a source of electricity. Funded by an REIP grant, the team set out to investigate how nanomaterials could effectively treat water contaminated with bacteria like *E. coli,* which can cause life-threatening gastrointestinal illness.

When mixed into room-temperature water, the powder interacts with photons from sunlight to create hydrogen peroxide and hydroxyl radicals that quickly kill bacteria by damaging their cell membranes. The chemical byproducts dissipate quickly so that it's possible to drink the water immediately.

The nontoxic powder is also recyclable. Iron oxide enables the nanoflakes to be removed from water with a simple magnet, making it an ideal portable solution for hikers and backpackers. The nanoflakes are easy to make, which opens opportunities for rapidly scaling up for use by water treatment plants.

Read more…

Wu, T., Liu, B., Liu, C., Wan, J., Yang, A., Liu, K., Shi, F., Zhao, J., Lu, Z., Chen, G., Pei, A., Hwang, H. Y., & Cui, Y. (2023). Solar-driven efficient heterogeneous subminute water disinfection nanosystem assembled with fingerprint MoS_2. *Nature Water*, *1*, 462-470.
DOI: 10.1038/s44221-023-00079-4

> "The materials are low cost and fairly abundant. The key innovation is that, when immersed in water, they all function together."
>
> **Yi Cui,** the Fortinet Founders Professor of Materials Science and Engineering, Energy Science and Engineering

A new nontoxic powder could provide a portable, reusable, and low-cost solution for water disinfection. IMAGE CREDIT: GETTY IMAGES

Incorporating justice, equity, and access into land trust conservation efforts

Land trusts have traditionally focused on preserving "pristine" open spaces and biodiversity, but the recent shift of some organizations to engage in environmental justice issues poses unique opportunities and tradeoffs, according to an analysis published in *Biological Conservation*.

A team of Stanford researchers conducted one of the first empirical studies of land trusts and their justice, equity, and access impacts as part of an REIP-funded project to develop an open space management practicum.

Interviews and surveys of a broad range of land trust directors, staff members, and volunteers revealed common challenges around integrating social justice initiatives into conservation work. For example, many organizations have limited staff and capacity to start up new justice-oriented initiatives and outreach. However, they also found that conservation organizations can embrace non-traditional partnerships and draw on volunteers and visitors to support projects related to the specific needs of local communities, such as transportation or food security.

Although the study does not prescribe a universal conservation approach, it emphasized how socio-ecological framing can help balance ambitious conservation goals with place-based community engagement.

Beckman, C. M., Wheaton, M., Sawe, N., & Ardoin, N. M. (2023). Incorporating justice, equity, and access priorities into land trusts' conservation efforts. *Biological Conservation*, *279*, 109926. DOI: 10.1016/j.biocon.2023.109926

> "This study sheds light on how private conservation organizations can balance environmental protection with social justice for a more inclusive and sustainable approach to conservation."

Caroline Beckman, PhD candidate in Environment and Sustainability at the University of Michigan and Stanford Earth Systems undergraduate '21

Garin and Dry Creek Pioneer Regional Parks overlook an urban area in the San Francisco East Bay. IMAGE CREDIT: YHELFMAN / GETTY IMAGES

Research Highlights

Stanford marine conservation scientist Nur Arafeh-Dalmau swims in a giant kelp forest in Baja California in August 2023. An avid diver, he documented Mexico's worst marine heat wave from 2014 to 2016. Arafeh-Dalmau led an international team to publish the first comprehensive framework, featured on page 21, for designing climate-resilient marine protected areas. IMAGE CREDIT: JENNIFER ADLER / MASKELP

A new chance at global wetlands conservation despite high losses in many regions

Global losses of wetlands have likely been overestimated, according to Stanford research published in *Nature*. The results can help better explain the causes and impacts of wetland loss, enabling more informed plans to protect or restore ecosystems crucial for human health and livelihoods.

Wetlands provide a variety of ecosystem services, such as purifying water, preventing flooding, and enhancing biodiversity. However, relentless drainage for conversion to farmland and urban areas has caused wetlands to become one of the most threatened ecosystems in the world. Incomplete and inaccurate historical data have hindered effective conservation efforts that rely on a clear picture of wetlands loss.

To fill this data gap, researchers mapped the distribution of drained and converted wetlands onto maps of present-day wetlands to understand what the original wetland area might have looked like in 1700. They found that 1.3 million square miles of wetlands have been lost globally since 1700 — a decline of 21-35% compared to previous estimates of 50-87%. Although wetland conversion and degradation have slowed globally, it continues apace in some regions, highlighting the importance of prioritizing conservation and restoration to prevent further declines.

Read more…

Fluet-Chouinard, E., Stocker, B. D., Zhang, Z., Malhotra, A., Melton, J. R., Poulter, B., Kaplan, J. O., Goldewijk, K. K., Siebert, S., Minayeva, T., Hugelius, G., Joosten, H., Barthelmes, A., Prigent, C., Aires, F., Hoyt, A. M., Davidson, N., Finlayson, C. M., Lehner, B., Jackson, R. B., & McIntyre, P. B. (2023). Extensive global wetland loss over the past three centuries. *Nature*, *614*, 281–286. DOI: 10.1038/s41586-022-05572-6

> “Despite the good news that our results might imply, it remains urgent to halt and reverse the conversion and degradation of wetlands. The geographic disparities in losses are critical to consider because the forgone local benefits from drained wetlands cannot be replaced by wetlands elsewhere.”
>
> **Etienne Fluet-Chouinard,** former postdoctoral scholar of Earth System Science

Peatland sites, like this one near Riisitunturi National Park, Northern Finland, purify water, recharge groundwater, and store carbon.
IMAGE CREDIT: KARL ANDER ADAMI / GETTY IMAGES

Warmer weather has left a fifth of California's Sierra Nevada conifer forests stranded

A Stanford-led study revealed that about a fifth of all Sierra Nevada conifer forests are a "mismatch" for their regions' warming weather. The paper, published in *PNAS Nexus*, highlights how such "zombie forests" are temporarily cheating death, likely to be replaced with tree species better adapted to the climate after one of California's increasingly frequent catastrophic wildfires.

Even if global heat-trapping pollution decreases to the low end of scientific projections, the number of Sierra Nevada conifers no longer suited to the climate will double within the next 77 years, according to the analysis. The speed of change has outpaced the ability of many low-elevation conifers to adapt or shift their range, making them highly vulnerable to replacement, especially after stand-clearing wildfire.

The study's first-of-its-kind maps painted a picture of rapidly changing landscapes that will require more adaptive wildfire management that eschews suppression and resistance to change for the opportunity to direct forest transitions for the benefit of ecosystems and nearby communities. Similarly, conservation and post-fire reforestation efforts will need to consider how to ensure forests are in equilibrium with future conditions, according to the researchers.

