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EARTH SCIENCES
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WATER FLOWS DOWNHILL: HOW LOOKING "UPSTREAM" CAN HELP MAINTAIN A HEALTHY SEA

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YOUNG REVIEWERS:

AYAT
AGE: 12

Our planet is in trouble. We are losing plants, animals, and habitats, and the processes that link them are changing. Nature is becoming sick. People have been trying to fix this problem, but the situation keeps getting worse. One problem is people ignore a simple law of

GERMOGLI-AMO
AGES: 9–10

nature—ecosystems are connected. For example, when forests are cut down, soil is exposed to rainfall and washed into the sea, where it covers and kills shellfish. We made a computer model to explore what happens when the people making the rules on land are slow to respond to problems in the sea. We found that paying attention to the natural land-to-sea connections can help save all ecosystems from sickness. Our computer model demonstrates to governments that a major solution to environmental crises is to realize the connections between ecosystems, and talk and work with each other. Our job is to make them listen!

PEOPLE ARE NOT HELPING ECOSYSTEMS QUICKLY ENOUGH!

You have probably heard about the multiple crises the planet and humanity are facing, from a warming climate to the widespread loss of species. It sounds grim, but there are solutions! First, we need to understand the problems that we might encounter on the path to finding those solutions.

The **biodiversity** crisis—the loss of many of the unique forms of life on Earth—is one of the biggest problems humanity faces. Since humans started roaming the Earth, half of all natural forests and most species of wildlife have been lost [1, 2]. This loss is a massive problem because it puts **ecosystems** out of balance, making them vulnerable to collapse and threatening our existence. This crisis is not just about the loss of forests and large animals. All forms of life have important roles to play in our planet's life-support system, contributing to our food, water, and the air we breathe.

But humans are smart, right? And we know a lot about the causes of the biodiversity crisis. So why are we not doing more to stop it? The good thing is that people everywhere are working to solve this problem, and **conservation** is helping protect ecosystems from further damage. The problem is that our progress is too slow. To find a solution and speed up our progress restoring ecosystems, we first need to figure out why people's reactions to environmental problems are so slow.

BIODIVERSITY

The variety of life on Earth. Biodiversity can be the variety of animals, plants, fungi, microbes, and habitats. High biodiversity is generally considered important for the function of the Earth.

ECOSYSTEM

An area where both living (plants, animals, microbes) and non-living elements (weather, rocks, sand, water, natural chemicals) work together and interact in balance to form a unique bubble of life.

CONSERVATION

The practice of protecting the natural environment from negative impacts of human activities.

WHY ARE PEOPLE SLOW TO PROTECT AND RESTORE ECOSYSTEMS?

One of the reasons people are slow to act is because people do not talk to each other. This might sound too simple, but it is true—people in charge tend to focus on only one problem at a time rather than looking for ways to solve many problems together. For example, in most countries there are separate departments in government,

with different people writing different rulebooks (called policies) for things like building cities, cutting down forests, and catching fish from the sea. Then there are other departments writing policies about protecting ecosystems. These are all busy people, so they do not talk to each other often enough—and this can create confusing policies.

Different rules for different places, activities, or ecosystems make it hard to make fair decisions for everyone and to protect ecosystems. This is a problem because the plants and animals on land, in streams and lakes, and in the sea are all connected. If people do not talk about all the connections, they might make decisions that have bad consequences elsewhere on the planet.

LAND, FRESHWATER, AND SEA ARE CONNECTED

Ecosystem connections are a natural part of the balance of life on Earth. For example, fish such as salmon migrate from streams out to sea, where they feed and get lots of nutrients for their journey back upstream, where they breed and release their eggs (Figure 1A). On their way upstream, some salmon get eaten by bears (Figure 1B), who poo in the forests and fertilize the trees with the nutrients that the fish brought from the sea [3]! In island ecosystems, seabirds provide the same **"Nature's contribution to people"** (sometimes also called "ecosystem services"). These connections between ecosystems can be found everywhere, and they often involve the movement of plants, animals, nutrients, and other forms of energy.

"NATURE'S CONTRIBUTIONS TO PEOPLE"

All the ways that nature can benefit people's quality of life. Examples include providing food and water, and regulating environmental conditions like reducing flooding risks.

