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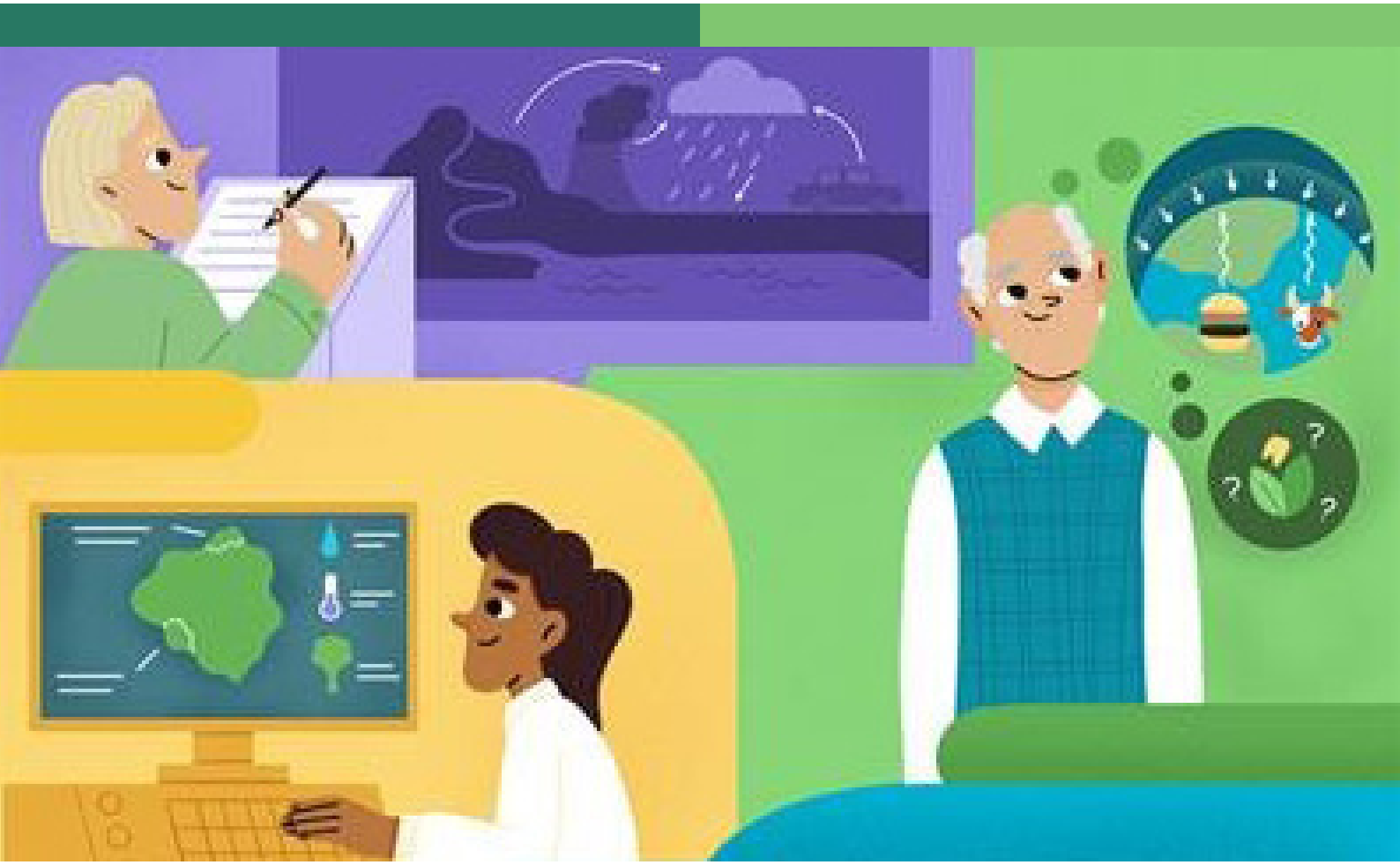
Frontiers Planet Prize 2023 – Mobilizing Breakthrough Solutions for a Healthy Planet

Edited by
Idan Segev and Jc Burgelman



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Frontiers Planet Prize 2023 – Mobilizing Breakthrough Solutions for a Healthy Planet

Collection editors
Idan Segev — Hebrew University of Jerusalem, Israel
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Human Health

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About this collection

The ecological balance required for living healthy lives is changing on planet Earth, and we humans play a critical role in it. Scientists from around the world have mapped nine areas that are critical for the Earth's ecological stability as described by Professor Johan Rockström and Owen Gaffney in their book Breaking Boundaries. These are called the nine planetary boundaries and crossing these boundaries might lead to irreversible environmental change that threatens living healthy lives on a healthy planet.

Now it is the time to act, with hope and determination. Many scientists around the world are already working on finding solutions to prevent our planet from crossing these boundaries. They are developing practical scientific solutions and technological breakthroughs to mobilize widespread global action at the scale needed to preserve our planetary health. In 2023, the Frontiers Planet Prize gave its first awards to celebrate and support the work of researchers who are leading the most impactful solutions with measurable effects to help humanity save our ecosystem.

Dive into this Collection to hear from these champions from all over the world who were acknowledged in the first edition of the Frontiers Planet Prize in 2023. They will tell you about their latest breakthrough research covering everything from forest regrowth to dietary changes of people, the concept of blue carbon, and much more. Let them inspire and motivate you to help save our planet!

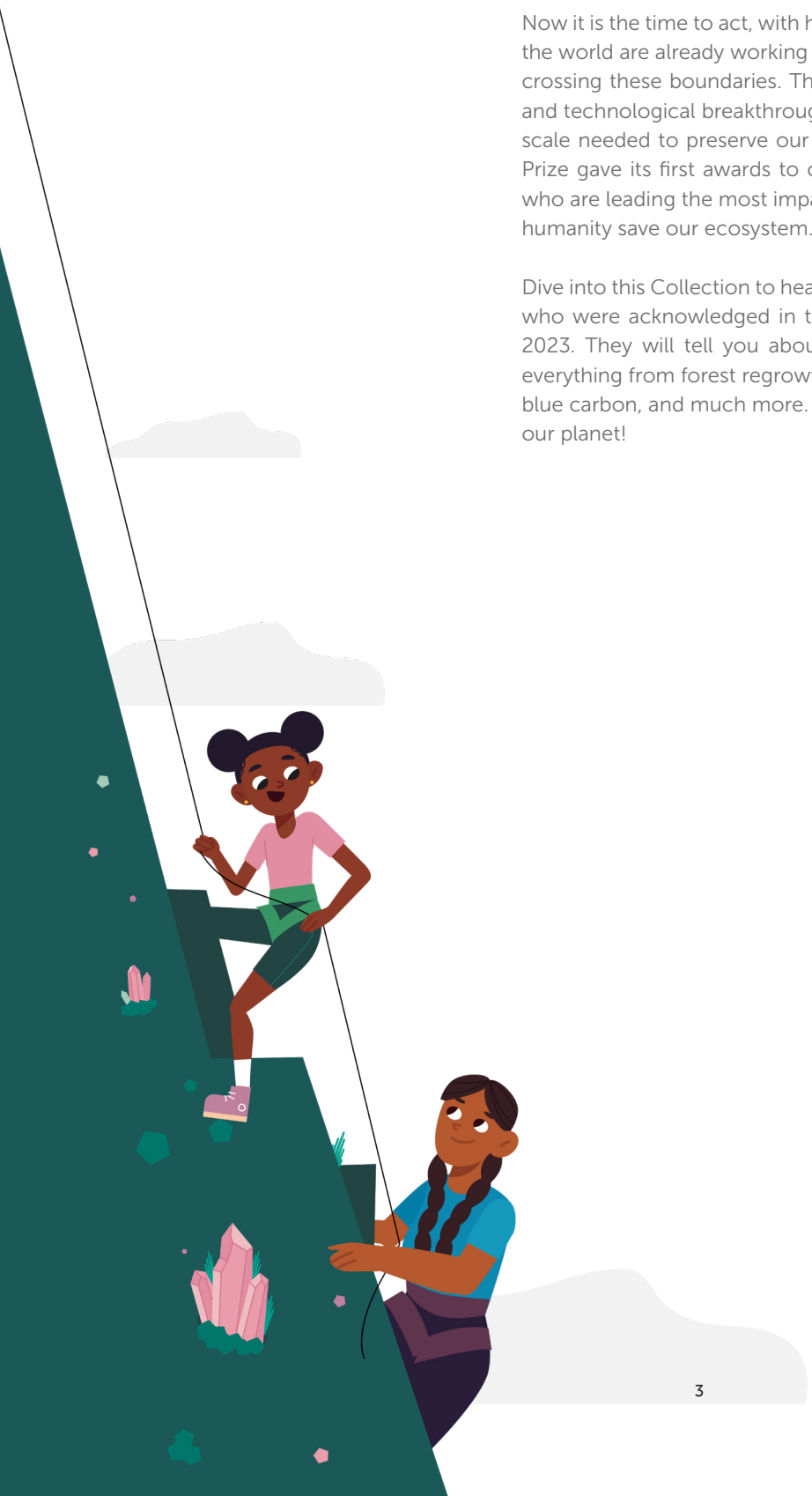

Table of contents

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BIODIVERSITY
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HOW THE SPREAD OF YOUNG CORAL CAN HELP SAVE CORAL REEFS

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YOUNG REVIEWERS:

JEWEL
AGE: 11

LAUREL
AGE: 12

Coral reefs around the world are getting sick (and sometimes dying) at alarming rates due to climate change. Certain coral reefs (low-risk reefs) are predicted to be less at risk of getting sick than others. We wondered whether low-risk reefs can help save other reefs. We found that this is possible—through the movement of young coral from healthy reefs to damaged or dying reefs. We found that coral reefs worldwide are connected through the spread of young coral, forming 604 reef networks. Some networks are very large, but most are very small. If only the low-risk coral reefs survive, many of these networks will be preserved, which will help the overall survival of coral reefs into the future. However, young coral from these low-risk reefs do not reach *all* reefs worldwide, so it is important to find and protect reefs that are good at sending young coral to rescue the rest of the world's reefs.

DEGRADED REEFS MAY BE SAVED BY YOUNG CORAL

Coral reefs are made up of many types of living creatures including fish, seaweed, urchins and turtles but all of those creatures live on reefs because of the coral, which provides them with homes and food. Coral organisms themselves rely on tiny algae that live inside them for food, while these tiny algae receive a home. When the ocean water becomes too warm, coral organisms and the algae that live inside them get stressed, and sometimes the algae are forced to leave their coral homes. When this happens, the coral turns white, which is called **coral bleaching**. If the coral organism is separated from its algae for too long, the coral will die. If this happens to many coral organisms on a reef, the reef itself will degrade. Researchers predict that 70–99% of reefs worldwide will have degraded due to bleaching by 2100 [1]. However, some reefs are in areas of the ocean that have not yet heated up as much as others and are not predicted to heat up as much in the future. These reefs are at low risk of degrading in the future [1, 2]. One group of researchers gave every reef around the world a score based on how likely it is to be degraded by **climate change** (e.g., by bleaching or by storms) [2]. Reefs with a high score are unlikely to degrade because of climate change, so we will call them low-risk reefs for the rest of this article.

Adult coral are stuck to the ocean floor and cannot move, but they produce young coral that are released into the ocean and are carried by ocean currents until they mature and settle on the ocean floor. If they settle where the conditions are just right for them to grow, they will mature into adult coral. If there is a strong enough ocean current between two reefs, young coral from a low-risk reef may be carried to a less healthy reef, possibly saving it from degradation (Figure 1A). In this way, reefs are connected by ocean currents into **reef networks**, made up of all the reefs that can send or receive young coral to/from each other. Reefs in the same reef network may be able to rescue each other.

WHICH REEFS ARE IN WHICH REEF NETWORKS?

We determined which reefs are connected within the same reef networks by calculating how likely it is that many young coral will be carried by ocean currents from any one reef to any other reef. To calculate this, researchers from around the world used a **computer model** to simulate the movement of young coral among reefs [3]. They then used these movement data to calculate the number of times young coral moved to and from particular reefs between 2003 and 2011. We only included the connections between reefs that young coral traveled along often (based on data collected by other researchers [4]) to determine which reefs were and were not connected into reef networks. This became our present-day young

CORAL REEF

A coastal ocean ecosystem in the tropics dominated by coral, which provide homes and food for a huge variety of fish, invertebrates, and other organisms.

CORAL BLEACHING

When coral become stressed due to increased ocean temperatures or pollution, they lose the algae inside them and turn white. If coral stay bleached for a long time, they die.

CLIMATE CHANGE

Around the world, climates are becoming more variable and more extreme than before (hotter or colder) owing to human development causing increasing levels of greenhouse gases in the atmosphere.

REEF NETWORK

The set of reefs that send or receive young coral to/from each other often enough that they may be able to rescue each other.

COMPUTER MODEL

A set of instructions that a computer uses to simulate how a real-world ecosystem or collection of ecosystems (like a reef network) may behave under changing conditions.

Figure 1

(A) One large reef network, including an example of a reef (reef X) that can send young coral to another reef (reef Y) and potentially rescue reef Y if reef Y is degraded. **(B)** If reef X or reef Y is degraded, a large reef network could become multiple, smaller networks. This shows us that losing certain reefs (like reef X) breaks apart more of the reef network than losing other reefs (like reef Y) does.

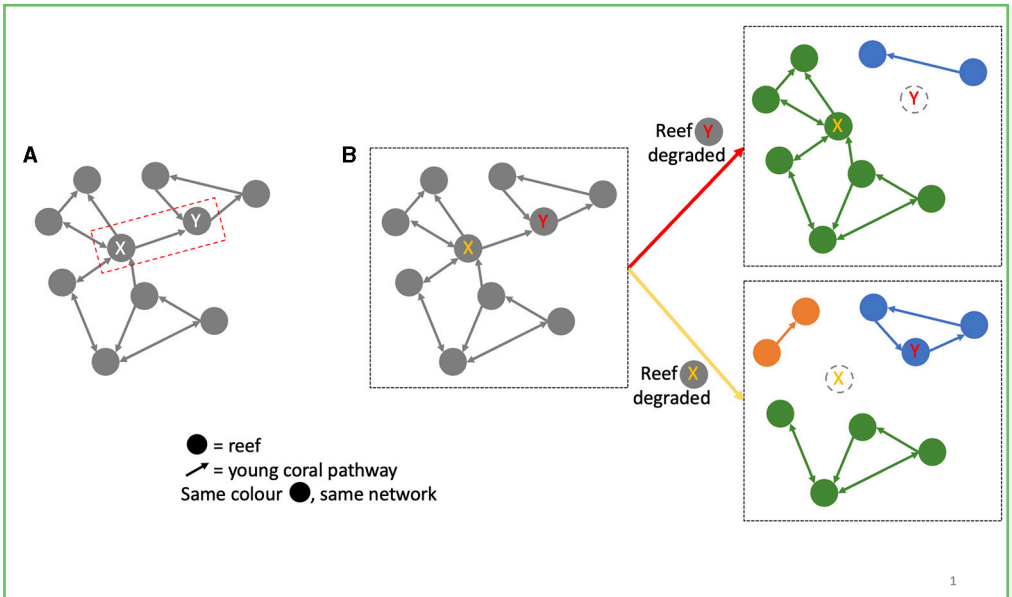

Figure 1

coral movement computer model. Over the 12,292 reefs of the world, we found 604 reef networks, with six particularly large ones (>290 reefs) and many small ones (Figure 2).

Figure 2

Every dot on the world map represents a reef. The colors of the dots indicate which reef network each reef is in. Each reef network was assigned a unique color. This map shows that most present-day reefs are either in very large reef networks or in very small reef networks. The six largest networks are circled and numbered 1–6, in size order.

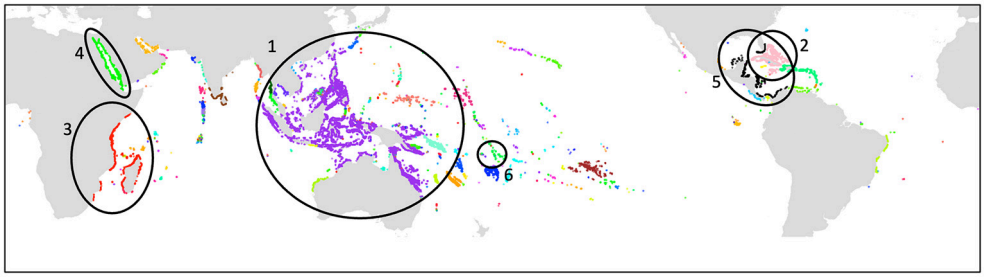

Figure 2

WHAT IF ONLY THE LOW-RISK REEFS SURVIVE?

To determine which reefs are low-risk, we re-calculated the reef scores (from [2]) to only account for how likely a reef is to be degraded by climate-related factors, such as bleaching and dangerous storms. A reef was designated as low-risk if it scored in the top 29% of our re-calculated reef scores. We then determined which reefs were in which reef networks if only the low-risk reefs survived. We found that many of the reef networks remained fairly large. This tells us that the reefs that degraded in our model must have been in either small reef networks or that the reefs themselves were not essential to keeping the surviving networks together (that is, they must have been like reef Y in Figure 1B). This is good news for coral reefs, as it tells us that, if only the low-risk reefs survive into the future, they may be able to send

young coral to each other, increasing the chances that those reefs will survive.

CAN LOW-RISK REEFS RESCUE ALL THE WORLD'S CORAL?

If only the low-risk reefs survive into the future, how many of the world's reefs will they be able to send young coral to? We used our computer model to answer this question by calculating which reefs young coral could land on if they spread from the low-risk reefs. This meant that we calculated all the reefs (the "rescued reefs") that the low-risk reefs could send young coral to, even those that can only receive young coral via formerly degraded reefs (Figure 3A). Unfortunately, we found that over half of present-day coral reefs could not be rescued by the low-risk reefs ("degraded reefs" in Figure 3B). This is because most of the low-risk coral reefs are in the same big reef networks and are unable to rescue the many reefs outside of those networks.

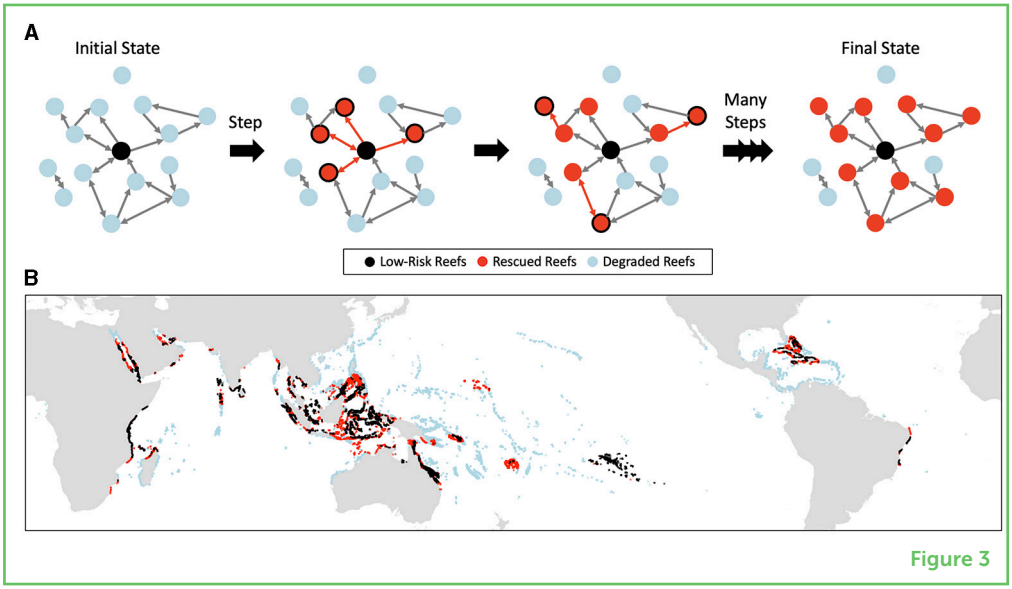

Figure 3

Figure 3

(A) In our computer model, each low-risk reef first rescues the reefs it sends young coral to. In the next step, those newly rescued reefs (red dots with black borders) rescue the reefs *they* are connected to. We ran the computer model through 50 steps like this, until all the reefs that could receive young corals from low-risk reefs had been rescued. **(B)** The dots represent all present-day reefs, either low-risk, rescued, or degraded (see legend). This map shows that <50% of present-day reefs can be rescued by young coral spreading from low-risk reefs.