Read more…

Hill, A. P., Nolan, C. J., Hemes, K. S., Cambron, T. W., & Field, C. B. (2023). Low-elevation conifers in California's Sierra Nevada are out of equilibrium with climate. *PNAS Nexus*, *2*(2), pgad004. DOI: 10.1093/pnasnexus/pgad004

> "Forest and fire managers need to know where their limited resources can have the most impact. This study provides a strong foundation for understanding where forest transitions are likely to occur, and how that will affect future ecosystem processes like wildfire regimes."
>
> **Avery Hill,** PhD student in Biology

Sierra Nevada conifers, such as ponderosa pine, sugar pine, and Douglas fir are among Earth's tallest and most massive living things. A Stanford study estimated that about 20% of all Sierra Nevada conifers are mismatched with the climate around them.

IMAGE CREDIT: ADAM MUSTAFA / GETTY IMAGES

Two oil spills a world apart reveal lessons in disaster response

The first few days after an oil spill are the most important for mitigating long-term impacts to livelihoods and health. Yet few studies have focused on this initial period, in part because it's often difficult for researchers to access disaster zones quickly. Stanford research published in *Ecology & Society* compared emergency responses following two oil spills that hit close to home for co-authors Josheena Naggea, PhD '22, and Rebecca Miller, PhD '21.

In August 2020, the bulk carrier MV *Wakashio* ran aground and poured 318,000 gallons of oil into mangroves, seagrass beds, and coral reefs around Mauritius, an island nation in the Western Indian Ocean where Naggea grew up. Naggea witnessed firsthand how delayed government aid and insufficient preparation forced Mauritians to scoop buckets full of oil from the water until protective equipment and international experts arrived, their travel delayed by the COVID-19 pandemic.

Thirteen months later, an underwater pipeline emptied 25,000 gallons of oil into coastal waters near Huntington Beach where Miller spent her childhood. Miller observed city officials quickly mobilize protective equipment for clean-up teams and implement public safety protocols like beach closures.

Naggea and Miller, classmates in the Emmett Interdisciplinary Program in Environment and Resources at the time of their research, examined the environmental justice implications of these observed differences. Small island states like Mauritius face increasing hazards from climate change driven by burning of fossil fuels, while also contending with outsized impacts when those fuels spill. Naggea and Miller emphasized that regional networks could work together to provide resources and assistance to nearby countries that lack local oil spill expertise.

Read more…

Naggea, J. & Miller, R. K. (2023). A comparative case study of multistakeholder responses following oil spills in Pointe d'Esny, Mauritius, and Huntington Beach, California. *Ecology & Society*, *28*(1), 24. DOI: 10.5751/ES-13737-280124

Following a 2020 oil spill from a vessel grounded off the island nation of Mauritius, local residents used donated hair and sugarcane bagasse, a fibrous byproduct of the local sugar industry, to fabricate oil spill booms until international cleaning companies arrived. Coauthor Josheena Naggea, E-IPER PhD '22, is pictured second from left. IMAGE CREDIT: JOSHEENA NAGGEA

> By choosing two cases so close to our hearts but so opposite in terms of magnitude and response, we could better highlight the contrast in responses in the short period of days after the incidents, and the implications of these differences.

Rebecca Miller, AAAS Science and Technology Policy Fellow,
E-IPER PhD '21

Emergency personnel in protective suits clean oil from the shoreline of Huntington Beach following the October 2021 spill.
IMAGE CREDIT: NICK UT / GETTY IMAGES

Leveraging blue foods to address multiple global challenges

The Blue Food Assessment — an international initiative led by the Center for Ocean Solutions and Center on Food Security and the Environment, the Stockholm Resilience Centre at Stockholm University, and EAT — launched a comprehensive, online national dataset and new research for scholars to explore four key roles that aquatic, or "blue," foods play in improving food systems globally.

Published in *Nature*, the paper delved into the potential of blue foods and their ability to improve four policy dimensions: vitamin B12 and omega-3 nutrient deficiencies, high rates of cardiovascular disease associated with excessive red (particularly processed) meat consumption, high environmental impacts, and climate adaptation and resilience.

The publication equips policymakers with research-backed information and an interactive tool to create relevant and effective legislation. For example, the paper suggested that policymakers in nations characterized by high environmental food footprints and high nutrient deficiencies could choose to support greater diversity of blue food production and promote lower-cost blue foods. Taken together with insights from the entire Blue Food Assessment, the study helps policymakers safeguard the contribution of blue food systems to nutrition, just economies, livelihoods, and cultures.

Read more…

Crona, B. I., Wassénius, E., Jonell, M., Koehn, J. Z., Short, R., Tigchelaar, M., Daw, T. M., Golden, C. D., Gephart, J. A., Allison, E. H., Bush, S. R., Cao, L., Cheung, W. W. L., DeClerck, F., Fanzo, J., Gelcich, S., Kishore, A., Halpern, B. S., Hicks, C. C., Leape, J. P., Little, D. C., Micheli, F., Naylor, R. L., Phillips, M., Selig, E. R., Springmann, M., Sumaila, U. R., Troell, M., Thilsted, S. H., & Wabnitz, C. C. C. (2023). Four ways blue foods can help achieve food system ambitions across nations. *Nature*, *616*, 104–112. DOI: 10.1038/s41586-023-05737-x

> "By further customizing the different parameters in the online tool, decision-makers can explore the blue food policies most relevant for their national setting and use the paper to inspire blue food policies that can overcome existing environmental and nutritional challenges."
>
> **Jim Leape,** co-director of the Stanford Center for Ocean Solutions and the William and Eva Price Senior Fellow at the Stanford Woods Institute for the Environment

A stall at a seafood market in Hong Kong displays a variety of live blue foods. IMAGE CREDIT: DANIEL V. FUNG / GETTY IMAGES

How to design marine protected areas that keep pace with climate change

An international Stanford-led team developed the first comprehensive framework for designing networks of marine protected areas that can help vulnerable species survive as climate change drives habitat loss.

In a paper published in *One Earth*, the researchers outlined guidelines for governments to provide long-distance larval drifters, like urchins and lobsters, as well as migratory species, like turtles and sharks, with protected stopovers along coastal corridors.

As a case study, the authors used the 21 biological and physical guidelines presented in their framework to map out protections for giant kelp ecosystems and species across the Southern California Bight. In this vast region where California's coastline curves to the southeast along the peninsula of Baja California, Mexico, giant kelp forests provide nursery areas, shelter from predators and storms, and food to hundreds of commercially and culturally valuable species.

Although parts of Baja California and the California coast are marine protected areas, the network doesn't account for how species move between the U.S. and Mexico, which means the benefits of a protected nursery may not extend to where larvae may drift into the neighboring country to settle and grow into adults.

The proposed framework could be more cost-effective and resilient by prioritizing protection for sites where species have the highest chance of survival and by explicitly planning for how various future climate scenarios, like worsening heat waves, might play out.

Read more…

Arafeh-Dalmau, N., Munguia-Vega, A., Micheli, F., Vilalta-Navas, A., Villaseñor-Derbez, J. C., Précoma-de la Mora, M., ... Knight, C. J., ... Giron-Nava, A., ... Olguín-Jacobson, C., ... Smith, A., ... & Possingham, H. P. (2023). Integrating climate adaptation and transboundary management: Guidelines for designing climate-smart marine protected areas. *One Earth*, 6(11), 1523-1541.
DOI: 10.1016/j.oneear.2023.10.002

Giant kelp grow in dense, underwater forests that provide nursery areas, shelter from predators and storms, and food to hundreds of commercially and culturally valuable species like abalone.
IMAGE CREDIT: LIFE CAPTURED / GETTY IMAGES

> "Until now, marine protected areas have been designed for biodiversity conservation, but not necessarily for climate resilience. They suffer from climate impacts but aren't designed to endure them."

Nur Arafeh-Dalmau, postdoctoral scholar in Oceans, honorary fellow at The University of Queensland

Why the world's largest whales needed to be so big

The largest animals to ever live owe their enormous size to feeding on the tiniest creatures in the sea, but their survival requires a minimum body size, according to Stanford-led research published in *Nature Ecology & Evolution*.

The study focused on the "rorqual whales," a lineage that includes the blue whale, the largest animal of all time. The group is characterized by a lunging maneuver where individuals engulf an enormous amount of water along with their prey, which they then filter through fringed structures at the roof of their mouth.

The authors examined the smallest living species in this group, the Antarctic minke whale, to calculate the minimum size required for lunge-feeding whales. They used suction cups to affix a "biologging tag" packed with sensors and cameras to the backs of individual minke whales that, combined with drone photography, allowed them to document engulfment events and estimate body length.

Minke whales dove deeper than predicted to find prey, meaning that they're operating at maximum capacity, and can't possibly forage any more given size constraints and the time it takes to lunge feed. For whales constrained by body size and operating at physiological extremes, like minkes and possibly blue whales, rapid environmental change could put them at greater risk of extinction.

Read more…

Cade, D. E., Kahane-Rapport, S. R., Gough, W. T., Bierlich, K. C., Linsky, J. M., Calambokidis, J., Johnston, D. W., Goldbogen, J. A., & Friedlaender, A. S. (2023). Minke whale feeding rate limitations suggest constraints on the minimum body size for engulfment filtration feeding. *Nature Ecology & Evolution*, *7*, 535-546.
DOI: 10.1038/s41559-023-01993-2

> "We're working to define the upper and lower limits of life at physiological extremes. This is important given the pace of environmental change so we can determine which species are at greatest risk and how we manage populations into the future."
>
> **Jeremy Goldbogen,** associate professor of Oceans

Researchers used instrumented tags to study the feeding activity of Antarctic minke whales.
IMAGE CREDIT: DUKE MARINE ROBOTICS AND REMOTE SENSING. THIS RESEARCH WAS CONDUCTED UNDER NATIONAL MARINE FISHERIES SERVICE PERMIT #2309

Moving communities to safety

As climate change drives sea level rise and more frequent flooding, many countries are considering an extreme and controversial strategy: relocation of communities.

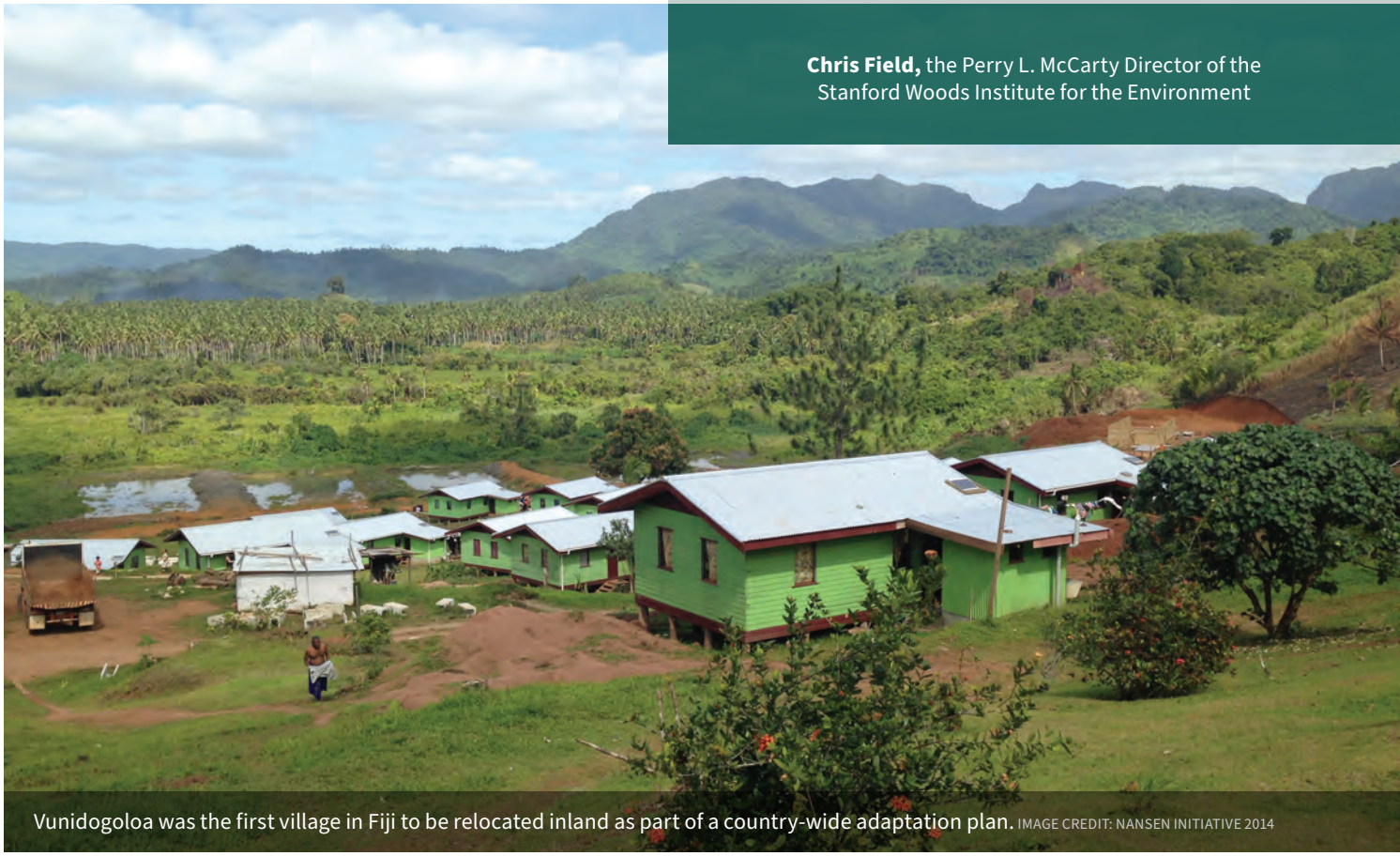
A Stanford analysis of 14 planned relocations around the world, published in *Nature Climate Change*, revealed a blueprint for positive outcomes. The authors found that community engagement matters: the more community members drive decisions about whether, where, and how to relocate, the more successful the outcomes.

Moving communities away from zones endangered by flooding risk in a planned and anticipatory way can prevent future forced displacement, but has been considered an option of last resort because of its potential to lead to unemployment, food insecurity, heritage loss, and other damages. The study highlighted how climate change adaptation is highly context-dependent, and that specific strategies for successful planned relocation will vary based on the size of the community, jurisdictional factors, and cultural dimensions.