WHAT DID WE LEARN AND WHY IS IT IMPORTANT?

In this study, we learned that most reefs are either in very big or very small reef networks and that these networks will mostly survive if only the low-risk reefs survive. Knowing which reefs are connected to which other reefs and whether those reef networks will survive is really important, as it helps us determine how to protect coral reefs worldwide—it tells us which reefs should be managed together, and which should not. Our results also stress the importance of finding and protecting at-risk reefs that are good sources of young coral for degraded reefs (see Figure 3B), since we now know that the degraded reefs cannot be rescued by low-risk reefs. We are currently working

hard to figure out where these good source reefs are, so that we can protect them from future harm. Climate change is degrading reefs around the world at frightening rates, so any information that tells us which reefs can help us restore the world's coral reefs will help us avoid riskier and more expensive methods for saving reefs. Overall, these results will help save worldwide coral reef networks by guiding reef-preservation efforts around the world.

ACKNOWLEDGMENTS

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ORIGINAL SOURCE ARTICLE

Greiner, A., Andrello, M., Darling, E., Krkošek, M., and Fortin, M. J. 2022. Limited spatial rescue potential for coral reefs lost to future climate warming. *Global Ecol. Biogeogr.* 31:2245–58. doi: 10.1111/geb.13571

REFERENCES

1. Van Hooidonk, R., Maynard, J., Tamelander, J., Gove, J., Ahmadia, G., Raymundo, L., et al. 2016. Local-scale projections of coral reef futures and implications of the Paris Agreement. *Sci. Rep.* 6:1–8. doi: 10.1038/srep39666
2. Beyer, H. L., Kennedy, E. V., Beger, M., Chen, C. A., Cinner, J. E., Darling, E. S., et al. 2018. Risk-sensitive planning for conserving coral reefs under rapid climate change. *Conserv. Lett.* 11:e12587. doi: 10.1111/conl.12587
3. Wood, S., Paris, C. B., Ridgwell, A., and Hendy, E. J. 2014. Modelling dispersal and connectivity of broadcast spawning corals at the global scale. *Global Ecol. Biogeogr.* 23, 1–11. doi: 10.1111/geb.12101
4. Manel, S., Loiseau, N., Andrello, M., Fietz, K., Goñi, R., Forcada, A., et al. 2019. Long-distance benefits of marine reserves: myth or reality? *Trends Ecol. Evol.* 34:342–54. doi: 10.1016/j.tree.2019.01.002

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

JEWEL, AGE: 11
I live in the southeast of the United States. I love dancing, taekwondo and pretty much any physical activities. I have two cats and one turtle. I love animals and going to the zoo and I am thinking about becoming a marine biologist. My favorite subjects include math, science, and spelling. I love reading fantasy and WW2 novels.

LAUREL, AGE: 12
Hello, I like mechanical engineering and Lego. I like to making things and tinkering. I like learning science.

AUTHORS

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Ariel is a quantitative ecologist who uses mathematics and computer models to determine the best methods for saving human, animal, and plant populations around the world. She develops these models in collaboration with organizations in charge of protecting these populations and works with them to communicate solutions to the public. She is also passionate about increasing equity, diversity, and inclusion in science and beyond. She received a Ph.D. in biology from the University of Toronto in 2023 and is currently a postdoctoral fellow at Pennsylvania State University and the University of Oxford. *ariel.greiner@mail.utoronto.ca

MARCO ANDRELLO

Marco is a researcher at the Italian National Research Council, where he carries out research in population biology and biological conservation. He mainly works on understanding animal and plant movement processes, tracking the youngest stages of marine fishes through computer simulations. He also studies how populations of animals and plants can persist in their natural habitats by adapting to new environmental conditions thanks to evolution. His recent work has focused on marine protected areas, which are areas of the sea where human activities like fishing and tourism are strictly regulated to allow fish and other ocean animals to live better in absence of human disturbance.

MARTIN KRKOŠEK

Martin holds a Canadian Research Chair of Marine Epidemiology and is a professor at the University of Toronto. His research aims to understand what causes animal populations to change in size and how to prevent them from becoming too small, to save the animals and the humans that rely on them. To study this, he measures animal population sizes in the wild and uses those data to develop computer models to simulate how they may be affected by human industry and climate change. He is particularly interested in studying how fish populations may be impacted by aquaculture, fisheries, and diseases.

MARIE-JOSÉE FORTIN

Marie-Josée is a University Professor in the Department of Ecology and Evolutionary Biology. She is a Fellow of the Royal Society of Canada and holds a Canada Research Chair in Spatial Ecology. She is recognized internationally as a leader in spatial ecology. Her research aims to understand how landscapes becoming more disconnected might affect the survival and distribution of animals and plants. From those results, she designs conservation strategies to maximize the survival of all animals and plants, which she then proposes to governments and organizations around the world.

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EARTH SCIENCES
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BLUE CARBON ECOSYSTEMS: OCEAN HEROES IN THE FIGHT AGAINST CLIMATE CHANGE

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YOUNG REVIEWERS:

JUDE
AGE: 15

MILES
AGE: 13

Our planet is facing a critical challenge: climate change. This is caused by human activities that release carbon dioxide and other greenhouse gases into Earth's atmosphere. As temperatures rise and weather becomes more extreme, scientists are searching for solutions. Blue carbon ecosystems could be part of the answer! These ecosystems include mangrove forests, tidal marshes, and seagrass meadows—ocean and coastal ecosystems that capture and store carbon, keeping it out of the atmosphere. In our research, we found that these ecosystems cover a huge area of Earth's surface, up

to the size of Mexico. They store a whopping 30 billion tons of carbon, which is huge! If we stop destroying blue carbon ecosystems and restore the ones we have lost, it could balance out 3% of the greenhouse gases we put into the atmosphere. Pretty important, right! Overall, blue carbon ecosystems are nature's heroes in the fight against climate change.

OCEANS AS A LIFE SOURCE

Did you know that the oceans cover 71% of our planet's surface? That makes them the largest ecosystem in the world. They are also a life-support for the Earth and are critical to human survival. Oceans provide things that humans depend on, such as food and energy, and they are home to millions (if not billions) of sea creatures. Oceans also help regulate Earth's climate. They absorb excess heat from the atmosphere, and they influence when and where it rains. The famous marine conservationist Dr Sylvia Earle once said: "*If you think the ocean isn't important, imagine Earth without it. Mars comes to mind. No ocean, no life support system*".

BLUE CARBON ECOSYSTEMS

BLUE CARBON

Carbon that is captured and stored by coasts and oceans; in particular, by coastal vegetation such as seagrasses, mangroves, and tidal marshes.

ECOSYSTEM

An area where organisms (like animals, plants, bugs) interact with the physical environment (like water, dirt, rocks, nutrients, and sunlight).

Coastal habitats, like mangrove forests, seagrasses, and tidal marshes, are three marine ecosystems that play a big role in regulating Earth's climate (Figure 1) [1]. Seagrasses are underwater flowering plants, like the grass you see on land, but living in the sea. Mangrove forests are made up of trees with clusters of tangled roots that grow in saltwater, and tidal marshes are made up of plants like herbs, grasses, and shrubs, growing on land where the tides flow in and out. Scientists have found that these ecosystems, sometimes called **blue carbon ecosystems** ("blue" as they are near the oceans, which look blue) are very good at capturing carbon dioxide (CO_2) from the atmosphere and trapping it. This is important because when CO_2 builds up in Earth's atmosphere it can trap heat from the sun and cause weird and dangerous weather, similar to what people all around the world have been witnessing in recent years.

How do blue carbon ecosystems capture and store CO_2? Think back to your lessons on photosynthesis and how trees and other plants capture and store carbon. Just like plants on land, mangroves, seagrasses, and marsh plants capture CO_2 from the atmosphere and store it in their leaves and roots. But blue carbon ecosystems have a secret weapon for storing carbon longer than most plants on land can—they bury it in the ground and trap it there for thousands of years. This is because their roots are in wet, muddy soil, where there is very little oxygen and decomposition is very slow. This long-term

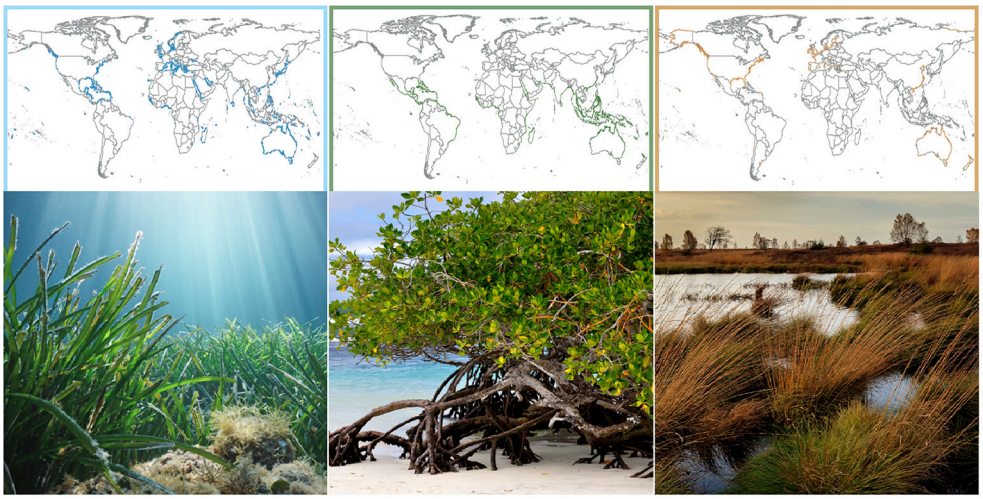

Figure 1

The bottom of each panel shows what blue carbon ecosystems (seagrass meadows, mangrove forests and tidal marshes) look like, and the top part shows where they can be found in the world. Tidal marshes are sometimes called saltmarshes.

carbon storage is important for keeping CO_2 out of the atmosphere and reducing climate change (Figure 2).

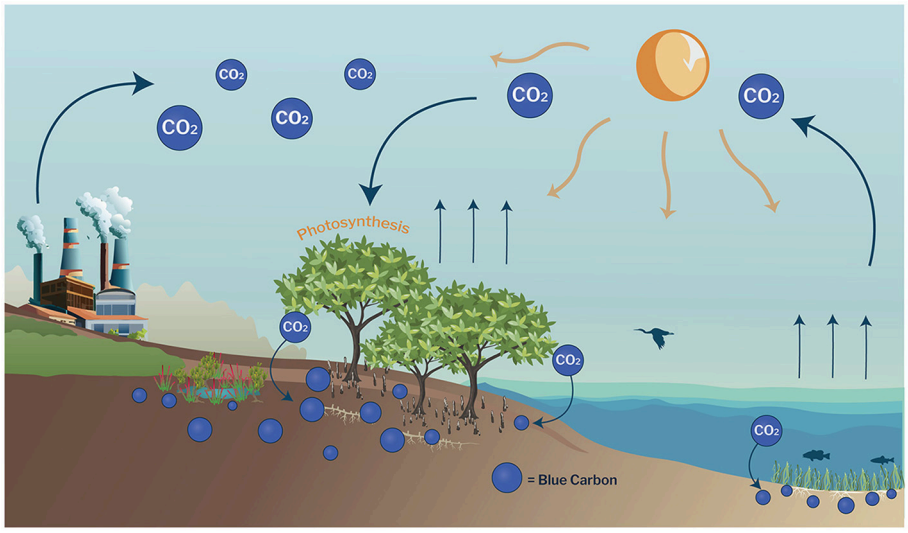

Figure 2

This is how blue carbon ecosystems capture and store carbon dioxide (CO_2). CO_2 produced by human activities enters the atmosphere and contributes to global warming. Through photosynthesis, plants use some of the CO_2 (along with energy from sunlight) to grow. When the plants in blue carbon ecosystems (seagrasses, mangroves, and tidal marshes) take up CO_2, they capture and store it e.g., in leaves, roots, and soil. This way, they help to store carbon deep in the ground. Blue carbon ecosystems are great at storing carbon because wetland soil is thick, muddy, and low in oxygen. Under these conditions, it takes a long time for plant materials to break down, so the carbon is locked away for thousands of years.

BEYOND CLIMATE CHANGE

Blue carbon ecosystems offer more than just their remarkable carbon capture and storage functions. Blue carbon ecosystems provide valuable services to humans and the environment (Figure 3). They act as natural shields that protect coastlines and coastal cities from the fury of big waves and storms, and they help clean pollutants from the water. These special ecosystems are also home to many marine animals, including animals that people like to catch and eat, such as fish and crabs. They are also nature's storehouses, supplying

communities with important resources including wood, medicine, and recreational opportunities. Who does not enjoy a day outdoors marveling at all the birds, fish, interesting plants, and other incredible creatures that call blue carbon ecosystems home?

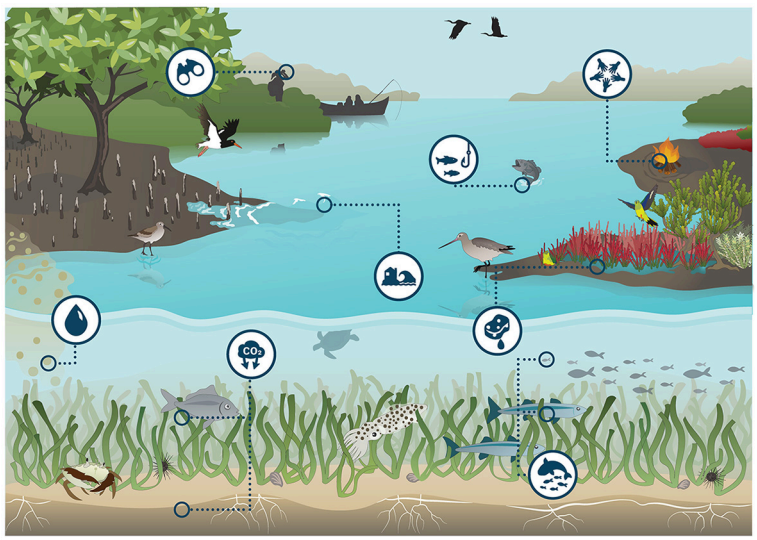

Figure 3

Figure 3

Blue carbon ecosystems have many benefits in addition to storing carbon. They are great places for recreation (birdwatching, fishing, and learning), and are important to the culture and survival of many Indigenous communities, who have a deep connection to the lands and waters (hunting, fishing, gathering resources, holding cultural ceremonies). These ecosystems are great places for animals to live, which can feed people and support jobs, and to raise their young, acting as nurseries for young animals. The plants in blue carbon ecosystems filter pollutants from the water, making it cleaner and healthier for other plants and wildlife. They also act like sponges, soaking up flood waters and reducing floods, while the plants and roots help to protect coastlines from erosion.

THE BIG QUESTIONS

Our team of scientists has been studying blue carbon ecosystems for over a decade. We have been trying to answer some big, important questions about how tidal marshes, mangrove forests, and seagrasses help control Earth's climate [2]. One of our first discoveries was that good information on exactly where these ecosystems are found or how they have changed over time did not exist. We needed to find out this important information because it tells us how many of these valuable blue carbon ecosystems have disappeared (Spoiler alert: more than 50% of our blue carbon ecosystems have already vanished [3]). We also needed to know how much carbon is being trapped by blue carbon ecosystems, and what happens to all the carbon trapped in the ground when these ecosystems are destroyed. After all, if that carbon gets released back into the atmosphere as CO_2, it will make climate change worse—yikes! Finally, we wanted to know whether bringing back the blue carbon ecosystems we have lost, a process called **restoration**, can help us battle climate change in a big way.

RESTORATION

Actions taken to repair natural ecosystems that have suffered from human or natural impacts. For example, replanting mangrove trees after they were chopped down for firewood.

In general, we can combine all of our research questions into one big question: What can we achieve if we use blue carbon as a natural solution to Earth's changing climate [4]?

WHAT WE DISCOVERED

Through our research, we made a number of fascinating discoveries about blue carbon ecosystems. First, we found that when we add

up all of Earth's blue carbon ecosystems, they cover an area that is somewhere between 0.36 million km^2 (about the size of Japan) and 1.85 million km^2 (about the size of Mexico). That is a super wide range, and it illustrates just how uncertain we are about how much of Earth's surface is made up of blue carbon ecosystems. The biggest problem is that we do not have good tools for finding seagrass ecosystems. We can use satellites to search for mangrove forests and tidal marshes from space, because their plants mostly grow above the water's surface, making them easy for satellites to spot. However, seagrasses grow beneath the water, where satellites cannot see them so well.

Using our estimates of the size of blue carbon ecosystems, as well as other data like the amount and condition of plants and soil in them, we can use advanced calculations to estimate how much blue carbon exists on Earth. We found that the total amount of carbon stored in mangroves, seagrasses, and tidal marshes ranges from 10–30 billion tons. That is a really large number! To put it into perspective, an adult blue whale weighs about 140 tons. That means all the Earth's blue carbon ecosystems together are storing the equivalent weight of more than 100 million blue whales!

Finally, we found that protecting the blue carbon ecosystems that remain and restoring the ones that have been lost are powerful tools in the fight against climate change. By protecting current blue carbon ecosystems from human-caused destruction, we can prevent 300 million tons of CO_2 from escaping to the atmosphere each year. To put that in perspective, that is the same amount of CO_2 emitted into the atmosphere yearly by the country of Australia. Additionally, if we restore the blue carbon ecosystems that have been lost, we can trap an additional 840 million tons of CO_2 each year. If we take care of the blue carbon ecosystems that remain and work on restoring the ones that have been lost, it could balance out 3% of the **greenhouse gases** we put into the atmosphere! And do not forget that when blue carbon ecosystems trap carbon, it remains buried in those systems for thousands of years!

GREENHOUSE GAS (GHG)

Gases in Earth's atmosphere that trap heat from the sun. The most concerning greenhouse gases produced by humans are the ones causing global warming, which include carbon dioxide and methane.

TAKING ACTION TOGETHER

In conclusion, this article reveals the hidden heroes of our planet: blue carbon ecosystems. These incredible marine ecosystems play a vital role in fighting climate change by capturing CO_2 and keeping it safely stored underground for thousands of years. By protecting and restoring blue carbon ecosystems, communities can make a significant contribution to reducing climate change, safeguarding coastlines, and preserving the homes of millions of sea creatures. So, what can young people do to help blue carbon ecosystems thrive? Learning about these incredible environments and spreading awareness about their importance is a significant step—you can help

others to understand how critical these ecosystems are to our planet! Supporting conservation activities and being mindful of actions that might harm blue carbon ecosystems can also make a real impact. As future stewards of Earth, you hold the key to ensuring the health and survival of blue carbon ecosystems and, therefore, a healthier and safer planet for all living beings. Let us embark on this journey together and celebrate the wonders of nature's natural climate solutions!

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. Nellemann, C., Corcoran, E., Duarte, C. M., Valdes, L., Deyoung, C., Fonseca, L., et al. 2009. *Blue Carbon: A Rapid Response Assessment.* Grid-Arendal: United Nations Environment Programme, Arendal Norway.
2. Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., et al. 2019. The future of blue carbon science. *Nat. Commun*. 10:1–13. doi: 10.1038/s41467-019-11693-w
3. Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., Marbà, N. 2013. The role of Coastal Plant Communities for climate change mitigation and adaptation. *Nat. Clim. Change*. 3:961–8. doi: 10.1038/nclimate1970
4. Macreadie, P. I., Costa, M. D., Atwood, T. B., Friess, D. A., Kelleway, J. J., Kennedy, H., et al. 2021. Blue Carbon as a natural climate solution. *Nat. Rev. Earth Environ*. 2:826–39. doi: 10.1038/s43017-021-00224-1

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

JUDE, AGE: 15

I am a big fan of both dogs and cats, I have trained my cat to walk on a lead so we can go for walks together in my spare time. I also love music and spend a lot of time playing my guitar. I enjoy reading about biochemistry (especially plant related) and one day would like to study the subject at university.

MILES, AGE: 13

My name is Miles, and I live in California. I am a 7th-grade student, and I love science. I have a few pets at home and enjoy learning about all creatures, big, and small.

AUTHORS

PETER I. MACREADIE

Peter is a professor in marine science at Deakin University, Australia and leads the Blue Carbon Lab. A lot of his research focuses on understanding the impacts of global change on blue carbon ecosystems, such as mangroves, tidal marshes, and seagrass, and he is especially interested in creating novel research solutions to reduce the effects of climate change. He loves snorkeling with his three kids; Millicent, Henry, and Loretta. *p.macreadie@deakin.edu.au

MICHELI D. P. COSTA

Micheli is a marine biologist and senior research fellow at the Blue Carbon Lab, where she co-leads the Blue Carbon research team. Micheli's main interests are in marine ecology, where she calculates the numbers of living things in marine ecosystems, and coastal conservation, where she uses maps and modeling to better understand and protect blue carbon ecosystems. A lot of Micheli's research focuses on making smart decisions to help conserve blue carbon ecosystems and inform their management. As part of her work, she works closely with different people from universities, companies, and governments in Australia and internationally.

TRISHA B. ATWOOD

Trisha is a professor at Utah State University, USA and leads the Aquatic Ecology and Global Change Lab. Her research focuses across all aquatic ecosystems and her research looks at aquatic food webs and species interactions, the effects of global

change, and the role aquatic ecosystems can play in reducing the effects of climate change and conserving biodiversity. By focusing on these topics, her research has taken her all over the world, with studies in Hawaii, Canada, Costa Rica, and Australia, including the Great Barrier Reef.

DANIEL A. FRIESS

Dan is a coastal scientist at Tulane University, USA. His research focuses on blue carbon and ecosystem services in mangrove forests; threats to mangroves, such as deforestation and sea-level rise; and the use of blue carbon to promote mangrove conservation and restoration. His research includes modeling, collecting field data, and social science methods. As part of his research, he works closely with government and other groups, such as non-governmental organizations and companies, particularly in Southeast Asia.

JEFFREY J. KELLEWAY

Jeff is an environmental scientist at the University of Wollongong, Australia. Through his research, Jeff aims to better understand wetlands and their ecosystem function—that is, the roles they play within nature and the services they provide for humans. He is especially interested in the carbon-capture potential of blue carbon ecosystems, such as mangroves, saltmarshes, and supratidal forested wetlands. He aims to improve our understanding of blue carbon stocks in coastal wetlands, and their response to environmental change.

HILARY KENNEDY

Hilary is a marine scientist and professor in Chemical Oceanography at Bangor University, UK. She is interested in studying tiny particles called stable isotopes, which are like tags, to understand how things move in nature. She uses these tags to reconstruct and describe what the environment looked like a long time ago. Her research also focuses on the importance of seagrass meadows as coastal carbon sinks.

CATHERINE E. LOVELOCK

Catherine is a marine ecologist at the University of Queensland, Australia. Her research focusses on the influence of environmental change, including climate change, on the ecology of coastal and marine plant communities and on providing knowledge to better understand the conservation and restoration of these ecosystems now and in the future. She leads projects in Australia and internationally that focus on adapting to climate change, carbon capture, and restoring mangrove forests.

OSCAR SERRANO

Oscar is an environmental scientist at the Spanish National Research Council. His work focuses on the study of how humans impacted the landscape over the past centuries. His research contributes to understand how we can manage coastal ecosystems to mitigate climate change and to preserve the biodiversity of plants and animals living in our coasts. His research influences policy and management, and spans multiple countries and regions, including South America, Australia, and the Mediterranean.

TALLULAH DAVEY

Tallulah is a marine ecologist, based at the Blue Carbon Lab at Deakin University, Australia. She has a keen interest in conserving biodiversity and helping to reduce climate change using nature-based solutions. She is passionate about driving a positive change for the planet through research, science-communication and community engagement.

CARLOS M. DUARTE

Carlos is a marine researcher who, after nearly four decades documenting how human pressures impact marine life, wants to drive a science-based global effort to rebuild the abundance of marine life. He loves dogs and enjoys being away in the open sea, as well as reading, swimming, snorkeling, walking, and playing with his grandson Oliver.

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EARTH SCIENCES
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THE DOUBLE BENEFIT OF EATING FEWER ANIMAL PRODUCTS

***Paul Behrens*[1*], *Zhongxiao Sun*[2], *Laura Scherer*[1], *Arnold Tukker*[1], *Seth A. Spawn-Lee*[3], *Martin Bruckner*[4] and *Holly Gibbs*[3]**

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YOUNG REVIEWERS:

EDNA
AGE: 10

EVAN
AGE: 10

Scientists around the world have been studying how the food we eat impacts the planet. The demand for animal products, especially meat and milk, creates a lot of greenhouse gas emissions that heat our world. In rich countries, people often eat more animal-based foods than needed, which can be bad for people's health. So, eating more plants can reduce climate change while also making our bodies healthier. Eating more plants would also save huge areas of land, which is another benefit for the climate. This is because 75–80% of all the world's farming land is used to produce animal products. If we ate more plants, we could give this land back to nature or make new nature parks that would draw greenhouse gases out of the atmosphere. More natural land would also mean more plants and

animals could make their homes in these parks, and humans would have more places to play and explore.

REDUCING GREENHOUSE GASES BY EATING PLANT-BASED FOODS

Eating more plants and less meat is better for the planet. This is because raising animals for food releases up to 100 times more **greenhouse gases** into the air than growing plants does (Figure 1). There are three main ways that animal foods emit more greenhouse gases. First, some animals, like cows, produce the greenhouse gas methane when they digest their food, and methane is even more potent than carbon dioxide at trapping heat close to the Earth. Second, we must grow a lot of food to feed the animals, but we do not get that same amount of food back in the form of animal products. This is because when animals grow, they use a lot of energy just to stay alive, for example for breathing or digesting food. Third, animals and the foods we feed them take up a lot of space, so people must cut down forests to make more farmland. This is called **deforestation**, and the trees and the soil beneath them hold a lot of greenhouse gases that are released when the trees are cut down. By choosing more plant-based foods, we can help reduce the release of harmful greenhouse gases and save more trees from being cut down.

GREENHOUSE GASES

Any gas that increases the temperature of the planet when it is in the atmosphere.

DEFORESTATION

When large areas of forest are cleared and the trees cut down.

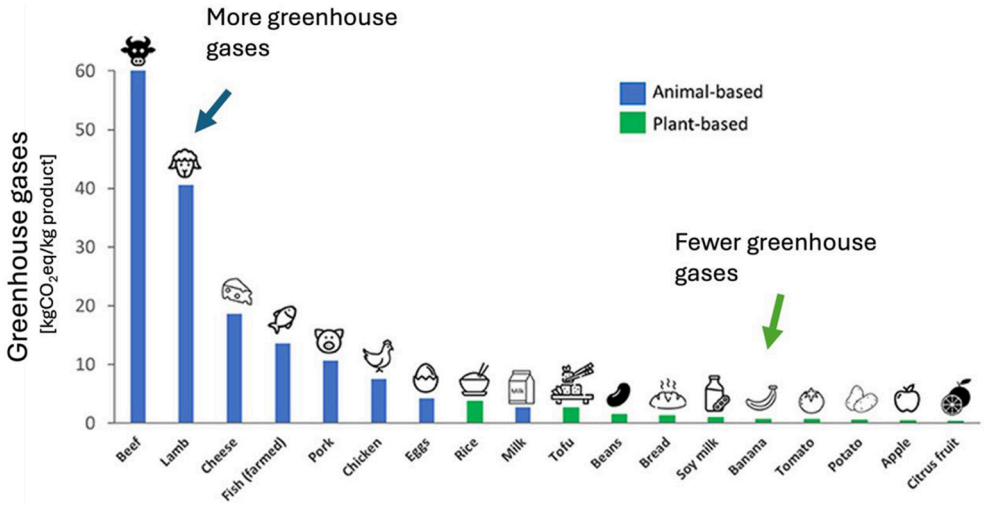

Figure 1

Greenhouse gas emission from different kinds of foods. Animal-based foods are shown in blue and plant-based foods are shown in green. The bars show a general value of greenhouse gases released per kg of food (data sourced from [1]; this figure was originally included in this Frontiers for Young Minds article).

RESTORING NATURE AND REDUCING CARBON IN THE ATMOSPHERE

Another exciting benefit of eating more plant-based foods is that we will need less land to grow all the food for the animals, as well as less land to keep them on. The extra land that is not used for

REVEGETATION

When areas that have been cleared of natural plants are replanted by humans or by nature.

PHOTOSYNTHESIS

The process that plants use to stay alive. They use energy from sunlight to turn carbon dioxide into food for themselves.

farming can be restored to its natural state, with trees and other plants (Figure 2). This process is called **revegetation**. Plants are super helpful for the environment because they soak up carbon dioxide from the air during **photosynthesis**. Photosynthesis is a process by which plants use sunlight, water, and carbon dioxide to create energy and grow. Carbon dioxide is one of the greenhouse gases that cause climate change, so when plants absorb it, they help to keep Earth's atmosphere in balance. By restoring land to its natural state, we can have more trees and other plants working together to remove carbon dioxide from the air, which is good for the planet.

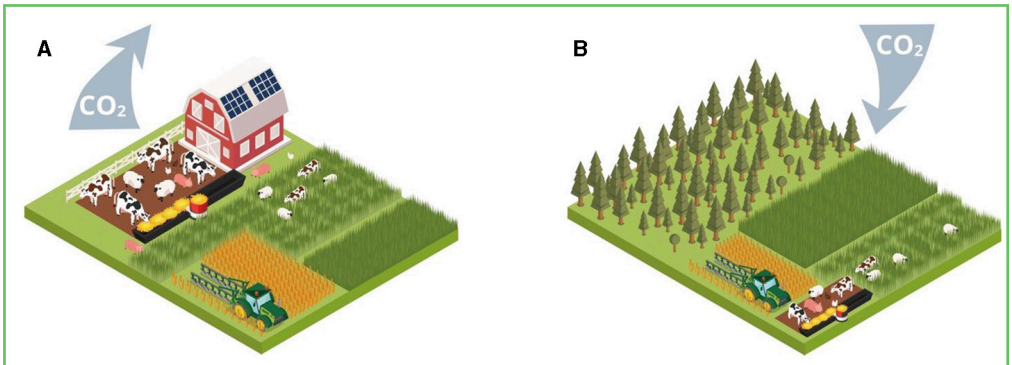

Figure 2

Here you can see two options for farming, using the same amount of land to feed the same number of people. **(A)** Current farming, with a lot of animal agriculture taking up a large amount of space. This contributes to carbon dioxide (CO_2) emissions, which contribute to climate change. **(B)** If people eat more plants and fewer animal-based foods, we can save a lot of land. Through revegetation, this land could be given back to nature so that the trees and other plants could help take up carbon dioxide from the air.

DOUBLE THE BENEFIT

Scientists came up with a special diet called the EAT-Lancet planetary health diet [2]. This diet is both healthy for us and healthy for the planet. People on this diet are advised to eat more foods like beans and lentils along with more nuts. They eat much less meat and cheese. We wondered what would happen if people in rich countries, like the U.S. and European countries, ate this diet, so we did research to find out. We discovered that, if everyone in these countries ate the EAT-Lancet planetary health diet, we could reduce greenhouse gas emissions from the foods we eat by a whopping 61% straight away [3]. This is because the diet avoids lots of animal foods, which release lots of greenhouse gases into the atmosphere. Releasing less greenhouse gases is the first important climate benefit of eating more plants.

Then we looked at the land-saving aspect of eating a plant-based diet. Because animal farming takes up so much space, shifting to eating plants would save lots of land that could be returned to its natural state. This means we could plant more trees and other plants, which help to soak up more carbon dioxide from the air. This is the second climate benefit from eating more plants rather than animal products. Revegetation can remove a huge amount of carbon dioxide from the air. If everyone in rich countries switched to the EAT-Lancet diet, we estimate that almost 100 billion tons of emissions could be extracted from the air over the long term. This is equal to around 14 years of

greenhouse gases currently produced around the world by farming. We would benefit most over the short term—around 20 years—as plants grow fast in the beginning and need lots of carbon dioxide from the atmosphere, but we would continue to benefit for over 100 years in many cases.

So, switching to a plant-based diet gives us a double climate benefit. The first part of the benefit comes from reducing greenhouse gas emissions. When we eat more plant-based foods, we produce fewer greenhouse gases from farming, which is good for the planet. The second part of the benefit comes from the carbon stored in nature through revegetation, and that is also good for the planet.

HELPING WILDLIFE THRIVE

There are many other environmental benefits to switching to a plant-based diet. When we choose to eat more plant-based foods and free up land that was used for farming, it is not only good for the climate but also fantastic for wildlife and for people, too. By restoring land to its natural state with trees, flowers, and grasses, we can create a safe and welcoming home for many kinds of animals, like birds and insects. Trees provide cozy homes for birds to build nests, and flowers attract busy bees and colorful butterflies. The more we plant, the more diverse and exciting the wildlife community becomes!

When we restore land to its natural state, we create amazing places where people can explore and have fun. This is really good for human health. Breathing in the fresh air among the trees makes us feel happy and relaxed. When we spend time outdoors, nature gives us the special gift of feeling healthy and strong.

WE CAN MAKE A BIG DIFFERENCE

Now you know that eating more plant-based foods gives us a double climate benefit—it reduces greenhouse gases produced from farming *and* it helps the planet by freeing up land for more trees and other plants to grow and soak up carbon dioxide. We can also create homes for wildlife, explore nature's playground, and stay healthy. Everyone can play a part in protecting our planet by eating fewer animal products and more plants. Remember, every little step counts, and together we can make a big difference. We can also encourage our friends, family, and communities to join in. By doing so, we can raise awareness about the importance of more eating plant-based foods and the positive impacts it can have on Earth's climate.

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REFERENCES

1. Poore, J., and Nemecek, T. 2018. Reducing food's environmental impacts through producers and consumers. *Science* 992:987–992. doi: 10.1126/science.aaq0216
2. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. et al. 2019. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. doi: 10.1016/S0140-6736(18)31788-4
3. Sun, Z., Scherer, L., Tukker, A., Spawn-Lee, S. A., Bruckner, M., Gibbs, H., et al. 2022. Dietary change in high-income nations alone can lead to substantial double climate dividend. *Nature Food.* 3:29–37 doi: 10.1038/s43016-021-00431-5

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AI TOOL STATEMENT: Before starting the article, the author used AI-assisted technologies to help explore age-appropriate terminology. No text generated by the tool appears in the article.

YOUNG REVIEWERS

EDNA, AGE: 10

Edna is a bright and curious 10-year-old. Her curiosity drives her to explore the wonders of nature and she constantly brainstorms about ways to make the world a better place. Edna is also passionate about helping others. Her sociable nature brings joy to everyone she encounters. In addition to her passion for baking, she also plays piano and enjoys gymnastics.

EVAN, AGE: 10

Evan has a passion for science from coding and designing robots, to learning about planets, volcanoes and flags, to understanding how viruses work (thanks to corona virus) and learning about different animals and their habitats. Evan is also a talented artist and loves to draw and design robots when he is not at school. He loves playing soccer with his teammates, brothers and dad. He enjoys his mother's home baked cakes and his favorite fruit is banana.

AUTHORS

PAUL BEHRENS

Paul Behrens is an environmental scientist from the United Kingdom. He studied physics and then wind energy after school. His current work is on food, energy, and climate change. He wrote a book to explore how climate change might change the world this century. He does not fly or eat animal foods so he can lower his impact on climate change and nature. *p.a.behrens@cml.leidenuniv.nl

ZHONGXIAO SUN

Zhongxiao Sun is an environmental scientist. He comes from China and works at China Agricultural University now. His work mainly focusses on the sustainable development of food systems. He has been trying to find dietary patterns that can benefit both human and planetary health.

LAURA SCHERER

Laura Scherer is an environmental scientist. She comes from Germany and lives in the Netherlands, where she works at Leiden University. She cares a lot about nature and the wellbeing of animals. In her research, she studies how people's activities affect both and tries to identify ways to do better. She does not eat animal products because they can harm nature and animals.

ARNOLD TUKKER

Arnold Tukker is from the Netherlands. He studied chemistry after high school. After this, he learned a lot of other things by doing research on the environment at a big research institute (TNO). He now works as a professor at Leiden University. He wants to understand how all people on Earth can live well, without polluting the Earth.

SETH A. SPAWN-LEE

Seth A. Spawn-Lee is a geographer who studies how farms, forests, and grasslands influence our climate. He maps where in the world plants are storing and absorbing carbon and how these patterns are changed by people. He is currently a researcher at The Nature Conservancy.

MARTIN BRUCKNER

Martin Bruckner is an environmental scientist trying to better understand the impact of our consumption on the global climate and distant ecosystems. He is currently a senior researcher at ETH Zurich.

HOLLY GIBBS

Holly Gibbs is a land systems scientist who works to understand how and why people use land around the world and what it means for the environment. She is a professor at the University of Wisconsin-Madison and is currently focused on finding solutions to deforestation in the Amazon and learning how private landowners can better support biodiversity, especially in the United States.