Read more…

Bower, E. R., Badamikar, A., Wong-Parodi, G., & Field, C. B. (2023). Enabling pathways for sustainable livelihoods in planned relocation. *Nature Climate Change*, *13*, 919-926. DOI: 10.1038/s41558-023-01753-x

> “It would be great if people never had to move. But relocations will be necessary, and we should be doing everything we can to ensure that, when people need to move, it is to locations that are safer and lives that are better.”
>
> **Chris Field,** the Perry L. McCarty Director of the Stanford Woods Institute for the Environment



Vunidogoloa was the first village in Fiji to be relocated inland as part of a country-wide adaptation plan. IMAGE CREDIT: NANSEN INITIATIVE 2014

Increasing urban access to nature with a justice-focused framework

Access to nature – now considered a human right thanks to its benefits for physical and mental health and wellbeing – is not evenly distributed, especially for those living in urban areas. Stanford researchers at the Natural Capital Project began thinking about how people's access to nature would change during the pandemic lockdown in March 2020.

Synthesizing design thinking, principles of environmental justice, and relevant case studies, the team identified a framework that can guide interventions to improve urban access to nature, described in a paper published in *People & Nature*.

The paper provides both academics and practitioners, such as city planners, with concrete guidance for integrating justice into both theoretical and applied work on improving access to nature. In addition to a framework, they included three case studies that model this approach in their efforts to improve nature access for Latinx/Chicanx/Hispanic, Indigenous, and incarcerated communities.

These approaches may be useful to policymakers in achieving both equity and biodiversity conservation goals through efforts like the U.S. Justice40 Initiative and California's 30x30 Initiative.

Read more…

Langhans, K. E., Echeverri, A., Daws, S. C., Moss, S. N., Anderson, C. B., Chaplin-Kramer, R., Hendershot, J. N., Liu, L., Mandle, L., Nguyen, O., Ou, S. X., Remme, R. P., Schmitt, R. J. P., Vogl, A., & Daily, G. C. (2023). Centering justice in conceptualizing and improving access to urban nature. *People & Nature*, 5(3), 897-910. DOI: 10.1002/pan3.10470

> "Environmental and social issues are intimately intertwined, and if we want to address the biodiversity and climate crises, we need holistic solutions that bring people along and center justice."
>
> **Kelley Langhans**, PhD '23 in Biology at the Natural Capital Project

Latino Outdoors, a Latinx outdoor excursion group, seeks to create community in the outdoors, as well as highlight Latinx, Chicanx, and Hispanic voices and their ways of relating to nature. IMAGE COURTESY OF MODESTA MCGRATH-MARTINEZ

Decision-support tool offers new method to analyze flood adaptation measures

In response to catastrophic 2022 flooding from the Indus River in Pakistan, researchers from the Natural Capital Project and the Carnegie Institution for Science collaborated on a new way to quickly calculate the approximate depths of flooding in different areas and number of people affected. Their analysis, published in *Environmental Research Letters*, offered insights into potential options and costs for incorporating adaptation to future floods into rebuilding efforts, showing that climate adaptation measures like these could have helped most, if not all, of the people affected by the flood.

The team brought together satellite data on where flooding occurred, which are readily available in nearly real-time; ground elevation data combined with simplified hydrologic principles (e.g., water flows downhill) to reveal depth; and demographic data on population density, housing, and other infrastructure. This produced their "Floodplain Adaptation Strategies Testbed" or "FAST," a rapid overview of flood severity and exposure that shows how deep the flooding was in different locations, and how many people were exposed to those depths.

Without analyses like FAST, reconstruction funding can often be directed to those with the greatest influence, who perhaps need the least support. The FAST tool could offer a more data-driven and equitable approach to prioritization.

Read more…

Schmitt, R. J. P., Virgüez, E., Ashfaq, S., & Caldeira, K. (2023). Move up or move over: mapping opportunities for climate adaptation in Pakistan's Indus plains. *Environmental Research Letters*, *18*(11), 114024. DOI: 10.1088/1748-9326/acfc59

> "Flood models are data-intensive, and you need specialized knowledge to run them. We need adaptation research that is easier to use and act on. FAST is a step toward that goal."
>
> **Rafael Schmitt,** lead scientist at the Natural Capital Project

Flooding in Gandakha City, Balochistan, Pakistan in August 2022. IMAGE CREDIT: KAFEEL AHMED / PEXELS

Diversified farms create habitat key to food security and biodiversity

In one of the longest-running studies of tropical wildlife populations in the world, Stanford researchers found that over 18 years, smaller farms with varying crop types — interspersed with patches or ribbons of forest — sustain many forest-dependent bird populations in Costa Rica, even as populations decline in forests. The findings were published in the *Proceedings of the National Academy of Sciences.*

While this research implies that diversified farming could be key for biodiversity, the relationship goes both ways: biodiversity is also key for food security. In this case, that means having a variety of birds feeding on insects and helping to pollinate crops. In addition, diversified farms are not necessarily yielding less food than intensive agriculture, overturning a long-held assumption.

It has become increasingly apparent around the world that while protected areas remain critical, they are too few and far between to provide the ecosystem services people and nature need to thrive. Working landscapes are crucial now for preserving biodiversity and its benefits. The study will help inform Costa Rican policymakers in understanding the benefits provided over time by different farming practices as they develop incentive programs.

Read more…

Hendershot, J. N., Echeverri, A., Frishkoff, L. O., Zook, J. R., Fukami, T., & Daily, G. C. (2023). Diversified farms bolster forest-bird populations despite ongoing declines in tropical forests. *Proceedings of the National Academy of Sciences, 120*(37), e2303937120. DOI: 10.1073/pnas.2303937120

The Costa Rican countryside showcases the interplay between farmlands and trees that serve as vital wildlife habitats in agricultural landscapes. Such landscapes underscore the importance of maintaining tree cover in farming areas, offering essential habitats for species outside of protected zones.
IMAGE CREDIT: NICK HENDERSHOT

> We believe the findings of our research are new to science, but in a sense, it merely confirms what Indigenous communities around the world have already known for a long time, which is that humans can and should have reciprocal relationships with the rest of the local ecological community they are part of.

Tadashi Fukami, professor of Biology and Earth System Science

A male Royal Flycatcher *(Onychorhynchus coronatus mexicanus)* flaunts its vibrant red and blue crest. This species exemplifies the diverse and unique birdlife of Costa Rica, underscoring the importance of preserving habitats to support such biodiversity. IMAGE CREDIT: NICK HENDERSHOT

Illegal market for water expands in Jordan

In Jordan, a shadow market for drinking water is booming. For every gallon of water that's pumped and trucked to consumers from the country's officially licensed wells, 10 gallons are sold illegally, according to Stanford-led research published in *Nature Sustainability*. The study revealed a massive and accelerating transfer of water from rapidly dwindling rural groundwater sources to residents and businesses in urban areas, where public water supplies are often unreliable and unequally distributed.

The study noted that growth of the tanker market is a "warning sign" of the declining capacity of public supply systems to meet the United Nations' goal of ensuring sustainable freshwater management and universal access to clean water and sanitation.

The research pointed to several complementary solutions, ranging from fixing deteriorating water pipes to desalinating seawater at large scale. The authors were surprised to find that simply closing illegal wells — an approach that has helped to curb excess groundwater pumping for agriculture — would do more harm than good by limiting water access. The analysis indicated a more effective policy would curtail licenses for tanker sales to businesses over time, while allowing sales to households to grow in proportion to the population.

Read more…

Klassert, C., Yoon, J., Sigel, K., Klauer, B., Talozi, S., Lachaut, T., Selby, P., Knox, S., Avisse, N., Tilmant, A., Harou, J. J., Mustafa, D., Medellín-Azuara, J., Bataineh, B., Zhang, H. Gawel, E., & Gorelick, S. M. (2023). Unexpected growth of an illegal water market. *Nature Sustainability, 6*, 1406-1417. DOI: 10.1038/s41893-023-01177-7

> "Without revenues accruing to the government from the vast quantity of unlicensed tanker supplies, significant funds remain unavailable to improve the nation's intermittent and inefficient supply system."
>
> **Steven Gorelick,** the Cyrus Fisher Tolman Professor of Earth System Science

A man pumps water into a tanker in northeastern Jordan. IMAGE CREDIT: GETTY IMAGES

Leveling the food industry playing field for alternative animal products

Meat and dairy industry lobbying has influenced government regulations and funding to stifle competition from alternative meat products with smaller climate and environmental impacts, according to a Stanford analysis. The paper, published in *One Earth*, compared major agricultural policies related to animal food product systems and alternative meat technologies in the U.S. and the European Union.

Livestock production is the agriculture sector's largest emitter of the potent greenhouse gas methane and the main direct cause of tropical deforestation. Numerous studies have demonstrated that dietary changes, especially a reduction in red meat consumption, hold great potential to reduce humanity's ecological footprint. However, Western-style meat-heavy diets are becoming more popular globally.

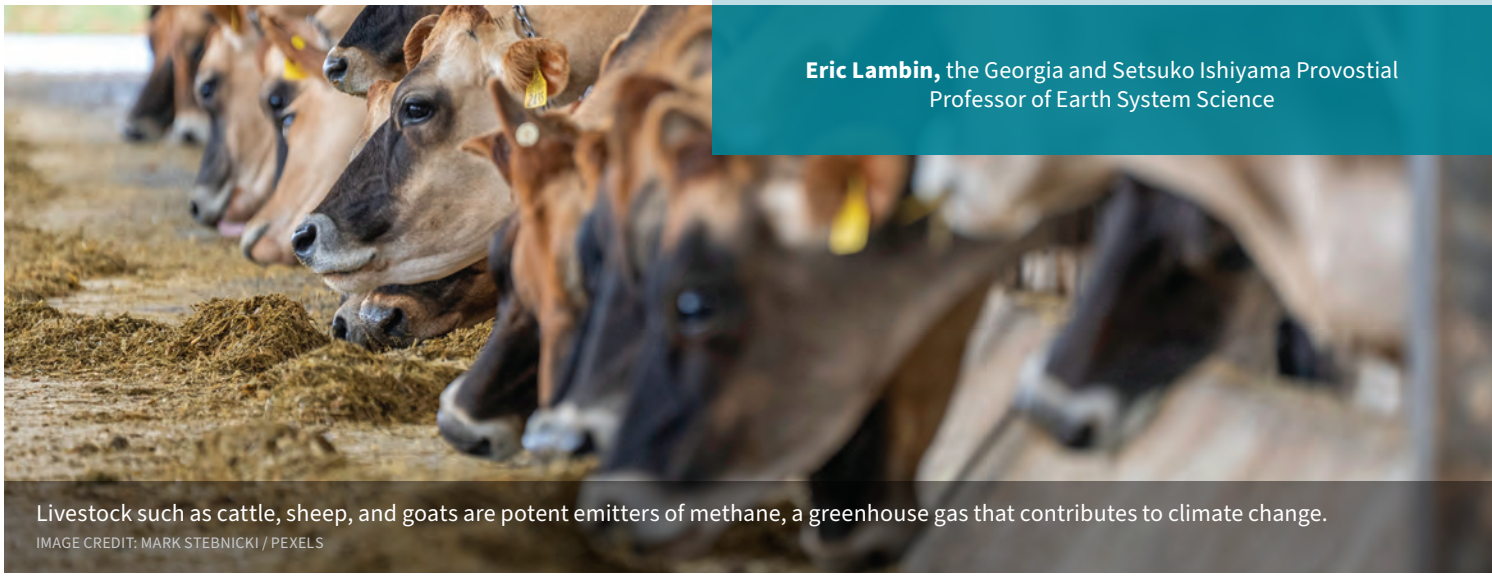
The researchers found that governments consistently devoted most of their agricultural funding to livestock and feed production systems, avoided highlighting food production sustainability dimensions in nutrition guidelines, and attempted to introduce regulatory hurdles to the commercialization of meat alternatives. Major U.S. meat and dairy companies actively lobbied against environmental issues and regulations to tip the scales in their favor.

To ensure a fair marketplace for alternative meat products, policymakers should craft legislation that ensures meat's price reflects its environmental costs, increases research on alternative meat and dairy products, and informs consumers on alternatives to meat via dietary guidelines, according to the researchers.

Read more…

Vallone, S., & Lambin, E. F. (2023). Public policies and vested interests preserve the animal farming status quo at the expense of animal product analogs. *One Earth*, *6*(9), 1213–1226.
DOI: 0.1016/j.oneear.2023.07.013

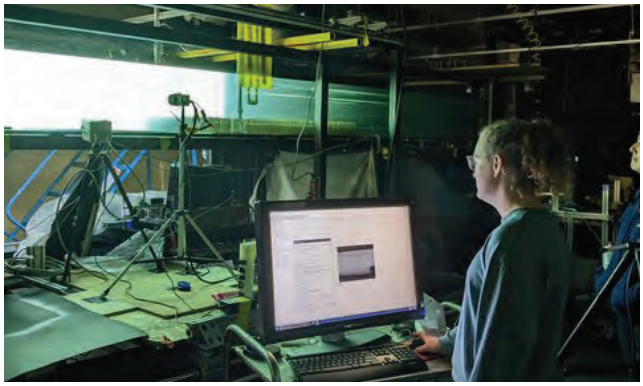
> "It's clear that powerful vested interests have exerted political influence to maintain the animal-farming system status quo. A significant policy shift is required to reduce the food system impact on climate, land use, and biodiversity."
>
> **Eric Lambin,** the Georgia and Setsuko Ishiyama Provostial Professor of Earth System Science



Livestock such as cattle, sheep, and goats are potent emitters of methane, a greenhouse gas that contributes to climate change.
IMAGE CREDIT: MARK STEBNICKI / PEXELS

How the physics of a forest canopy can help predict wildfire spread

Understanding the physics of wind currents above forest canopies may help forecast the flight paths of burning embers and firebrands responsible for most home destruction during wildfires. To do this, Stanford fluid mechanics researchers connected their previous work on the physics of ocean currents to wildfire plumes.