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BIODIVERSITY
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ADVENTURE IN THE TROPICS: JOINING FORCES TO HEAL THE BRAZILIAN ATLANTIC FOREST

***Markus Gastauer*[1]*, *Angela S. Miazaki*[2], *Paulo A. Tavares*[3], *Eric D. S. M. Lino*[4] *and Ricardo R. Rodrigues*[5]**

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YOUNG REVIEWERS:


EMANUELE
AGE: 15


GIORGIA
AGE: 15


SAMUELE
AGE: 15


SANTIAGO
AGE: 8

Imagine a magical place with tall trees and amazing animals—the tropical forest. But these forests are disappearing, and we want to make the world better by bringing back their beauty. Restoring forests also helps fight climate change and keeps plants and animals safe. However, we cannot do everything at once, so we need a plan. Planting trees costs money, but some scientists have found that certain forests can grow back all on their own! This is excellent news, but we must also be careful to help other very important places that cannot regrow alone. We need a plan to bring back the forests that can regrow on their own and those that cannot. Ideally, if everyone joins, the cost will be minimal. By working together with nature, we can make the forest healthy again!

This article was written with important contributions from Emmily Gastauer from the Colégio Militar de Belém.

FOREST RESTORATION—KNOWING WHERE TO START

Tropical forests are globally disappearing due to the expansion of pastures and farmlands. To make the world a better place, we need to stop this negative trend and bring back these beautiful ecosystems. Replacing forests is called **forest restoration**, and it helps us fight climate change and protect plants and animals [1]. Large areas of tropical forests need restoration, but we cannot do everything at once. So, how do we decide which areas to restore first?

Planting trees is expensive. Some researchers are searching for smarter ways to restore forests to reduce costs. One possibility is called **natural regeneration**. This means letting the forests grow back by themselves without planting new trees. Natural regeneration works better in places with more forests, while places without forests nearby may have a more challenging time growing back on their own. A recent study found that lots of damaged land in the Brazilian Atlantic Forest can grow back naturally. This can prevent tons of carbon dioxide from getting into the atmosphere, which helps to fight climate change, and create habitats for many plant and animal species [2].

While natural regeneration seems like a beautiful solution, we must be careful. If we just let all forests grow back naturally, we might miss some important areas. Many sensitive areas have suffered illegally from **deforestation** and may not regrow on their own, so we should immediately take care of these areas. Some of these areas can contain many rare species or fragile habitats such as springs, river banks, or mountaintops—some of which are protected by a Brazilian law called the **Brazilian Forest Code**.

When we work to restore forests, it is important to make sure restoration efforts are distributed fairly to everyone who owns the land (Figure 1). We do not want all the restoration work to go to those who might not have a strong say in politics, like small farmers who just grow food for their families. Everyone should help, and we do not want more vulnerable people to have too much work while the influential owners of large farms keep doing things the easy way. Further, when we bring back forests on farmland, the farmers might lose money because they can no longer use the land for farming. These are called opportunity costs and depend on what (and how much) farmers are growing on the land. So, adding it all up, forest restoration might end up costing more than just the money spent on planting trees!

To plan restoration efforts, we analyzed the possible consequences on both the environment and people, such as farmers, so we could prioritize which areas to restore in the Brazilian Atlantic Forest. To

TROPICAL FORESTS

Forests that are found in warm regions near the equator with dense vegetation and where many different animal species live.

FOREST RESTORATION

Planting trees and taking care of them to regrow a forest in an area impacted by deforestation or other damaging factors like wildfires.

NATURAL REGENERATION

The ability of forests to regrow on their own without human help. Regeneration is greater if extensive forests exist near a deforested area.

DEFORESTATION

Removal of trees from forests to build cities, roads, or farms, which causes harm to all kinds of species living in the forest and even the climate.

BRAZILIAN FOREST CODE

Laws in Brazil that protect ecologically sensitive areas, such as riverbanks, springs, lakes, steep slopes, and mountaintops, from logging and other impacts.

Figure 1

To choose which areas of the Brazilian Atlantic Forest to restore first, we must include all the unique places where animals and plants live while ensuring that everyone plays a fair role in helping to fix things.

Figure 1

do this, we analyzed the land in terms of its potential for natural regeneration while also considering types of land ownership.

POSSIBLE FOREST RESTORATION PLANS

BIODIVERSITY

It can refer to all the different species of plants, animals, fungi, and other organisms that live on Earth or in a particular area.

ECOLOGICALLY SENSITIVE AREAS

Natural areas that need extra care and protection because they are unique and home to rare species of plants and animals.

The Brazilian Atlantic Forest is a global **biodiversity** hotspot that spans 1,110 million hectares (a football pitch is roughly around 1 hectare in size) along the Brazilian coast. This forest has been highly damaged in many areas and requires ambitious restoration goals, with a target of restoring 15 million hectares of forest by 2050.

First, we wanted to know how the potential for natural regeneration is distributed among various land cover types, such as pastures, soy plantations, sugar cane crops, **ecologically sensitive areas**, and farm size. To do so, we combined a map showing the natural regeneration potential [2] with a map of land-cover types [3]. To include ecologically sensitive areas, we mapped all ecologically sensitive areas [4]. Finally, we added information about land ownership [5], which we classified into urban areas, public areas (including conserved lands and indigenous lands), private farms (separated into small, medium, and large farms), and areas without information.

We then created two plans to restore 15 million hectares of the Brazilian Atlantic Forest. Plan 1 focuses on places where trees can grow back by themselves, which is called natural regeneration. In Plan 2, we give nature a little hand by planting trees where they cannot grow back on their own. This helps bring back forests in all the ecologically sensitive areas. We also figured out which areas have the lowest overall restoration costs: the cost to plant trees plus money losses because restored areas can no longer be used for farming.

To restore an area with zero natural regeneration potential, we determined that it would cost US$ 5,482 per hectare, while an area with

100% natural regeneration potential costs nothing to regenerate. The amount of money that farmers no longer earn because their farming is interrupted was also estimated for each area based on the various types of farming, like cattle raising or soy farming [4].

WHERE FORESTS CAN REGROW—AND WHERE THEY CANNOT

We found more than 15 million hectares of ecologically sensitive areas protected by the Brazilian Forest Code in the Brazilian Atlantic Forest. The bad news is that about half of this area is seriously damaged and must be restored immediately. This is 10,000 times the area of New York City! Even worse, only 38% of this area can regrow by itself, while 62% will depend on tree planting to recover (Figure 2).

Figure 2

Comparison of two plans for forest restoration activities in the Brazilian Atlantic Forest (image designed using icons from Flaticon.com).

Figure 2

Furthermore, forests that can regrow by themselves are concentrated in a land-use category called Mosaic of Agriculture and Pastures that provide livelihoods for the most vulnerable Brazilian citizens. However, the area that can regrow by itself in huge plantations is ten times smaller! Another shocking result of our research was that small rural properties hold 2.5 times more areas that can regrow by themselves than large rural properties.

So, if we opt for Plan 1 and let nature recover 15 million hectares in the Brazilian Atlantic Forest, we would restore more places from the Mosaic of Agriculture and Pastures than places in large plantations. This would impact the farming activities of vulnerable people and small farm owners, while large farming companies would continue their business as usual.

PLAN 2 IS THE BETTER WAY

Plan 2 is a fantastic way to help nature. Plan 2 aims at planting new trees where needed to repair all the special places currently not covered by forests. This is good for nature and for people. The restored areas will be protected by the Brazilian Forest Code so that they will be safe from damage, including future deforestation. Further, Plan 2 helps to reforest regions that do not have many trees left, which brings animals and plants back to regions where they have been lost.

Plan 2 also makes sure that all landowners become involved, especially those with enormous properties. Although Plan 2 costs more to implement, it also saves money in the long term compared to just letting nature do its thing. This is so because the money spent on trees is less than when farmers stay a long time without farming. So, it is smarter to choose areas that are not so good for farming to help forests get better.

MOVING FORWARD

Saving forests is crucial for animals, plants, people, and the planet. In this article, we showed that a mix of letting nature grow back on its own and planting new trees is the best way to help the Brazilian Atlantic Forest. This helps the environment, spreads costs fairly, and does not cost too much. Now that we have a plan, it is time to put it into action! For that, we must figure out which trees to plant to help animals affected by deforestation. There are some challenges, like making sure we have enough seedlings for planting or checking how well the restoration is going. Currently, we are developing procedures to check how animals repopulate the regrowing forests. We also need to make sure everyone joins in. Teamwork is key and, by working together, we can make a big difference in saving our forests and helping all the plants and animals that call these forests home!

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. Brancalion, P. H. S., Niamir, A., Broadbent, W., Crouzeilles, R., Barros, F. S. M., Zambrano, A. M. A., et al. 2019. Global restoration opportunities in tropical rainforest landscapes. *Sci. Adv.* 5:eaav3223. doi: 10.1126/sciadv.aav3223
2. Crouzeilles, R., Beyer, H. L., Monteiro, L. M., Feltran-Barbieri, R., Pessôa, A. C. M., Barros, F. S. M., et al. 2020. Achieving cost-effective landscape-scale forest restoration through targeted natural regeneration. *Conserv. Lett.* 13:e12709. doi: 10.1111/conl.12709
3. Souza, C. M., Shimbo, J. Z., Rosa, M. R., Parente, L. L., Alencar, A. A., Rudorff, B. F. T., et al. 2020. Reconstructing three decades of land use and land cover changes in Brazilian biomes with landsat archive and earth engine. *Remote Sens.* 12:2735. doi: 10.3390/rs12172735
4. Gastauer, M., Miazaki, A. S., Crouzeilles, R., Tavares, P. A., Lino, E. D. S. M., and Rodrigues, R. R., 2021. Balancing natural forest regrowth and tree planting to ensure social fairness and compliance with environmental policies. *J. Appl. Ecol.* 58:2371–83. doi: 10.1111/1365-2664.14065
5. Freitas, F. L. M., Guidotti, V., Sparovek, G., and Hamamura, C., 2018. *Nota Técnica: Malha Fundiário do Brasil*. Available online at: https://www.imaflora.org/public/media/biblioteca/1594237486-imaflora_atlasagropecuario_documentacao_malhafundiaria_v1812.pdf (accessed February 18, 2021).

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YOUNG REVIEWERS

EMANUELE, AGE: 15

I am Emanuele and I am at the third year at the GB Grassi scientific high school in Latina. I found this work very interesting because the topic covered is very close to my heart. I think it is very important to involve more kids with these initiatives.

GIORGIA, AGE: 15

Hi, my name is Giorgia and I am in my third year of scientific high school. I have always had a passion for the world around us and I do not like the fact that it can be destroyed by human beings at all. I think we should all, even if in a small way, contribute to the recovery of our planet.

SAMUELE, AGE: 15

Hi, my name is Samuele. I live in Latina and I am in my 3rd year of scientific high school at the G.B. Grassi. I am very passionate about scientific subjects such as biology, math, and physics. I really liked this marine biology course and it made me discover many things that I did not know, including how to review a scientific paper.

SANTIAGO, AGE: 8

Hello, I am Santiago and I am 8 years old. I like to build 3D-puzzles, play video games, and play at the park with other kids. I love reading adventure books and drawing.

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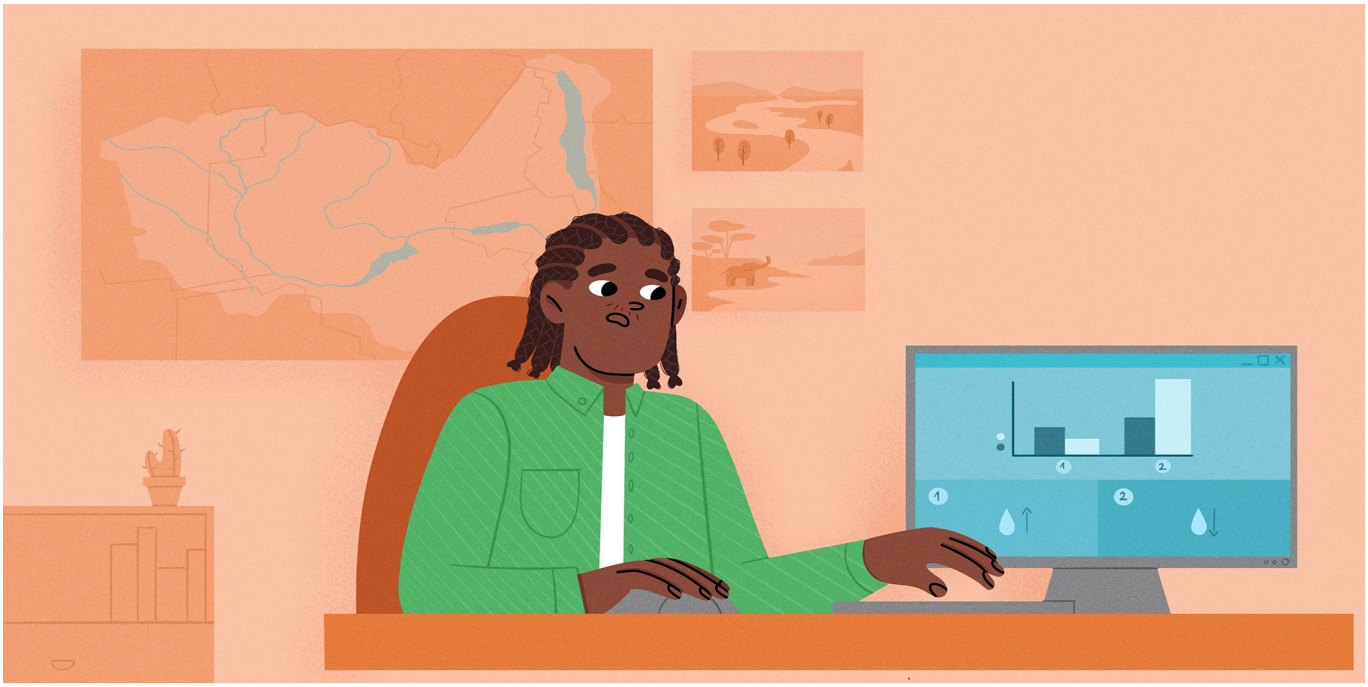

EXPLORING THE CLIMATE PUZZLE: A SURPRISING TWIST IN FIGHTING CLIMATE CHANGE

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YOUNG REVIEWERS:

ALAE

AGE: 13

HADIL

AGE: 13

Sometimes, when scientists try to help people, they can end up with a surprise ending in which things do not work out as expected. Their "help" might even accidentally make the situation worse for some people. We wanted to know if this could be true for a strategy to slow down climate change: charging countries a fee when they cut down forests to create farmland. We used computers to predict what might happen if countries were charged different fees, to keep things fair. Specifically, countries with less money would only have to pay low (or no) fees, while rich countries would pay higher fees. However, our computer model showed that this plan could have unexpected negative consequences for water availability in some places that pay low fees, like certain regions in Africa. This tells us that, as we fight climate change, we must keep our eyes open for unintended consequences that could result from our attempts to help the planet.

GOOD DEEDS CAN HAVE SURPRISE ENDINGS

Have you ever tried to do a good deed that did not turn out the way you planned? Maybe it had unintended consequences that were *not* so helpful for some people? Imagine a schoolyard so overgrown and messy that no one wants to play there. Weeds are popping up through the pavement, paint is peeling on the playground equipment, and kids have been carelessly throwing their trash on the ground. The principal decides to take action, so she assigns each grade a section of the schoolyard to tidy up and keep clean for the year. But wait—younger kids cannot do as much work as older kids, can they? To balance the workload, the principal assigns some of the teachers to help the younger grades, while the older students handle their areas without extra help. Sounds like a fair plan, right? A few weeks later, the schoolyard is much cleaner… but then something unexpected happens. The areas cleaned by the younger students end up looking really great because of the extra help they received. These areas become the most popular spots in the schoolyard, attracting lots of students during breaks. With more kids hanging around, these areas quickly get messy again. The younger students and their teacher helpers find themselves dealing with *even more* cleanup than before! Meanwhile, the areas cleaned by the older students remain less crowded and neater.

This situation, in which a well-meant plan has unexpected side effects for some groups, can happen in real life, too—with consequences more serious than just a messy schoolyard! In the rest of this article, we will explain how a similar situation might occur in our attempts to slow down **climate change**, if we are not careful.

CLIMATE CHANGE

Long-term changes in Earth's weather patterns, including rising temperatures, shifting rainfall, and more extreme weather events, affecting all life on our planet.

KEEPING EARTH'S ATMOSPHERE CLEAN

You probably already know that climate change is a huge problem facing the entire world [1]. Earth's climate has always been changing, but now it is happening really quickly because of things humans are doing, such as burning fossil fuels (coal, oil, and gas) to power our cars or to generate electricity. Burning fossil fuels adds a lot of carbon-containing **greenhouse gases** into the air—primarily carbon dioxide and methane. These gases act like a blanket, trapping heat close to Earth and warming up the planet. Global warming is causing serious problems for all of Earth's inhabitants, including humans. Seas are rising; heatwaves, storms, and other weather events are getting more extreme; and some animals and plants are struggling to survive because their ecosystems are changing. Humans struggle, too. For example, as the weather changes, it can become harder to grow crops in some places, leading to food shortages.

GREENHOUSE GASES

Gases in Earth's atmosphere, like carbon dioxide and methane, that help keep our planet warm. In excess, greenhouse gases make the planet too hot, causing problems with the weather and environment.

As the need to take action against climate change became more obvious, many countries decided to collaborate to try to limit

global warming. One big plan created in 2015, called the Paris Agreement, was supported by almost 200 countries. Supporting countries promised to work together toward a clear goal: to limit the global temperature increase in this century to 1.5–2°C above the temperatures that were present before the Industrial Revolution. Experts believe this target is critical if we want to avoid the most severe effects of climate change. Meeting this target will be very challenging, since the average global temperature increase recorded from 1991 to 2020 was 0.9°C.

PAYING THE PRICE FOR RELEASING CARBON

MITIGATION POLICIES

The actions that countries around the world are currently taking to combat climate change.

LAND USE CHANGE FEES

Fees charged by governments when land is altered from its natural state, like converting forests to farms or building areas, to manage environmental impacts from resulting greenhouse gas emissions.

Since the Paris Agreement was signed, many **mitigation** strategies have been proposed to decrease the amount of carbon released into Earth's atmosphere [2]. In addition to switching to energy sources like wind and solar power, one of the most discussed strategies for reducing carbon emissions involves charging a fee, kind of like a fine, when people or companies want to use land in a way that harms the environment. These are called **land use change (LUC) fees**. Some of the ways land is used can make climate change worse. For example, trees store a lot of carbon as they grow. So, when a forest is cleared to grow crops, less carbon can be stored on that land; and lots of carbon is released into the atmosphere when the trees are destroyed. LUC fees are meant to make people think more carefully about how they use land and discourage countries from contributing to climate change.

Some people think that charging the same LUC fees to everyone, all over the world, would be unfair. Think back to our schoolyard example, in which the younger kids needed more help to keep their section clean. Some countries have less money than others and might not be able to afford high LUC fees... but they might still need to convert land to farms to feed their growing populations. Maybe it would be better if these developing countries paid low (or no) LUC fees, right? After all, high fees might make things really tough for them. Or, as we saw in the schoolyard, might this good-hearted attempt to make things fair end up having unintended consequences?

ZAMBEZI WATERCOURSE—A DEVELOPING REGION

RIVER BASIN

An area that collects all the rainwater and snowmelt from the surrounding land, which eventually flows toward a central river.

BIODIVERSITY

The quality of having a lot of different living things. "Bio" means life and "diversity" means variety.

Our study focused on a **river basin** in southern Africa called the Zambezi Watercourse (ZW; Figure 1). The ZW is a good example of a developing region where LUC fees would be low or non-existent in some "fair" scenarios. The ZW is one of the largest river basins in the world [3]. It is shared by eight countries and contains 82 important **biodiversity** areas that provide homes for lots of wildlife, including migratory birds and threatened species like lions, hippos, and wild dogs. As you might expect in an area with so much water

available, the ZW is a good place for farming. Common crops include sugarcane, wheat, rice, and maize. Also, thanks to its rivers, the ZW gets much of the electricity it needs to power businesses and homes from **hydroelectric dams**, which is great because these dams do not burn fossil fuels.

HYDROELECTRIC DAM

A big wall that holds back a huge amount of water in a river, creating a reservoir. When water is released, it turns turbines to generate electricity.

Figure 1

(A) The ZW is the name for the area the Zambezi River flows through in southern Africa. **(B)** The Zambezi is one of Africa's longest and most important rivers. The ZW holds the entire Zambezi River and its tributaries, including the Kafue River and the Shire River. The ZW is shared by eight countries and contains 82 biodiversity areas, home to lots of wildlife.

Currently, about 40 million people live in the ZW, but the region's population is rapidly expanding—it is estimated that the ZW will be home to 70 million people by 2050! As the ZW's population grows, so will the demands for food and electricity—both of which require water. Right now, there is enough water for both of these critical purposes. But what will happen in the future? The ZW faces a double threat: rapid population growth *and* climate change. Climate change may lead to drier conditions in the region, which could decrease the amount of

water flowing through its rivers—at the same time that more water is needed for power and agriculture.

MODELING THE FUTURE OF THE ZW

COMPUTER MODELING

Creating virtual versions of a real system on a computer, to be used as a "laboratory" for experiments to explore and predict things that cannot be tested in the real world.

No one can see into the future to know exactly what will happen to the ZW, but scientists can use a technique called **computer modeling** to get a pretty good idea. Computer models are like virtual versions of the system scientists are studying, which allow scientists to experiment with various conditions to understand and predict how things might happen in the real world. Predictions generated using computer models can help policymakers make informed decisions to protect people and the environment, and they can also help to uncover any unintended consequences of human choices. Our group used a computer model to investigate what might happen to the ZW under many possible future conditions by integrating models simulating future climate conditions, models describing socio-economic development, and models showing the resulting impacts in the ZW [4]. We also compared three mitigation scenarios: no LUC fees at all; LUC fees that are the same all over the world; and LUC fees that differ from region to region, with lower fees in developing regions like the ZW.

When we used our computer model to look at the world as a whole, we found what we expected: LUC fees helped to decrease greenhouse gas emissions and limit global warming by the end of the century. At first glance, you might think that is good news for regions like the ZW—it might seem that the less the climate warms, the more water should be available in the ZW's rivers to irrigate crops and produce hydroelectric power for the growing population. But the story turned out to be more complicated.

When some regions of the world have very low or no LUC fees, these areas become attractive places for farming or other land uses. For example, a wealthy country that has a high LUC fee might have to pay a lot of money to change forest or grassland to farmland. But instead, if that country invests in farming in a developing region that has low or no LUC fees, clearing land to grow crops would be much less expensive. If this happens too frequently, the amount of land used for farming in developing regions could increase dramatically—and so would the amount of water needed to irrigate all the new crops. In fact, according to our computer model, the amount of water used in the ZW under varying LUC fees could increase by more than 400% by the end of the century. In contrast, under LUC fees that are the same across the world, that increase would only be about 100%—similar to the increase seen everywhere else in the world (Figure 2).

When too much water is removed from rivers and used for agriculture, less water flows downstream, which can harm the animals and

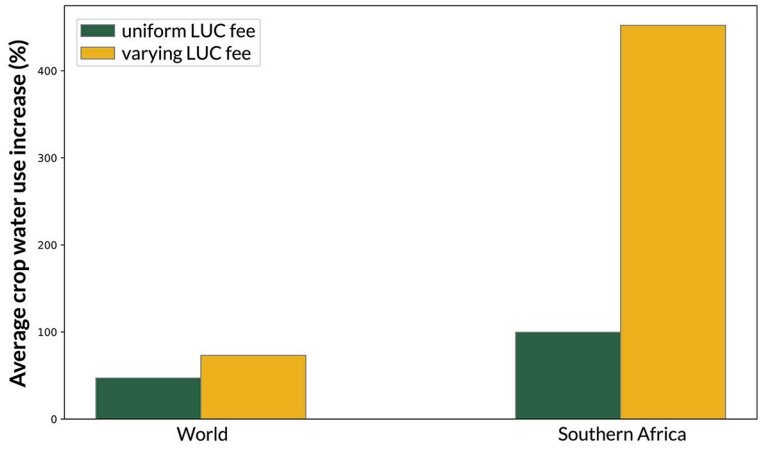

Figure 2

Giving the ZW a "break" on LUC fees might not be good for the ZW in the long term. This graph shows the average increase in future crop water use under two different scenarios, compared to 2015: globally uniform LUC fees (the same all over the world) and LUC fees that differ according to what regions can afford. When LUC fees are globally uniform, predicted water use in southern Africa is about the same as in the rest of the world (green bars). However, if regions like the ZW pay low or no LUC fees, water use in these regions may go up by 400%! This could have serious negative consequences for the region.

ecosystems that depend on that water to survive. Also, hydroelectric dams need a strong flow of water to produce electricity, so if water flow is reduced, some areas might not be able to produce enough power for the people who live there, or they might need to switch to less environmentally friendly methods that use fossil fuels.

THE IMPORTANCE OF LOOKING CLOSELY

Our research showed that, sometimes, what might seem like the "fair" way to address climate change might actually harm the very countries we are trying to help! At first glance, it might seem like we are helping developing countries by giving them a "break" on LUC fees. But when we look a little closer, we see that this strategy has unexpected side effects on water use, which could be really bad for the region overall.

The ZW is not an isolated situation—Africa alone has more than 60 international river basins and, in many of them, the population is expanding, and industries are growing. While expansion is good for the region's economy, more research is needed to find a fair way to balance global development with protecting the environment and limiting climate change for all. Along the way, researchers must keep their eyes open for unintended consequences that might do more harm than good for certain regions!

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REFERENCES

1. IPCC 2021. "Summary for policymakers", in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (Cambridge; New York, NY: Cambridge University Press), 3–32. doi: 10.1017/9781009157896.001
2. Luderer, G., Vrontisi, Z., Bertram, C., Edelenbosch, O. Y., Pietzcker, R. C., Rogelj, J., et al. 2018. Residual fossil CO_2 emissions in 1.5–2°C pathways. *Nat. Clim. Change* 8:626–33. doi: 10.1038/s41558-018-0198-6
3. ZAMCOM. 2019. *Strategic Plan for the Zambezi Watercourse*. Harare: Zambezi Watercourse Commission (ZAMCOM).
4. Lamontagne, J. R., Reed, P. M., Link, R., Calvin, K. V., Clarke, L. E., and Edmonds, J. A. 2018. Large ensemble analytic framework for consequence-driven discovery of climate change scenarios. *Earth's Fut.* 6, 488–504. doi: 10.1002/2017EF000701

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YOUNG REVIEWERS

ALAE, AGE: 13

Hello, my name is Alae E, I am 13 years old, I love reading books, I read my first book when I was 8 and that is what helped me ameliorate my English, I love writing too, I write poems from time to time, and I also love drawing and painting, it is my way of expressing. My favorite color is green, because it reminds me of nature, grass, trees, flowers, and everything that is peaceful.

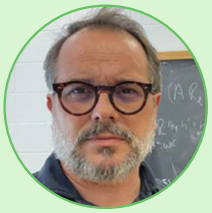
HADIL, AGE: 13

Hello everyone. I am Hadil, a Young Reviewer. I am very interested in natural and geological phenomena that happen and I am curious to know more while remaining with positive energy.

AUTHORS

MATTEO GIULIANI

I am an assistant professor in the Environmental Intelligence Lab at Politecnico di Milano, in Italy. I am an environmental engineer who uses computer models to study the management of natural resources under changing climate and societal demands. My work combines many fields, such as environmental, climate, and water sciences with machine learning and artificial intelligence. In my spare time, I enjoy watching several sports and taking outdoor excursions with my wife, our two kids, and our dog. *matteo.giuliani@polimi.it



ANDREA CASTELLETTI

I am a professor of natural resources management at Politecnico di Milano. I am the founder and head of the Environmental Intelligence Lab. My research interests include water systems planning and control under uncertainty and risk, decision making for complex engineering systems, and machine learning for environmental applications. In my spare time, I enjoy getting lost in the mountains while hiking or skiing.

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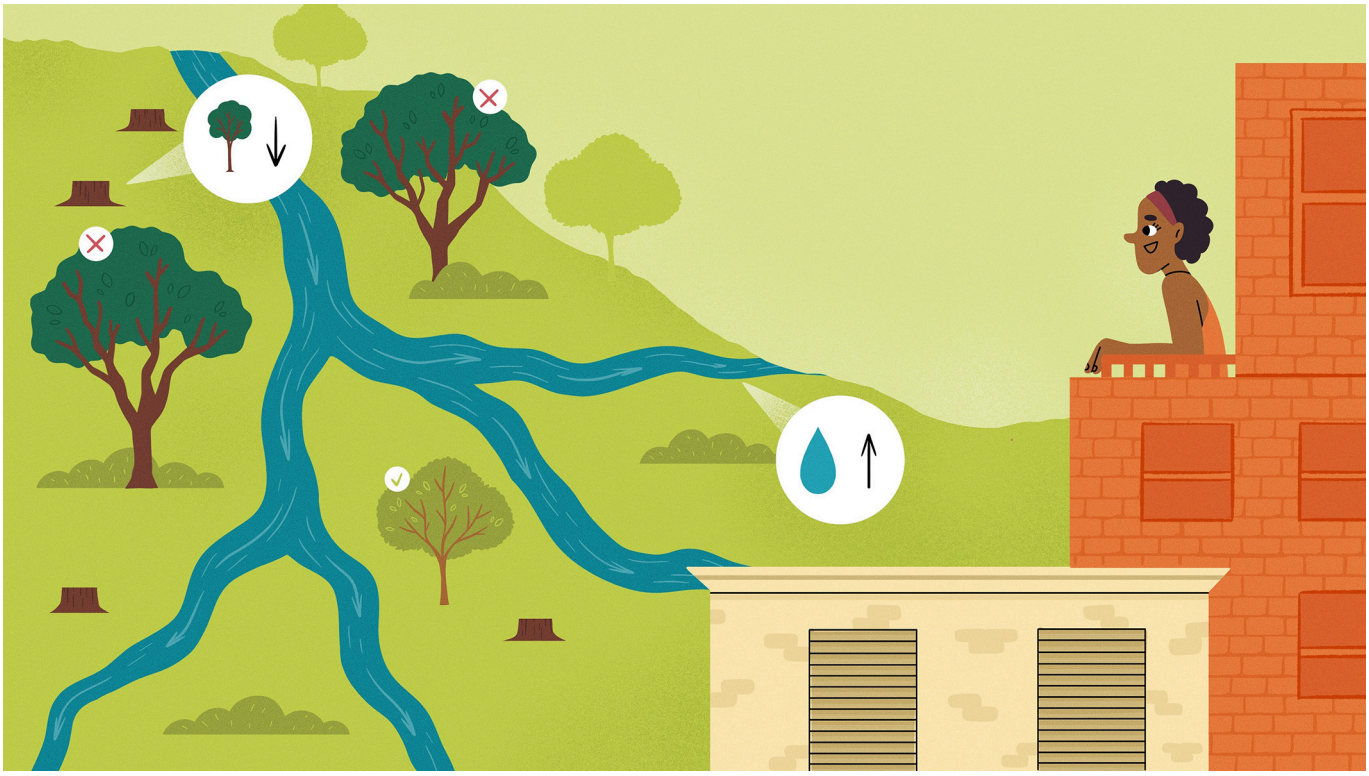

WORKING WITH NATURE TO REDUCE THE IMPACTS OF CLIMATE CHANGE

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YOUNG REVIEWERS:

MOMO

AGE: 12

SEA CREST SCHOOL

AGES: 12–13

Climate change is making extreme climate events, such as droughts and floods, more severe all over the world. Working with nature could help reduce or completely remove these dangerous impacts of climate change. We developed a way to measure how much working with nature can reduce the impacts of extreme drought on society. We applied it to one of the worst water crises experienced by a city: the Cape Town day zero drought, in which the taps of city dwellers almost ran dry. We found that clearing thirsty, non-native trees from the mountains that provide the city's water could have allowed more water to flow through rivers into the city's dams. But it would not have removed the full climate change impact. This tells us that working with nature is important in the fight against climate change, but that other types of solutions are also needed to protect societies, too.

CLIMATE CHANGE IS MAKING EXTREME WEATHER AND CLIMATE EVENTS MORE SEVERE

EXTREME WEATHER AND CLIMATE EVENTS

Unusual, intense weather and climate patterns like hurricanes, floods, or heatwaves that are much stronger than normal, and can cause big problems for people and nature.

Extreme weather and climate events include droughts, floods, heatwaves, and hurricanes. Some of the impacts from extremes are loss of life, damages to property, famine, water shortages, and disease outbreaks.

Scientists have shown that these extremes are happening more often, lasting longer, and becoming more severe. Humans are the reason for these changes—burning fossil fuels releases greenhouse gasses into the atmosphere, changing Earth's climate and affecting local weather all over the world [1].

Working with nature can help reduce the impacts of extremes on humans. This is because the local environment also plays a role in how the impacts of extremes are felt. For example, heavy rain falling on areas of bare soil cause more flooding and greater soil loss compared to what would happen if the same area was covered with grasses, shrubs, or trees. Working with nature to solve some of the problems caused by climate change is called **nature-based solutions** [2]. Examples include planting vegetation in urban areas for local cooling; restoring vegetation along rivers, in wetlands, and in mountains to reduce floods; restoring coastal wetlands to protect against storms and sea-level rise; and planting trees and shrubs on farms to help farmers grow more food.

NATURE-BASED SOLUTIONS

Using nature, like planting trees or restoring wetlands, to solve environmental and societal problems, such as reducing floods, cleaning the air, or protecting animals plants and people.

In our study, we wanted to know *how much* nature-based solutions could help fight changes in extreme weather and climate events caused by climate change—something no one had ever studied before.

STUDYING THE CAUSES OF EXTREME WEATHER EVENTS

The reason scientists had never studied exactly how much nature-based solutions could help to reduce the impact of climate change on extreme weather events was because the methods to do so were not yet available. Fortunately, since the early 2000's, the science of figuring out the causes of changes in extreme weather events has rapidly advanced [3]. This is a complicated topic to study because every extreme weather event is unique. In a world without greenhouse gasses in the atmosphere, extreme weather would come from natural processes in Earth's climate. But in the world we live in today, extreme weather events have both natural and human causes, because the Earth's climate has been warmed by greenhouse gases in the atmosphere, which affects weather processes.

If we do not know how much an extreme weather event has changed because of climate change, it is impossible to measure the role of nature-based solutions in reducing or balancing out these impacts.

We came up with a way to identify the factors responsible for the impacts we experience from extreme weather and climate events. This approach has three main steps (Figure 1). The first is to compare what an extreme event would look like in a world *with* greenhouse gas emissions and a world *without* them. The second step is to determine how these changed extremes interact with local land and environmental conditions. The third step is to determine what happens if we deliberately change the local environment using nature-based solutions. These three steps can help researchers to answer two questions:

1. Has an extreme weather event changed due to human-caused changes to Earth's climate?
   And if the answer is yes, then,
2. How much could nature-based solutions help to reduce or remove the impacts due to climate change?

THE CAPE TOWN DAY ZERO DROUGHT

To test our ideas, we tried to identify the factors responsible for one of the worst water crises experienced by a city in recent times: the Cape Town day zero **drought**.

DROUGHT

When an area does not get enough rain for a long time, causing water shortages, dry land, and problems for plants, animals, and people who need water.

Cape Town, in South Africa, is a diverse multicultural city surrounded by natural mountainous areas. Cape Town's water supply comes from rivers that flow from these mountainous areas. When it rains, the rainfall runs off the land and into the rivers, flows along the rivers, and is finally captured and stored in six large dams. Water from these dams is carried through an intricate system of pipes to people's houses and community access points in and around the city.

During a 3-year drought from 2015 to 2017, the city's dam levels dropped to below 20% of their normal levels, which forced Cape Town to prepare for no water—the day when the taps would run dry, which was called day zero. The rains did finally come, and Cape Town averted day zero, at least this time.

WORKING WITH NATURE BY CLEARING INVASIVE NON-NATIVE TREES

The natural vegetation in the Cape Town mountains is called fynbos. It is made up of shrubs and grass-like plants, with no large trees except in ravines (Figure 2A). Fynbos grows in part of the Cape Floristic Region, a global biodiversity hotspot with more than 9,000 plant

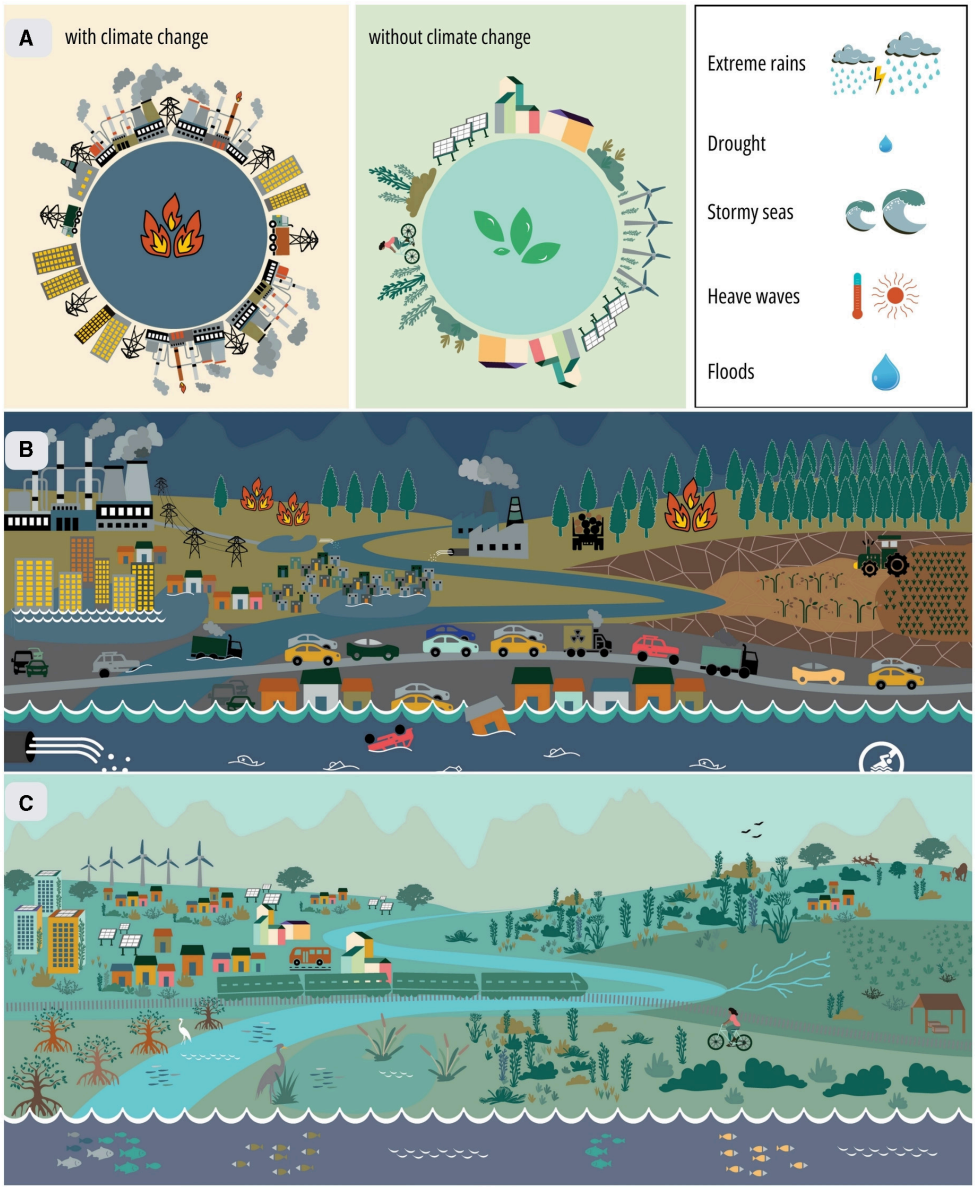

Figure 1

There are three main steps for identifying the factors responsible for changes in extreme weather and climate events. **(A)** First, we must compare what the extreme event would look like in a world with or without climate change. Then we compare what extreme events would look like **(B)** without nature-based solutions or **(C)** with nature-based solutions. This allows us to see whether nature-based solutions are helpful, and how much they might help (Illustrations: Theresa Wigley, Data Visualization: Tali Hoffman).

species. Because 70% of these plant species are only found here and nowhere else in the world, this region has been declared a UNESCO world heritage site—an area with outstanding natural, historical, and cultural value.