While running an experiment using hot water flowing over dowels to simulate hot air flowing over a forest canopy, civil and environmental engineering PhD students Hayoon Chung manages the plume and particle release, while Laura Clark Sunberg (foreground) monitors the camera and data and image collection. IMAGE CREDIT: JENNY HAMILTON

The team discovered that the length and overall size of a forest canopy strongly influences the behavior of fire plumes – the hot, turbulent air that rushes up and out from a flame and can launch embers into flight. Their findings, published in the American Physical Society's *Physical Review Fluids*, shows that a forest canopy creates its own wind currents and turbulence, and that wildfire behavior can shift depending on a canopy's dimensions.

The scholars are building upon this research to help inform efforts to mitigate "spot fires" ignited by flying embers, an increasingly common route of wildfire spread responsible for many, if not most, of the fires that end up destroying homes during wildfires.

Their experiments focused on the canopy structure because, unlike wind and terrain, wildfire managers have some control over it through fuel management practices, such as prescribed burns or cutting down trees.

Read more…

Chung, H., & Koseff, J. R. (2023). Interaction of a buoyant plume with a turbulent canopy mixing layer. *Physical Review Fluids*, *8*(6), 064501. DOI: 10.1103/PhysRevFluids.8.064501

A wildfire burns near Legget, California in 2014. IMAGE CREDIT: NATHAN PHOTO / GETTY IMAGES

> “The data we are generating is critically important for any kind of predictive scheme that wildfire managers might want to develop.”
>
> **Jeffrey Koseff,** the William Alden Campbell and Martha Campbell Professor of Civil and Environmental Engineering

When firefighters cut down strips of trees, it may unintentionally affect wind flow and turbulence in a way that exacerbates the spread of burning embers. IMAGE CREDIT GETTY IMAGES

Wildfires leave a trail of toxic metal in soil

Wildfires can transform a natural element in soils into a cancer-causing, airborne metal known as hexavalent chromium, according to Stanford research published in *Nature Communications*.

Stanford researchers focused on four ecological preserves in California's North Coast Range where wildfires have recently burned across soils formed from naturally chromium-rich rocks, such as serpentinite. They collected soil samples to measure hexavalent chromium and gathered data on local fire severity, soil types, geology, and ecosystem types.

"Our study suggests far more attention should be paid to wildfire-modified chromium, and we presume additional metals as well, to more thoroughly characterize the overall threats wildfires pose to human health," said study lead author Alandra Lopez, a postdoctoral scholar in Earth System Science at the Stanford Doerr School of Sustainability.

In terms of exposure risks, fire-induced toxic chromium would initially be encountered by first responders and people living near the conflagrations. Even after fires end, local communities downwind could be exposed because strong winds may carry fine particles of chromium-laced soil. Future research into wildfire-related toxic chromium exposure could help inform public health guidance and illuminate additional exposure risks as rainfall washes toxins into waterways or groundwater.

Read more…

Lopez, A. M, Pacheco, J. L., & Fendorf, S. (2023). Metal toxin threat in wildland fires determined by geology and fire severity. *Nature Communications*, *14*, 8007. DOI: 10.1038/s41467-023-43101-9

> "In the complex mixture of gasses and particles that wildfires spew out as smoke and leave behind as dust, heavy metals such as chromium have largely been overlooked."
>
> **Scott Fendorf,** the Terry Huffington Professor of Earth System Science

High temperatures and prolonged wildfire exposure catalyze the transformation of naturally occurring chromium in soils into toxic hexavalent chromium. IMAGE CREDIT: YELANTSEVV / GETTY IMAGES

Alandra Lopez, a postdoctoral scholar in Earth System Science, prepares dust samplers at McLaughlin Natural Reserve in July 2021, the year following the LNU Lightning Complex fire. IMAGE CREDIT: SCOTT FENDORF

Valuing prescribed fire

A study by researchers at Stanford and Columbia universities revealed that low-intensity burning, such as controlled or prescribed fires, managed wildfires, and tribal cultural burning, can provide a 60% reduction in risk of catastrophic wildfire in mixed conifer forests for up to six years. The findings, published in *Science Advances*, are some of the first to rigorously quantify the value of low-intensity fire.

For millennia, Indigenous people allowed wildfires to burn, and intentionally applied fire to the land for reasons ranging from ceremony to subsistence. As a result, pre-colonial forests across California contained less fuel for hungry flames and were better able to retain moisture — keys to fire and drought resilience.

The authors measured the protective effect of low-intensity fires using 20 years of satellite monitoring data across more than 100,000 square kilometers of California forests. With statistical and machine learning techniques, they assembled a synthetic landscape of unburned areas closely resembling the burned landscapes' attributes. This approach allowed them to assess how burned landscapes might have evolved had they not burned in that same year – and compare these counterfactuals to their actual evolution throughout time.

To be effective, wildland fuel treatments, including prescribed burning, have to be ongoing rather than a one-time intervention for forests, according to the researchers. The risk mitigation benefit of low-intensity burning will depend heavily on careful selection and targeting of the intervention to provide maximum protection for people, communities, and ecosystems.

Read more…

Wu, X., Sverdrup, E., Mastrandrea, M. D., Wara, M. W., & Wager, S. (2023). Low-intensity fires mitigate the risk of high-intensity wildfires in California's forests. *Science Advances*, *9*(45).
DOI: 10.1126/sciadv.adi4123

> "Beneficial fire is not without its own risks — but what our study shows is just how large and long-lasting the benefits are of this crucial risk reduction strategy."
>
> **Michael Wara,** director of the Climate and Energy Policy Program at the Stanford Woods Institute for the Environment

A wildland firefighter uses a drip torch to ignite dry prairie grass as part of a prescribed fire. IMAGE CREDIT: BANKS PHOTOS / GETTY IMAGES

Sierra Nevada snowpack confounds Central Valley groundwater readings

Billions of tons of snow atop the Sierra Nevada Mountains cause parts of the Central Valley, just west of the range, to sink — muddling groundwater assessments that confuse the sinking as a sign of depleted aquifers. A Stanford study, published in *Geophysical Review Letters*, showed how heaped-up snow and ice in the Sierra during California's wet season depresses the valley floor by up to an inch, accounting for the majority of the detected elevation change in 60% of the valley.