The mountains critical for Cape Town's water supply have been invaded by non-native trees, like pine and eucalyptus (Figure 2B). Non-native trees such as these are called **invasive species** because they have escaped from plantations and replace natural vegetation. These trees were introduced by people two centuries ago for timber and because people thought they looked nice. The problem is that these trees use substantially more water than the native fynbos vegetation does [4]. This is because the trees are taller and have larger leaf canopies and longer roots. They take up so much water that they

INVASIVE NON-NATIVE SPECIES

A plant or animal that comes from a different place, spreads quickly, and harms the local environment by taking over and outcompeting native species.

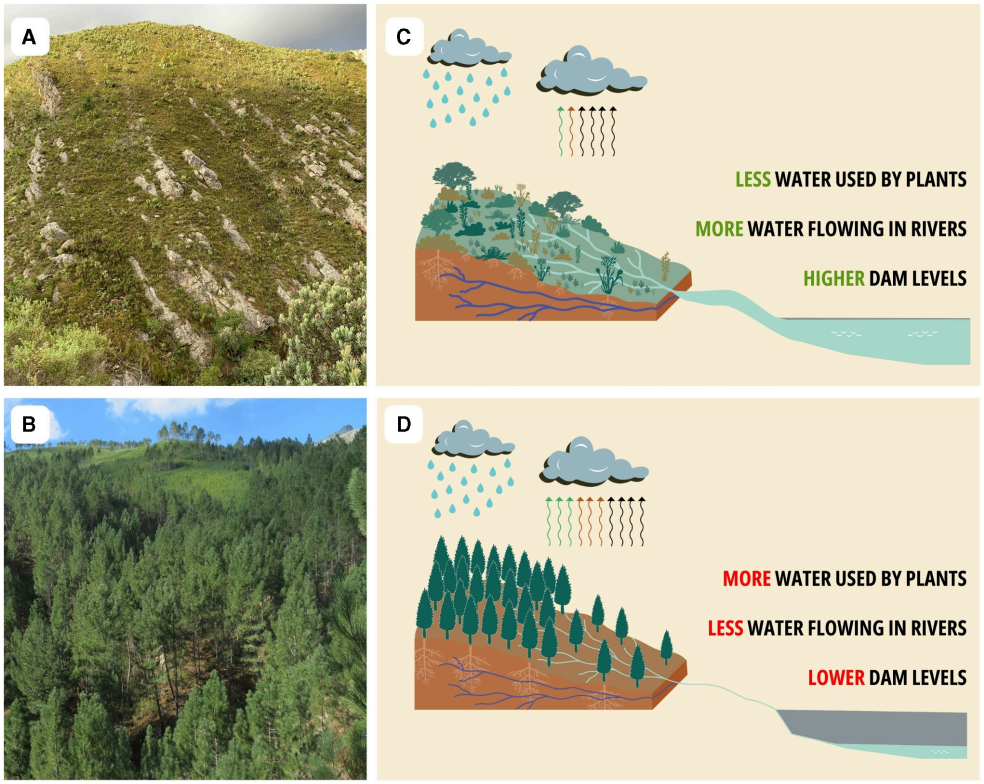

Figure 2

Figure 2

(A) A natural fynbos mountain slope in the Cape Town mountains. **(B)** Mountain slope where the natural fynbos vegetation has been invaded by non-native pine trees. **(C)** In areas with natural fynbos-type vegetation, less water is used by the plants so there is more water available in rivers to flow into dams. **(D)** In ecosystems where non-native trees are growing, more water is used because the trees are tall and have big leaves and long roots, and they lose lots of water to the atmosphere [Photo Credits: Petra Holden **(A)**; Martin Kleynhans **(B)**, Illustrations: Theresa Wigley, Data Visualization: Tali Hoffman].

reduce river flows to the dams that supply water to major cities (Figures 2C, D).

One nature-based solution is clearing these non-native trees from the mountainous areas of South Africa, to increase river flows and reduce extreme droughts. But does it work?

USING COMPUTER MODELS TO SIMULATE WORLDS

We used **computer models** to compare what river flows would be like during the Cape Town day zero drought in a world with and without greenhouse gasses in the atmosphere, and also in a world with and without the nature-based solution of non-native tree clearing. These computer models can predict water flows in and out of an area of land and through river channels in **watersheds**. The models were built based on data collected from the rivers themselves and from space, using satellites. Data included river width and depth, soil and vegetation properties, observed river flows, and the coverage of invasive non-native trees in the area [5]. This information, along with climate data, was used in the computer models to calculate the river flows.

Once we were satisfied that our computer models could accurately simulate the actual river flows in the mountains, we then used these models to answer our research questions. We ran 290 **simulations**

COMPUTER MODELS

A virtual simulation that uses math and data to imitate real-world processes, like weather, river flows or how diseases spread, helping scientists predict, and understand complex systems.

WATERSHED

An area of land where all the rainwater and streams flow into a common body of water, like a river or lake.

SIMULATIONS

Virtual experiments or tests that use computers to mimic real-life situations, like predicting weather or river flows, helping people test ideas, and predict outcomes.

of the drought weather (rainfall and evaporation) for the day zero drought through the computer models. Half of these simulations (145) represented rainfall and evaporation (the drought weather) for our current world, with greenhouse gases/climate change. The other half (145) represented the drought weather in an "imaginary" world without climate change.

We ran two further experiments using the computer models, by varying the vegetation cover. The first experiment represented clearing all the invasive, non-native trees and restoring the natural fynbos vegetation. The second represented the *entire* watershed fully invaded with non-native trees. We compared the river flows between all the modeled worlds, which told us how much climate change influenced the drought and whether nature-based solutions could have reduced this.

WHAT DID OUR COMPUTER MODELS SHOW?

Climate change reduced river flows by 22% compared to our computer model of a world without human-caused climate change (Figures 3A, B). In other words, there would have been 22% more water flowing in the rivers during the Cape Town day zero drought if there had been no climate change.

If we had cleared the non-native trees before the Cape Town day zero drought hit, we could have avoided 9% of the losses in river flows due to climate change (Figure 3C). But clearing the trees would not have completely balanced out the decrease in river flows caused by climate change. Encouragingly, however, preventing non-native trees from totally taking over the area avoided an additional 21% loss of river flows (Figure 3D).

The 9% increase in water due to nature-based solutions is critical. But we still would have 13% less water in the rivers because of climate change under current levels of global warming (Figure 3C). Higher levels of warming would lead to even less water in the rivers during drought years. This highlights the importance of keeping global warming levels below 1.5 and 2.0° to support nature-based solutions in their job of protecting society from extremes.

CONCLUSION

Working with nature is important for reducing climate change impacts on extreme weather and climate events. We found that clearing non-native trees could have prevented *some* of the climate change-driven losses of river flows experienced during the Cape Town day zero drought—one of the worst water crises experienced by a city in recent times. However, clearing non-native trees could

Figure 3

We used our approach to explore whether Cape Town could have used nature-based solutions to reduce the severity of its day zero drought. We calculated river water flowing to dams under different climate and land scenarios. **(A, B)** When compared with water levels that might be seen without climate change, climate change decreased river flows. **(C)** Using a nature-based solution (clearing non-native trees) could have reduced this impact. **(D)** Without any efforts toward a nature-based solution, the impact of climate change would have been even worse (Illustrations: Theresa Wigley, Data Visualization: Tali Hoffman).

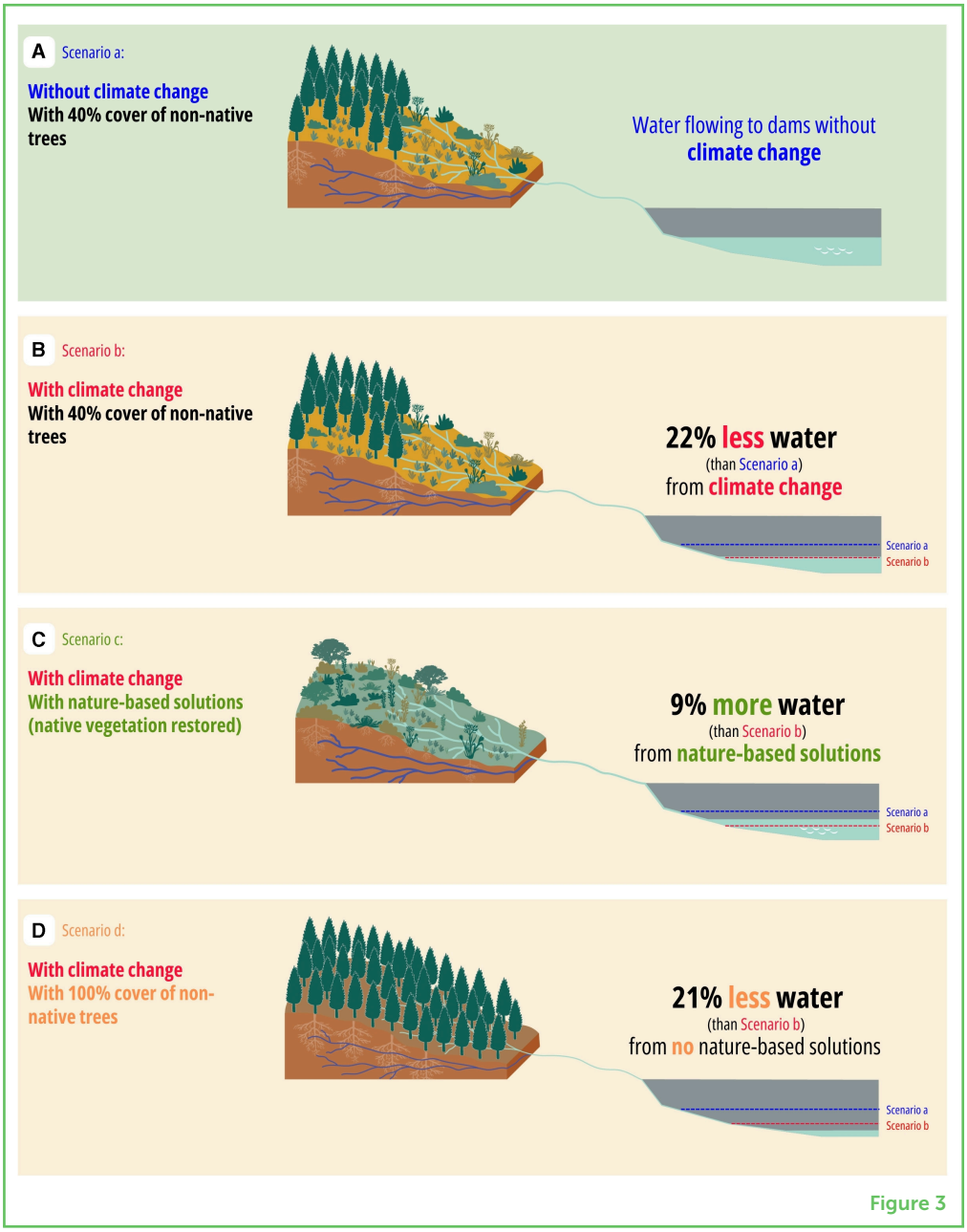

Figure 3

not remove all the climate change impact, which highlights the importance of working to combine nature-based solutions with other types of solutions, like water demand management, improvement of water transfer pipes, and desalination.

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. IPCC 2023. "Summary for policymakers", in *Climate Change 2023: Synthesis Report Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. Core Writing Team, H. Lee, and R. Romero (Geneva: IPCC). p. 1–34.
2. Seddon, D. 2022. Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. *Science* 376:1410–6. doi: 10.1126/science.abn9668
3. Otto, F. E. L. 2017. Attribution of weather and climate events. *Ann. Rev. Environ. Resour*. 42:627–46. doi: 10.1146/annurev-environ-102016-060847
4. Rebelo, A. J., Holden, P. B., Hallowes, J., Eady, B., Cullis, J. D. S., Esler, K. J., et al. 2022. The hydrological impacts of restoration: a modelling study of alien tree clearing in four mountain catchments in South Africa. *J. Hydrol*. 610:127771. doi: 10.1016/j.jhydrol.2022.127771
5. Holden, P. B., Rebelo, A. J., and New, M. G. 2021. Mapping invasive alien trees in water towers: a combined approach using satellite data fusion, drone technology and expert engagement. *Rem. Sens. Appl. Soc. Environ.* 21:100448. doi: 10.1016/j.rsase.2020.100448

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

MOMO, AGE: 12

Momo loves to travel the world and see new places. Even so, she is a self-proclaimed couch potato when she is at home. The two extremes can coexist in one person! Her favorite couchmate is her fuzzy and affectionate dog, Lita.

SEA CREST SCHOOL, AGES: 12–13

We are a curious group of 6th grade science students who live in coastal California. While we all have individual interests, we are united by a shared passion for environmental stewardship and, in all things, we are determined to "leave it better than we found it": our school's mantra. Our group members are guided by our humanities teacher, Leslie G., and include: Oliver, Mackey, Rowan, Stella, Daphne, Leena, Abigail, and Malina.

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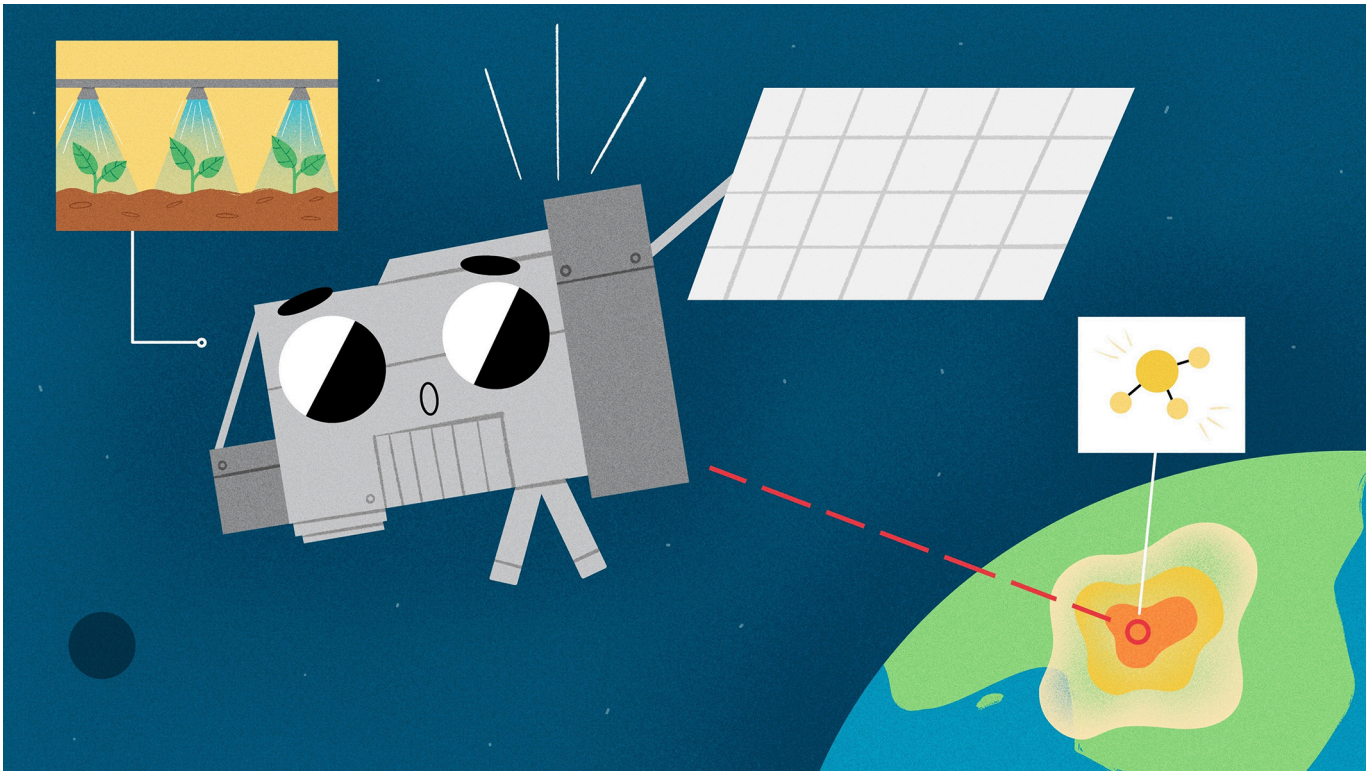

AN EYE IN THE SKY — TRACKING AMMONIA POLLUTION FROM SPACE

Pierre Coheur [1*], ***Martin Van Damme*** [1,2*], ***Lieven Clarisse*** [1], ***Simon Whitburn*** [1,3], ***Bruno Franco*** [1] ***and Cathy Clerbaux*** [1,4]

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YOUNG REVIEWERS:

LAURI

AGE: 15

Ammonia is a chemical commonly found in fertilizers, cleaning products, and even animal waste. While this substance does have some important uses, rising emissions of ammonia in the atmosphere can pose serious risks to human health, plant and animal health, and the environment. Therefore, measuring and tracking ammonia levels in the air is crucial, especially as human activities, such as large-scale farming and industrial processes, release more and more ammonia. In this article, we will tell you about the main sources of ammonia pollution, the dangers it poses to health and the environment, and how scientists are using satellites to monitor ammonia levels from space. By keeping a close eye on ammonia trends, researchers hope

to trigger ways to reduce emissions and protect the planet for future generations.

AMMONIA IS NO JOKE!

What do some cleaning products, garden fertilizer, and chicken poop have in common? While this might sound like the start of a corny "dad joke", there is no punchline—but there *is* a scientific answer! All three of these substances contain a chemical called **ammonia**. Maybe you have noticed the sharp, strong smell of ammonia in a recently cleaned school bathroom or gym locker room, or while emptying a cat's litterbox. Even if you have heard of (or smelled!) ammonia before, you might *not* be aware that scientists are actively monitoring ammonia levels in the air we breathe, both from land and from space. This is important because too much ammonia can be harmful to humans, animals, plants, and the environment. In the rest of this article, we will tell you about the sources of ammonia, why scientists are concerned about ammonia levels in the atmosphere, and how they monitor it from space.

AMMONIA

A gas made of nitrogen and hydrogen (NH_3), found in fertilizers, cleaning products, and animal waste. In excess, it can be harmful to human health, the environment, and air quality.

ANTHROPOGENIC

Caused by human activities, such as farming, industry, and pollution. Anthropogenic processes often contribute to environmental issues like climate change, deforestation, and air or water pollution.

WHERE DOES AMMONIA POLLUTION COME FROM?

In its pure form, ammonia is a gas with the chemical formula NH_3, meaning that each molecule has a nitrogen atom surrounded by three hydrogen atoms (Figure 1A). Ammonia is produced by both natural sources and **anthropogenic** (human-caused) processes (Figure 1B).

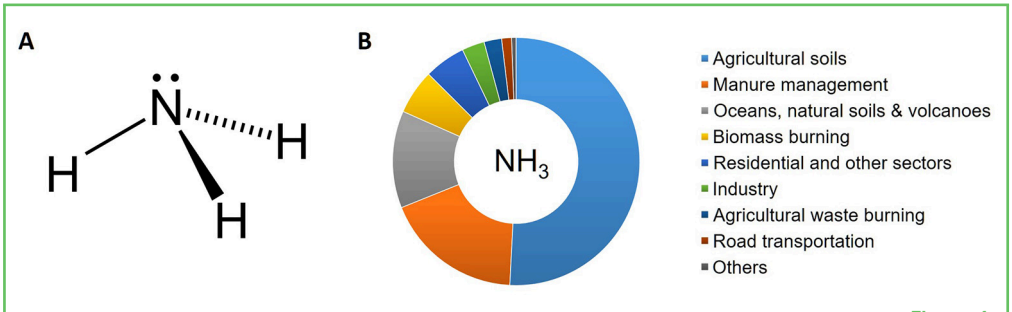

Figure 1

(A) Ammonia is made up of a nitrogen atom (N) surrounded by three atoms of hydrogen (H), forming a molecule with a pyramidal shape. **(B)** Main contributors to ammonia emissions in the air. You can see that the vast majority of ammonia emissions are from anthropogenic activities like farming and industry.

When dead plants and animals decompose (break down) in nature, ammonia is released into the soil and air. Living animals, including humans and livestock like cows, chickens, and pigs, contribute to ammonia production too, when their waste products (pee and poop) are decomposed by bacteria. Oceans also emit ammonia, and wildfires can generate large amounts of this gas as they burn trees and other plants.

Human activities, however, produce much more ammonia than natural processes. The giant farms that grow our food are by far the biggest anthropogenic source. Man-made fertilizers contain ammonia because it provides a readily available source of nitrogen, which plants need to grow. When farmers use large amounts of fertilizers on their crops, some of the ammonia gets released into the air. Huge cow, chicken, and pig farms also generate large amounts of ammonia from animal waste, as we mentioned above. Overall, in Europe, the United States, and China, livestock waste and fertilizer use account for over 80% of total ammonia emissions.

Besides farming, other anthropogenic sources of ammonia include industries that produce fertilizers, steel, explosives, and other chemicals. Waste treatment plants and gas-powered vehicles also contribute to ammonia pollution, though not nearly as much as agricultural sources.

BIODIVERSITY

The variety of life in a particular habitat or ecosystem, including all plants, animals, and microorganisms. High biodiversity helps ecosystems stay healthy and resilient to changes or threats.

PARTICULATE MATTER

Tiny particles in the air, like dust, dirt, soot, or chemicals, that can be inhaled into the lungs. Particulate matter can cause health problems, especially for the respiratory and cardiovascular systems.

WHY SHOULD WE WORRY ABOUT AMMONIA?

So, what makes ammonia so bad? At high levels, there are three main worries: human health problems, **biodiversity** loss, and climate change.

Human Health Problems

When ammonia mixes with other pollutants in the air, it can form tiny particles called **particulate matter**. These particles can be easily inhaled into the lungs due to their small size, leading to a variety of breathing issues like asthma, bronchitis, and other long-term respiratory illnesses. Particulate matter can affect more than just the lungs—it can also enter the bloodstream and impact other parts of the body [1, 2]. This can increase the risk of heart disease, stroke, and other serious health issues that can shorten people's lives. Children and the elderly are often the most vulnerable to health problems caused by particulate matter pollution.

Biodiversity Loss

Ammonia released into the atmosphere can also settle back to Earth, where it can change the chemistry of the soil and water. These changes can harm and even kill plants and animals by disrupting the natural balance in ecosystems, leading to a loss of critical biodiversity. For example, too much ammonia can lead to nutrient overload in water bodies, causing excessive growth of tiny plants called algae. This process is called **eutrophication**. As they grow, the algae use up all the oxygen in the water, creating "dead zones" where fish and other aquatic life cannot survive. By altering the chemistry of soil, ammonia can also affect the types of plants that can grow and thrive, further decreasing biodiversity.

EUTROPHICATION

A process in which excess nutrients, like ammonia, cause rapid algae growth in water bodies. This depletes oxygen in water, creating "dead zones" where aquatic life cannot survive.

Climate Change

Ammonia plays a relatively small but interesting role in **climate change**, too. It has both cooling and warming effects on the climate. One cooling effect relates to the formation of particulate matter, mentioned above. These tiny particles are efficient at reflecting sunlight back into space and thereby cool down our planet. Ammonia also influences the way plants grow, which in turn affects how much carbon dioxide (the main greenhouse gas responsible for climate change) is absorbed by plants and removed from the atmosphere. There are many other complex effects of ammonia on the climate. After considering the most important ones, most scientists around the world agree that ammonia cools down the climate a little, but not nearly enough to stop global warming.

CLIMATE CHANGE

A long-term change in Earth's climate, especially a rise in average global temperatures, primarily caused by human activities like burning fossil fuels, deforestation, and industrial processes.

So, now you know why keeping ammonia levels in check is important—but how do scientists monitor ammonia levels to understand whether they are changing over time?

KEEPING TRACK OF AMMONIA WITH SATELLITES

One way to measure ammonia in the air we breathe is by using instruments that can directly sample the air to check ammonia levels. Ammonia-detecting instruments can be found in air-sampling stations in various countries, and they can provide very accurate data. However, ground-based instruments can only measure ammonia in the specific places where they are located. There are not enough ground-based instruments spread out all over the world to give scientists the "big picture" of ammonia emissions.

To overcome this limitation, scientists can use satellites to monitor ammonia levels from space. Satellites can carry advanced instruments that can detect ammonia and other gases in the atmosphere by measuring the specific colors of light that these gases absorb and emit. Because they are "looking down" at Earth, satellites can show scientists how ammonia is distributed over vast areas, including remote places that cannot be measured with ground-based instruments.

For our study [3], we used 11 years of data (2008–2018) from a satellite-based instrument called the Infrared Atmospheric Sounding Interferometer (IASI). IASI takes measurements all over the Earth twice a day, and it is very sensitive, meaning it can accurately detect much smaller amounts of ammonia than previous satellite-based instruments could. We used data from IASI to understand where atmospheric ammonia is coming from, how it spreads, and how levels are changing over time.

AMMONIA IS INCREASING IN EARTH'S ATMOSPHERE

Data from IASI allowed us to pinpoint hundreds of ammonia sources, including major "hot spots" where a lot of ammonia is being released in a small area [4, 5]. Most of the hot spots were areas where intensive livestock farming and industrial activities were happening (Figure 2). We also created detailed maps of the Earth, showing how ammonia emissions changed for countries and regions over the 11-year measurement period.

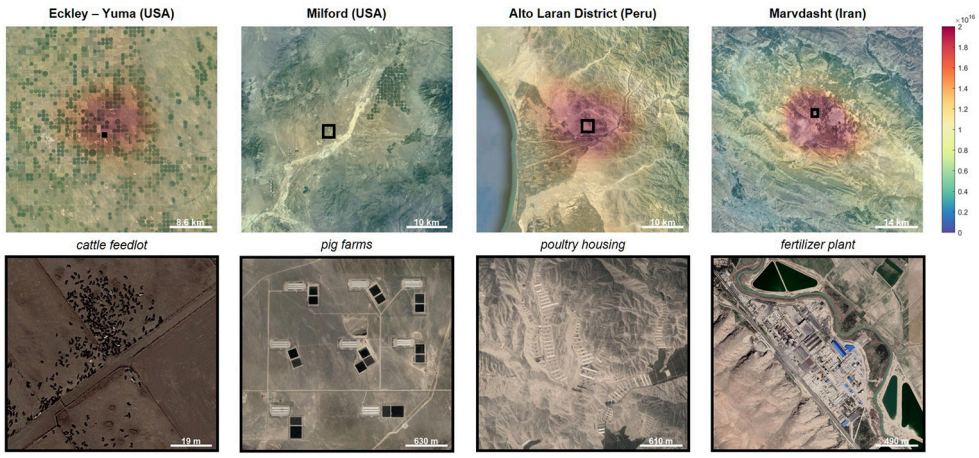

Figure 2

Figure 2

Examples of ammonia mega-emitters seen from space. **(Top row)** Atmospheric ammonia concentrations measured using IASI, overlaid on images of the ground. The color scale shows increasing ammonia concentrations, with blue representing low concentrations and red representing high concentrations. **(Bottom row)** Close-up view of the areas outlined in black in the top panels, showing the ammonia emitter (Image modified from Clarisse et al. [4] and Van Damme et al. [5] with permission).

Looking at the whole world, we saw an increase in ammonia levels by about 12.8% from 2008–2018. But this increase was not consistent all over the Earth—some areas saw big increases while others experienced decreases (Figure 3) [3]. East Asia, for instance, showed the largest increase in ammonia levels, with an increase of >75% over the observation period. Even in places like the European Union that have policies in place to try to reduce ammonia emissions, we still saw increases during the observation period.

WHY IS AMMONIA RISING?

A combination of two factors explains why ammonia concentrations in the air are rising: increasing ammonia emissions and changes in air pollution control measures that cause ammonia to last longer in the atmosphere.

The most obvious reason for rising ammonia levels is simply because more ammonia is being released into the air, primarily through increases in farming and industrial activities. In East Asia, for example, both factories and large-scale farming increased during the observation period. Fires—both wildfires and fires used to clear land for farming—also contribute to increased ammonia in the atmosphere. For example, in Indonesia, extensive peatland fires in 2015 released

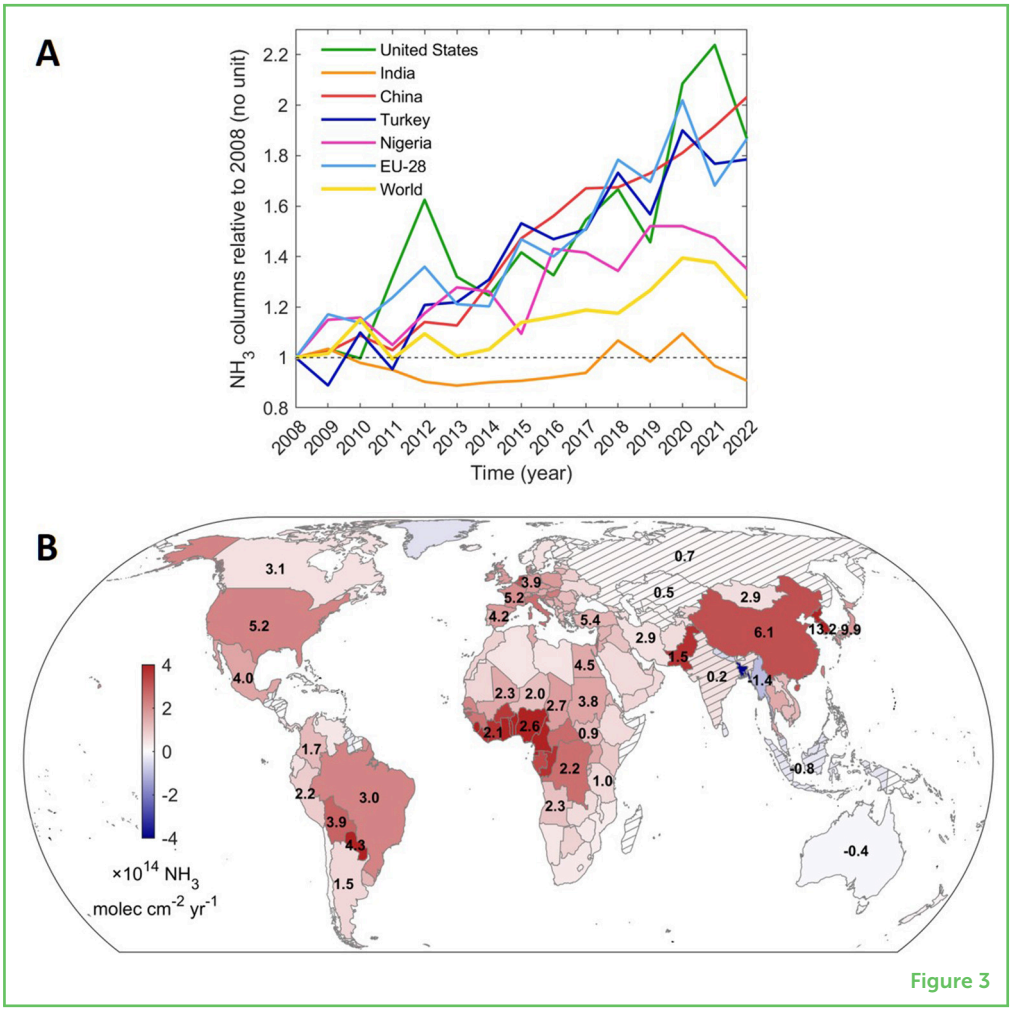

Figure 3

(A) Changes in the ammonia concentration from 2008–2022 (relative to 2008 levels) as monitored by IASI. Trends are shown for selected countries, Europe (EU-28), and the entire world. **(B)** Trends for each country over the same period. Red means increase and blue means decrease of NH_3 in the air. Relative trend values (in %) are included in black for selected countries (Image modified from Van Damme et al. [3] with permission).

significant amounts of ammonia, and in Nigeria, "slash-and-burn" forest clearing for agriculture contributed to rising ammonia levels during the observation period.

The second reason, air pollution control, might not seem to make sense at first. If ammonia is a type of air pollutant, why would *controlling* air pollution make atmospheric ammonia levels *worse*? The answer lies in the interaction between ammonia and other air pollutants. Remember how we said that ammonia can react with other pollutants to form particulate matter? The formation of those tiny particles reduces ammonia levels in the air. However, many countries have air pollution laws in place to reduce the pollutants that pull ammonia out of the air. When levels of those pollutants are reduced, ammonia stays in the atmosphere longer, leading to higher overall levels.

WHY IS THIS WORK IMPORTANT?

As we have explained, understanding and addressing rising ammonia levels is crucial for protecting both human health and the environment.

Data from IASI show that current air pollution control policies are not enough to keep ammonia emissions in check. Even in regions with fairly strict air pollution laws, ammonia levels are still rising. This tells us that new, more effective strategies are needed to mitigate (reduce) ammonia emissions.

Mitigation could include better farming practices, such as using more efficient fertilizers and improving animal waste management. Industries could also adopt cleaner technologies and processes to reduce the amount of ammonia they release. For example, advanced filtration systems could be installed to help capture ammonia, keeping it out of the air.

MITIGATION

Actions taken to reduce or prevent the harmful effects of something, such as limiting emissions or improving practices to lessen environmental damage or health risks.

It is important to keep an eye on how well pollution-control efforts are working. Satellite data, like that from IASI, help scientists monitor ammonia levels all over the world. By watching these levels closely, scientists can tell if efforts to reduce ammonia are actually making a difference or if we need to make changes to our plans. Satellite tracking is one way to ensure that ammonia mitigation efforts are successful, helping countries do their best to keep humans, the environment, and the planet safe from the dangers of air pollution and ecosystems degradation.

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REFERENCES

1. Plautz, J. 2018. Ammonia, a poorly understood smog ingredient, could be key to limiting deadly pollution. *Sci. News*. doi: 10.1126/science.aav3862
2. Thangavel, P., Park, D., and Lee, Y. C. 2022. Recent insights into particulate matter ($PM_{2.5}$)-mediated toxicity in humans: an overview. *Int. J. Environ. Res. Public Health* 19:7511. doi: 10.3390/ijerph19127511

3. Van Damme, M., Clarisse, L., Franco, B., Sutton, M.A., Erisman, J.W., Wichink Kruit, R., et al. 2021. Global, regional and national trends of atmospheric ammonia derived from a decadal (2008–2018) satellite record. *Environ. Res. Lett.* 16:055017. doi: 10.1088/1748-9326/abd5e0
4. Clarisse, L., Van Damme, M., Clerbaux, C., and Coheur, P.-F. 2019. Tracking down global NH_3 point sources with wind-adjusted superresolution. *Atmos. Meas. Tech*. 12, 5457–5473. doi: 10.5194/amt-12-5457-2019
5. Van Damme, M., Clarisse, L., Whitburn, S., Hadji-Lazaro, J., Hurtmans, D., Clerbaux, C., et al. 2018. Industrial and agricultural ammonia point sources exposed. *Nature* 564, 99–103. doi: 10.1038/s41586-018-0747-1

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YOUNG REVIEWERS

LAURI, AGE: 15
I am 15 and interested in natural sciences, especially chemistry, in the school. In my free time I like hiking, climbing, and playing piano.

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Cathy is a senior scientist at CNRS in Paris and a lecturer at the Université Libre de Bruxelles (Belgium). She plays a key role in the development of satellite missions aimed at monitoring pollutants and climate-related gases from space. Once the satellite is operational, the data collected can also be used to track exceptional events, such as wildfires, volcanic eruptions, and major pollution incidents. In addition to her research, Cathy is passionate about science communication, regularly giving public talks and writing popular science articles to engage a broader audience.

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HUMAN HEALTH
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PROTECTING HEALTH THROUGH CLIMATE ACTION IN EUROPE

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YOUNG REVIEWERS:

TRICIA

AGE: 14

Climate change is rapidly warming our planet, and Europe is heating up twice as fast as the rest of the world. You may have heard about polar bears being affected by melting ice caps, but did you know climate change affects humans too? Extreme weather events, like storms, droughts, floods, heatwaves, and wildfires, are becoming more common — leading to a rise in health issues including injuries, heart and lung disease, depression, diseases spread by mosquitoes, and food and water shortages. To protect people's health from climate change, we need to develop solutions to protect those who are most affected, like older people, children, people with disabilities, and people who have fewer opportunities and less support than others. Climate change may seem like a problem too big to fix, but together we can protect ourselves and each other and provide a lot of health benefits. Climate action is a win-win for people and the planet!