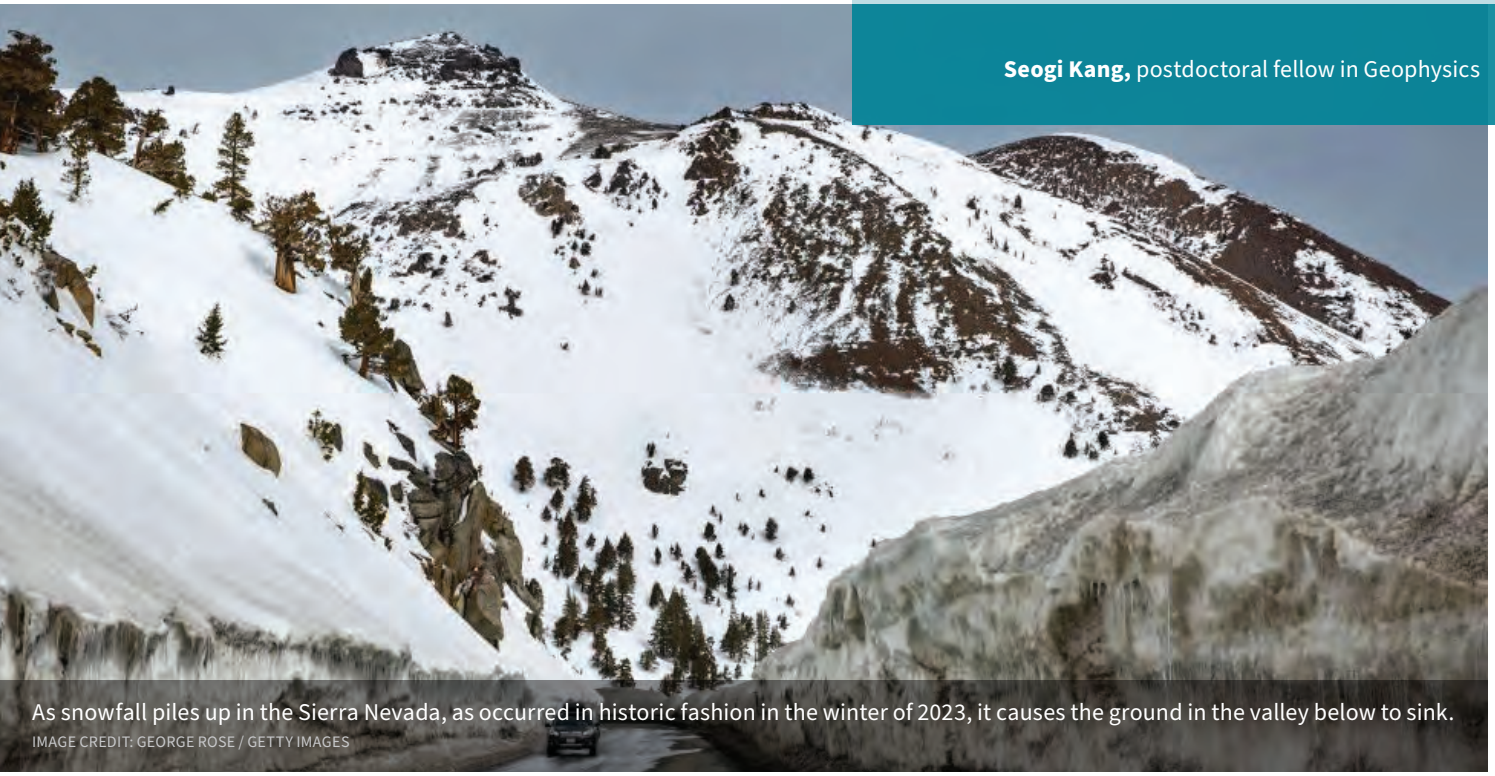
Although scientists have long suspected that snow and ice in nearby mountains could throw off groundwater assessments tied to elevation changes, they lacked a way to quantify the effect. This failure to properly account for the effect of snowpack loading often led groundwater managers to underestimate water levels.

The Stanford researchers filled in major data gaps in the current groundwater monitoring regime to best support and inform groundwater management decisions, from where and when to cap pumping to how best to allocate new water delivery infrastructure.

Read more…

Kang, S., & Knight, R. (2023). Isolating the poroelastic response of the groundwater system in Insar data from the Central Valley of California. *Geophysical Research Letters*, *50*(9), e2023GL103222.
DOI: 10.1029/2023gl103222

> "We've shown for the first time how to disentangle, decouple, and ultimately isolate the two effects of elevation changes due to groundwater levels and snowpack loading."
>
> **Seogi Kang,** postdoctoral fellow in Geophysics



As snowfall piles up in the Sierra Nevada, as occurred in historic fashion in the winter of 2023, it causes the ground in the valley below to sink.
IMAGE CREDIT: GEORGE ROSE / GETTY IMAGES

Artificial intelligence predicts Earth likely to cross critical climate thresholds even if emissions decline

Global warming is on track to hit 1.5 degrees Celsius above pre-industrial levels in the early 2030s, regardless of positive or negative changes in greenhouse gas emissions, according to a Stanford study published in *Proceedings of the National Academy of Sciences*. Researchers estimated this new "time to threshold" with an artificial intelligence (AI) model that uses global temperature observations to predict climate change.

The AI predicted that there is a one-in-two chance that Earth will become 2 degrees Celsius hotter on average compared to pre-industrial times by the middle of the century, and a more than four-in-five chance of reaching that threshold by 2060.

Countries pledged to keep global warming "well below" 2 degrees Celsius in accordance with the 2015 Paris Agreement. However, the world is already 1.1 degrees Celsius warmer on average than it was before the popularization of fossil fuel combustion in the 1800s. Because of this excessive increase in global temperatures, we are surpassing climate thresholds — or tipping points — such as melting of large polar ice sheets or massive forest die-offs. These adverse impacts are expected to escalate if Earth continues to surmount climate thresholds. However, the researchers wrote that it remains possible to bend the odds away from more extreme climate change by quickly reducing the amount of carbon dioxide, methane, and other greenhouse gasses being added to the atmosphere.

Read more…

Diffenbaugh, N. S., & Barnes, E. A. (2023). Data-driven predictions of the time remaining until critical global warming thresholds are reached. *Proceedings of the National Academy of Sciences*, *120*(6), e2207183120. DOI: 10.1073/pnas.2207183120

> "This was really the 'acid test' to see if the AI could predict the timing that we know has occurred. We were pretty skeptical that this method would work until we saw that result. The fact that the AI has such high accuracy increases my confidence in its predictions of future warming."
>
> **Noah Diffenbaugh,** the Kara J Foundation Professor of Earth System Science

The world is already 1.1 degrees Celsius hotter on average than it was before fossil fuel combustion began in the 1800s. More extreme rainfall and flooding are among the litany of impacts from that warming. IMAGE CREDIT: LISA MAREE WILLIAMS / STRINGER / GETTY IMAGES

Cooking on gas stoves emits benzene

A chemical linked to higher risk of leukemia and other blood cell cancers creeps into millions of homes whenever residents light their gas stoves. A Stanford-led analysis found that a single gas cooktop burner on high or a gas oven set to 350 degrees Fahrenheit can raise indoor levels of the carcinogen benzene above those in secondhand tobacco smoke.

Benzene drifts throughout a home and lingers for hours in home air, according to the paper published in *Environmental Science & Technology*. They also found residential range hoods are not always effective at reducing concentrations of benzene and other pollutants, even when stove hoods vent outdoors.

The new paper is the first to analyze benzene emissions when a stove or oven is in use. Previous studies focused on leaks from stoves when they are off, and did not directly measure resulting benzene concentrations. Research has also shown that gas-burning stoves have a substantial climate impact and expose users to other pollutants that can trigger respiratory diseases.

Beyond ensuring proper ventilation, the researchers suggested low-cost approaches to reducing exposure to pollutants from gas stoves, including using induction cooktops and electric kitchenware; and taking advantage of state, local, and federal rebates and tax credits to replace gas appliances.