WHAT IS CLIMATE CHANGE?

Think about the Earth's atmosphere as a big, cozy blanket. This blanket, made up of gases like carbon dioxide and methane, keeps us warm. The gases trap the sun's heat, so our planet does not get too cold. When humans burn coal, oil, and gas for energy, we add more gases to the air than should be there. It is like adding more and more layers to the blanket. A thicker blanket is nice if we are cold, but if we are already warm it can make us too hot. These extra gases are making Earth too hot. This is called the greenhouse effect. A greenhouse is a building made from glass, used to grow plants. Sunlight shines through the glass and warms the air inside. The glass traps the heat, making the air inside the greenhouse warm, even at night and during winter. Therefore, the gases that warm the Earth are called **greenhouse gases**. The Earth's extra warmth is called global warming, and it is changing weather patterns and making temperatures hotter, with more storms, **floods**, **droughts**, and **wildfires**. These changes are harmful for people, animals, and plants that are used to the weather patterns we had before humans released so many greenhouse gases into the air.

UNEQUAL RESPONSIBILITY FOR CLIMATE CHANGE

Rich countries and big companies have caused a lot of the climate problem by burning too much coal, oil and gas for energy, which are called. But rich countries and most companies are not doing enough to fix it [1]. For example, some European countries have produced a lot of greenhouse gases compared to many other countries. In 2021, the greenhouse gases emitted by each person in Europe from burning **fossil fuels** were six times higher than in Africa, and almost

GREENHOUSE GASES

Gases that act like a blanket around Earth, including carbon dioxide, methane, and nitrous oxide. In normal amounts, they help keep our planet warm enough to live on.

FLOODS

When water overflows from rivers, lakes, or the sea onto the land that is normally dry, like roads or fields. This usually results from a lot of rain or melting snow.

DROUGHTS

Periods when everything gets really dry, usually due to long periods without much rain. Water sources can dry up, making it hard for plants, animals, and crops to survive.

WILDFIRES

Big fires that spread quickly over vegetated areas like forests or grasslands.

FOSSIL FUELS

Energy sources like coal, oil, and natural gas that formed millions of years ago from dead plants and animals buried underground.

three times higher than in Central and South America [2]. Even within wealthy countries, there are big differences in how much pollution people create. Richer people and businesses often burn more fossil fuels compared to others. This is very unfair, as the people and places that have not used as much fossil fuels are often the hardest hit by climate change. Europe and other rich regions and industries must do their part and burn less fossil fuels to protect the health of people, animals, and plants all over the world.

HOW DOES CLIMATE CHANGE AFFECT HUMAN HEALTH?

Over the last 50 years, scientists have discovered many ways that climate change affects our health (Figure 1). For example, heatwaves are happening more often, making it hard to keep our bodies cool. Extreme heat can be dangerous, especially for older people, those who already suffer from diseases, and people who work outdoors, such as builders and farmers. In Europe, temperatures are becoming so hot that it can be dangerous to exercise or play outdoors in the middle of the day without proper shade [3, 4]. Combined with extreme heat, air polluted with greenhouse gases and particles can lead to heart and lung diseases. Droughts can lead to plants not getting enough water to produce food, making it harder for people to eat and stay healthy. At the same time, there may not be enough water for humans and animals to drink or clean themselves. Droughts can also contribute to wildfires that burn large areas of forests and create a lot of smoke. Smoke contains tiny particles that can make it hard to breathe, cause coughing, and irritate our eyes. Climate change can also shift and lengthen the flowering season for trees, making pollen allergies and asthma worse for longer periods of the year [3].

As if this is not enough, climate change can also make it easier for **infectious diseases** to spread. Infectious diseases are illnesses caused by tiny germs (e.g., viruses, bacteria, parasites) that can move from person to person, or from an animal or insect to a person. As the weather gets warmer, these diseases can spread to new places that used to be too cold for them. Warmer weather creates better conditions for ticks and many insects, like mosquitoes and sandflies, which feed on the blood of both animals and humans. Bites from these insects can transmit infectious diseases such as dengue, malaria, West Nile virus, Lyme disease, and leishmaniasis, which can make people very sick. As more people travel around the world in airplanes, infectious diseases spread to new regions. Doctors, veterinarians, and pest-control teams must be on the lookout for infectious diseases they have not had to deal with in the past.

INFECTIOUS DISEASES

Illnesses caused by tiny germs like bacteria, viruses, parasites, or fungi that can spread from one person to another or from an insect or tick to another person.

Figure 1

How climate change affects human health (Figure credit: Lancet Countdown in Europe).

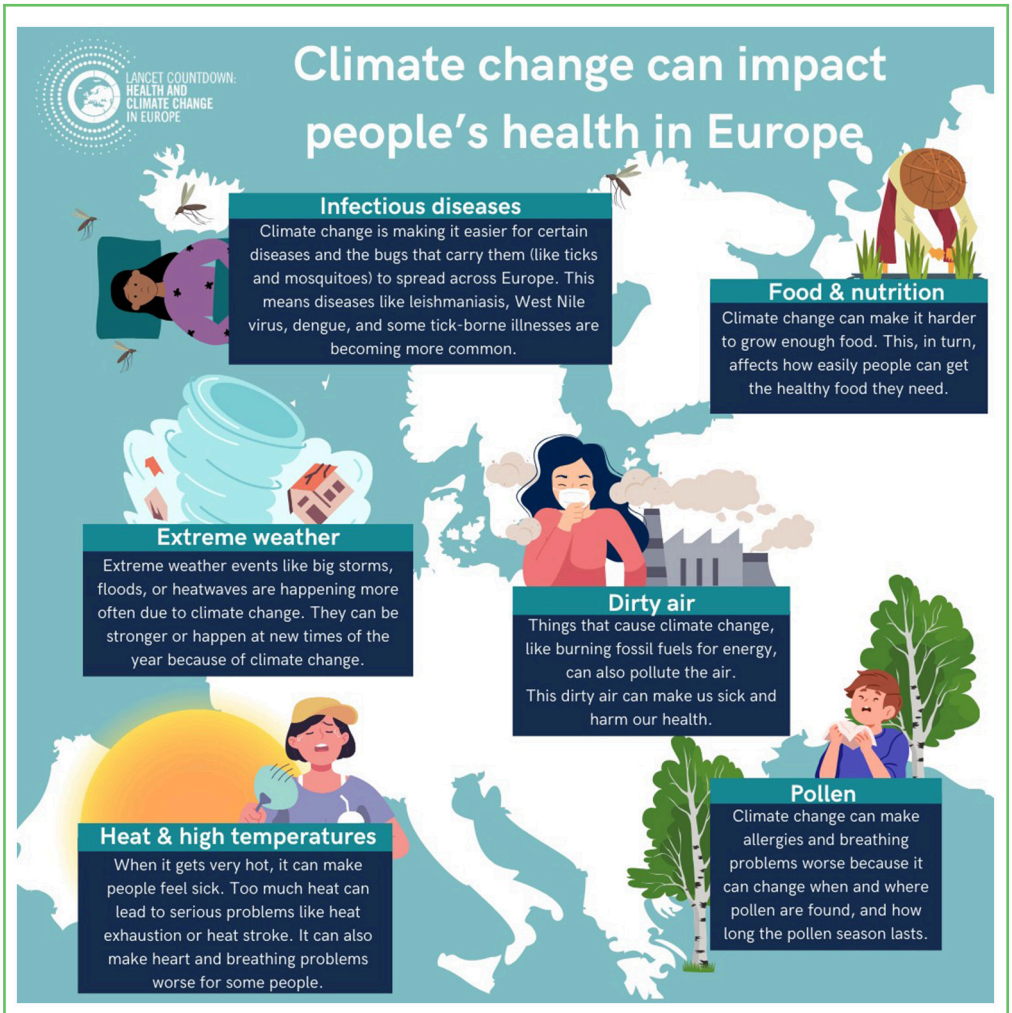

Figure 1

ADAPTING TO A CHANGING CLIMATE

In addition to reducing greenhouse gases, Europe needs to stop the harmful health impacts of climate change from getting worse. This is called climate change adaptation, and it includes creating early warning systems that can warn people about things like heatwaves, floods, or disease outbreaks. An early warning system, just like the weather forecasts you see on the news, can help keep us safe by letting us know about dangerous events before they happen. If alerts are shared early, governments and individuals can prepare in advance and try to minimize potential disruption, damage, and bad health outcomes.

As more people move to cities, urban areas must be designed to deal with higher temperatures and extreme weather. This could include planting more trees to provide shade and creating green spaces, like parks, gardens, or urban forests. Plants help the Earth to fight climate change naturally by removing carbon dioxide from the atmosphere. Cities can also reduce the amount of heat-trapping

pavement and improve buildings to make them stronger and cooler. Strong health systems are also important to adapt to climate change. Doctors, nurses, hospitals, and healthcare centers need to be ready to handle the new health challenges from climate change, including heat-related illnesses and new infectious diseases.

HEALTH BENEFITS OF CLIMATE ACTION

EMISSIONS

Release of gases into the air, through burning fuel to power cars and make electricity, or when cows digest their food.

Although the health harms from climate change may sound scary, there is good news! Doing things to reduce greenhouse gas **emissions** can have many positive effects, such as cleaner air, cleaner water, more healthy food, stronger health systems, better public health, and more environmentally friendly technologies (Figure 2). These changes will also improve people's health. Reducing greenhouse gas emissions is a win–win situation for both people and the planet. This action slows down climate change and its harmful impact on health, but it also makes people healthier in other ways. For example, when we burn fewer fossil fuels, the air becomes cleaner and fewer people get sick from breathing polluted air. Walking or riding a bike instead of driving a car helps keep the air clean *and* helps people keep fit and healthy. Producing meat from cows and sheep (also called red meat) releases large amounts of greenhouse gases. Eating less red meat and more beans, whole grains, fruits, and vegetables reduces emissions *and* improves our health at the same time. Healthy diets based mainly on plants reduce the risk of heart disease and other health problems.

RENEWABLE ENERGY

Energy that comes from natural sources like the sun, wind, or water. Renewable energy does not cause pollution or greenhouse gas emissions like burning fossil fuels does.

Ignoring climate change can be very expensive now and in years to come. Extreme weather, such as storms and floods, can damage buildings, roads, bridges, and homes. Health problems caused by climate change can also be expensive for doctors and nurses to treat. At the same time, investing in **renewable energy**, which is energy generated by nature, like wind, water, and sunshine, can save money in the long run. For example, switching to renewable energy could create new jobs and opportunities. By preventing damage and health problems caused by extreme weather, countries can save a lot of money. This money can be used for other important things, like better schools and hospitals.

Several infographics illustrating the various impacts of climate change on human health, as well as the health co-benefits of climate action, are available online; examples are shown in Figure 3.

TAKING ACTION TOGETHER

People are becoming more aware of the health harms of climate change. However, individuals, businesses, and the news are not talking enough about this important issue. In the European Parliament, where politicians from multiple European countries make important

Figure 2

Figure 2

Actions that help slow down climate change and are also good for human health. Dark blue boxes represent actions that individuals, communities and governments can take. Light blue boxes indicate positive outcomes of these actions to slow down climate change and improve human health. Each action is connected with the corresponding benefit using dotted lines (Figure credit: Lancet Countdown in Europe).

decisions, there is growing talk about climate change. However, more attention is needed on how climate change affects people's health. When leaders understand this connection, they can make better choices to protect both the environment and public health [3, 4].

Governments, businesses, and communities need to work together to fight climate change. Governments can create laws that reduce greenhouse gas emissions and help those whose jobs are affected by less use of fossil fuels. Laws and other government actions could include setting limits on how much greenhouse gases each country can release, investing in renewable energy, supporting public transportation, and building more bike lanes and green spaces. The early cost of fixing climate change is worthwhile because it helps us avoid larger expenses and damage in the long run.

Businesses can help by polluting less, by using more renewable energy, and by creating products that are more environmentally friendly. Scientists can help by communicating their findings on climate and health in a clear, easy-to-understand way. People who share news,

Figure 3

Figure 3

Four example infographics on climate and health. This figure showcases four sample infographics illustrating how climate change and health are connected. Each highlights a different theme: heat, fossil fuels, green spaces and food. All individual infographics are available at: https://idalertproject.eu/lancet-countdown-indicators-young-minds (Figure credit: Lancet Countdown in Europe).

like journalists and social media users, can share more about how climate change affects our health, to help everyone understand why taking care of our planet is so important for keeping people healthy. The public can help by making small changes in their daily lives, such as eating less red meat and more fruit and vegetables, or by walking or biking instead of traveling by car. You can also talk to your friends and family about how climate change affects health and how taking climate action can benefit health. The more people understand this connection, the more they might want to help. By taking action against climate change, we not only protect the planet but also make our lives healthier and safer. Every action, both big and small, helps fight climate change and protects our health. Together, we can and will make a big impact!

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REFERENCES

1. van Daalen, K. R., Tonne, C., Borrell, C., Nilsson, M., and Lowe, R. 2023. Approaching unsafe limits: climate-related health inequities within and beyond Europe. *Lancet Reg. Health Eur.* 31:100683. doi: 10.1016/j.lanepe.2023.100683
2. Romanello, M., Di Napoli, C., Green, C., Kennard, H., Lampard, P., Scamman, D., et al. 2023. The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. *Lancet* 402:2346–94. doi: 10.1016/S0140-6736(23)01859-7
3. Van Daalen, K. R., Tonne, C., Semenza, J. C., Rocklöv, J., Markandya, A., Dasandi, N., et al., 2024. The 2024 Europe report of the Lancet Countdown on health and climate change: unprecedented warming demands unprecedented action. *Lancet Public Health* 9:e495–522. doi: 10.1016/S2468-2667(24)00055-0
4. van Daalen, K. R., Romanello, M., Rocklöv, J., Semenza, J. C., Tonne, C., Markandya, A., et al. 2022. The 2022 Europe report of the Lancet Countdown on health and climate change: towards a climate resilient future. *Lancet Public Health* 7:e942–65. doi: 10.1016/S2468-2667(22)00197-9

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YOUNG REVIEWERS

TRICIA, AGE: 14

Hi, my name is Tricia, and I am 14 years old. I am interested in chemistry and biology. However, oncology has always been fascinating to me. I hope to be an anesthesiologist in the future. When I am not in school or learning, I enjoy playing volleyball and hanging out with my friends. It has been a privilege to work with Frontiers for Young Minds!

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Rachel is an ICREA research professor working at the Barcelona Supercomputing Center to develop computer models to solve global health challenges, such as the emergence and spread of infectious diseases. Rachel works together with mathematicians, climate scientists, epidemiologists, geographers, medical doctors, and policy makers to develop early warning systems and help United Nations agencies and governments protect local communities from global environmental change.

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Jan is an environmental epidemiologist and has studied climate change and health for 30 years. For example, he examined why so many people died in Chicago in 1995 during a terrible heat wave. He found that many lonely people died because they had no friends to look after them when they felt bad because of the heat. Now we know that we need to look after people when it gets hot during a heat wave.

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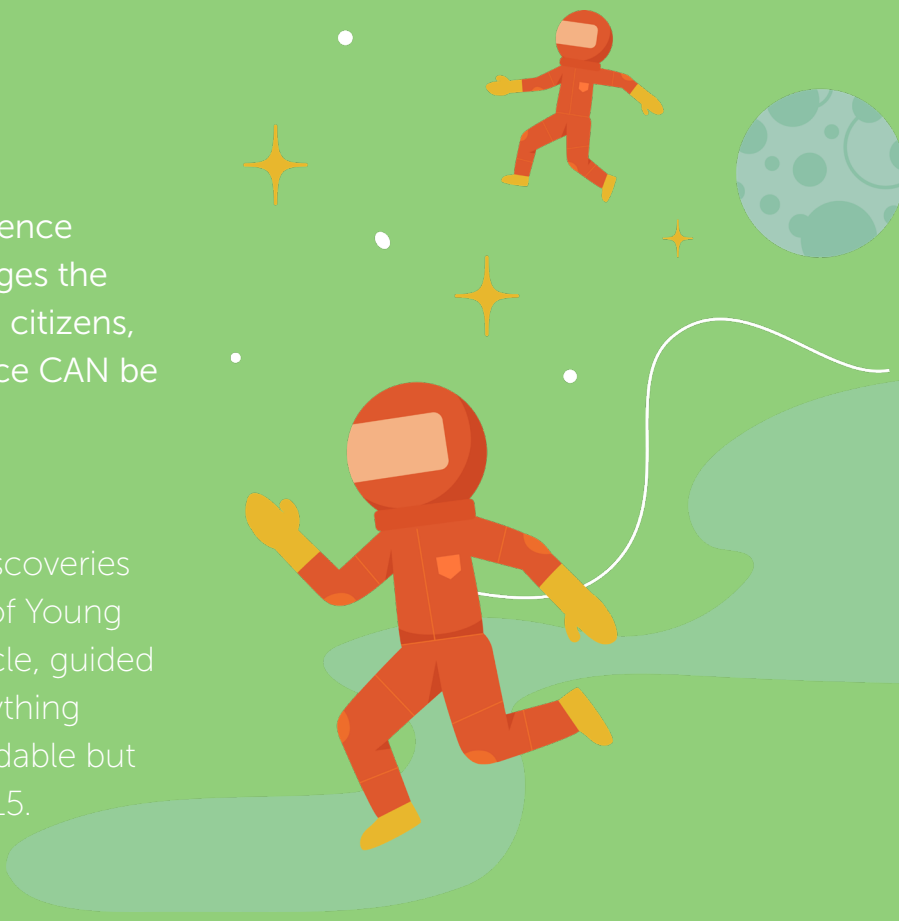

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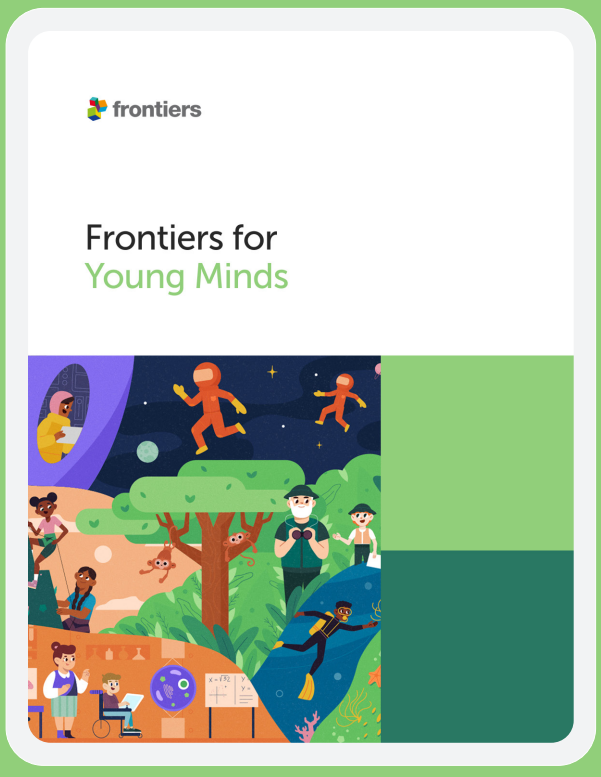

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