Read more…

Kashtan, Y. S., Nicholson, M., Finnegan, C., Ouyang, Z., Lebel, E. D., Michanowicz, D. R., Shonkoff, S. B. C., & Jackson, R. B. (2023). Gas and propane combustion from stoves emits benzene and increases indoor air pollution. *Environmental Science & Technology*, *57*(26), 9653-9663. DOI: 10.1021/acs.est.2c09289

> "Benzene forms in flames and other high-temperature environments, such as the flares found in oil fields and refineries. We now know that benzene also forms in the flames of gas stoves in our homes."
>
> **Rob Jackson,** the Michelle and Kevin Douglas Provostial Professor of Earth System Science

Metta Nicholson, a PhD student in the Emmett Interdisciplinary Program in Environment and Resources, runs a benzene emissions test at a home, boiling only water to prevent readings of benzene that can be released from fatty foods. IMAGE CREDIT: ROB JACKSON

Stanford Environment and Sustainability Special Reports

Stanford scholars co-authored six special reports in 2023, covering urban agriculture, sustainable infrastructure, water treatment technology, and wildfire resilience. For a searchable listing of published special reports and research briefs, visit: woods.stanford.edu/research/publications

Contributing to a federal white paper, a team of Stanford researchers explored the possibility of using plastic waste in infrastructure. They analyzed a California road project that used plastic bottles in asphalt.

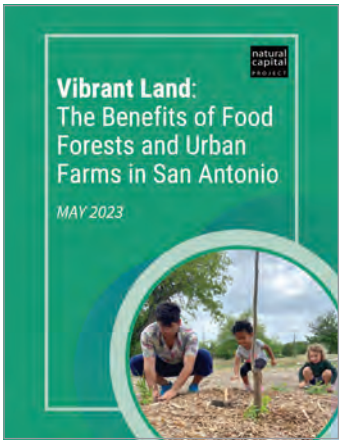
IMAGE CREDIT: GETTY IMAGES

Vibrant land: The benefits of food forests and urban farms in San Antonio

The Natural Capital Project

A collaboration among the Natural Capital Project, the Food Policy Council of San Antonio, and three San Antonio city departments, this special report modeled the benefits of converting publicly owned land to food forests and urban farms. It estimated food production as well as additional benefits of urban agriculture: urban cooling, carbon storage, flood retention, and green space. The report provided recommendations and guidance for how San Antonio can effectively target investments in food forests and urban farms to develop environmentally friendly and equitable urban agriculture expansion.

Read more…



Recycled plastics in infrastructure: Current practices, understanding, and opportunities

National Academies of Sciences, Engineering and Medicine (NASEM)

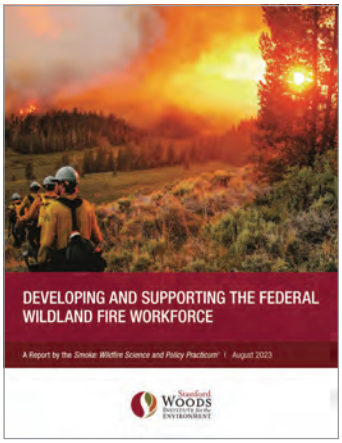
Upcycled plastic waste is a promising material for reuse in sustainable buildings and roads. Authored by Stanford engineers Michael Lepech and Zhiye Li, this report evaluated the current status, challenges, and needs of recycling plastics in a circular economy, and examined the long-term durability and environmental costs of doing so for use in infrastructure. NASEM published the white paper as an appendix to its report to Congress, the U.S. Department of Transportation, and the U.S. Environmental Protection Agency, and may use it as the basis of recommendations to policymakers.

Read more…

Developing and supporting the federal wildland fire workforce

Climate and Energy Policy Program

Despite rapidly growing wildfire size, season length, and pressure on essential frontline workers, national support for wildland firefighting resources has lagged in recent years. The U.S. Senate Committee on the Budget invited Climate and Energy Policy Program Director Michael Wara to brief legislators on the risks and ways to prepare for increasing fire in the American West. A request by Senator Ron Wyden (D-Oregon) during the hearing led to the publication of this Stanford white paper describing actions that Congress can take to support a strong, resilience-focused wildland firefighting workforce.

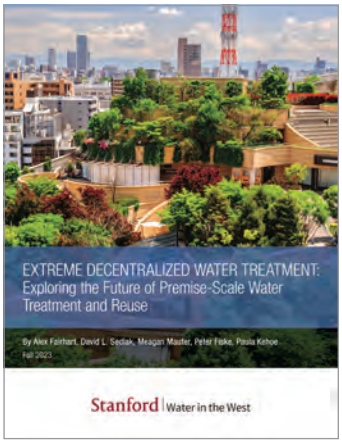


Read more…

Extreme decentralized water treatment: Exploring the future of premise-scale water treatment and reuse

Water in the West

Recent technology innovations, policy changes, and market shifts are accelerating deployment of scaled-down water treatment solutions, such as onsite reuse, but the market is still in its infancy. Scholars from Water in the West and the National Alliance for Water Innovation organized a workshop with academics, water technology innovators, public health experts, environmental regulators, and venture capitalists to explore the future of extreme decentralization and its role in interfacing with and supporting traditional centralized systems. The resulting white paper outlined key insights and questions about effectively combining new and existing water treatment technology, and highlighted barriers to progress.



Read more…

In pursuit of clean air: Laying the groundwork for public school resilience to wildfire smoke

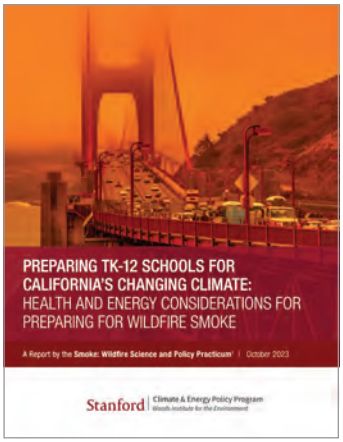
Climate and Energy Policy Program

Preparing TK-12 schools for California's changing climate: Health and energy considerations for preparing for wildfire smoke

Climate and Energy Policy Program

The Bipartisan Infrastructure Law and economic relief bills made tens of billions of dollars available for schools nationwide to modernize their infrastructure. Researchers from the Climate and Energy Policy Program authored these two reports to serve as an informational toolkit for decision-makers looking to use these resources to mitigate the impact of wildfire smoke on schoolchildren. One report laid the groundwork for a coordinated research project across school districts, including the installation of air quality monitors and standalone purifiers in TK-12 schools. The other report provided preliminary recommendations for statewide policy changes in California, encouraging upgrades to protect against wildfire smoke while helping the state achieve its energy efficiency and decarbonization goals.

Read more…



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Rebecca Miller, PhD '21, and Josheena Naggea, PhD '22, set out to understand differences in the emergency response to oil spills in places where they each have a personal connection: Pointe d'Esny, Mauritius, and Huntington Beach, California. Their findings, featured on page 18, highlight the policy and environmental justice implications of their observed differences. IMAGE CREDIT: NICK UT / GETTY IMAGES

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