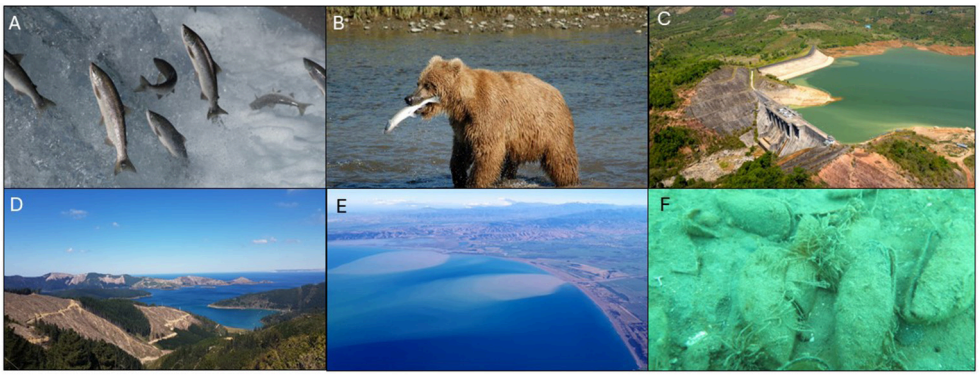

Figure 1

(A) Salmon migrate from the sea upstream. **(B)** Those salmon provide food for bears in the rivers. **(C)** Building dams stops this important connection. **(D)** Cutting down forests exposes large, bare patches of soil, like on the hillsides in this photo. **(E)** This soil is washed by the rain into rivers and out to sea. **(F)** The soil eventually settles to the seafloor and smothers shellfish species living there, like mussels. (Photo credits: **(A)** Russ Taylor, NPS, PDM 1.0 via Flickr; **(B)** Carl Chapman, USA, CC2.0 via Wikimedia; **(C)** Quang Nguyen Vinh via pexels; **(D)** R. Gladstone-Gallagher; **(E)** C. Cornelison; **(F)** J. Hillman)

Bears pooping in the woods are just one example—many connections are critical for the Earth to function and support life. However, these connections also mean that when we damage one ecosystem, it has consequences for other ecosystems. For example, when we build a dam to store water (Figure 1C), we can block fish from migrating and providing food for the bears and nutrients for the forest. Building that dam removes a major food source for the bears upstream! When we

cut down forests, large areas of bare soil are exposed (Figure 1D). When it rains, that soil gets washed into the rivers and out to sea (Figure 1E), smothering and killing the shellfish (like mussels) on the seafloor (Figure 1F) [4]. Thus, when we cut down trees, it can destroy the homes of forest animals (like bears) and animals downstream (like mussels living in the ocean).

You are probably starting to see the problem emerging—people make decisions "upstream" without thinking about the consequences for the people and ecosystems "downstream", like the shellfish in the ocean. On the other hand, people "downstream" make decisions without thinking about the consequences "upstream", like the bears living upstream of the dam.

WE NEED TO RESPECT THE CONNECTIONS!

We wanted to find out what happens to ecosystems when people do not look downstream before they make the rules and decisions. We made a **computer model** to explore the consequences for an ecosystem in the sea, depending on the upstream activities on land and how fast people react to environmental change. In our computer model we tested three cases, but we will just talk about two of them here.

COMPUTER MODEL

A computer program that simulates how parts of a system—like plants, water, and weather—interact, helping scientists explore what might happens when something changes.

TIPPING POINT

When a small environmental change results in a large reduction in the health of the ecosystem, from which it is difficult to recover.

In the first case, the people making policies on land were not the same people suffering the consequences downstream (e.g., the people who had fewer fish to catch or no clean beaches to swim at) (Figure 2A). This slows the action to help the downstream ecosystem, which can cause the ecosystem to reach its **tipping point**. Tipping points occur when small changes have big consequences. Think about kicking a ball up a hill. It takes lots of effort to kick it to the top of the hill, but once you get to the top of the hill, you only need one little kick over the top, and it will start rolling down the other side of the hill on its own. Once the ball is rolling down the hill, it gets faster, and it is hard to catch up to stop it. Tipping points in ecosystems are similar, but the consequence is rapid damage to the ecosystem (To learn more about tipping points, see this Frontiers for Young Minds article). It is difficult for us to catch up and reverse the ecosystem damage once it has started, and the ecosystem may never recover. Our model showed that tipping points can occur when people do not talk to each other and when they are slow to act.

In the second case, actions to protect the ecosystem are faster because everyone works together and recognizes that land, freshwater, and sea ecosystems are connected—ensuring healthy ecosystems for everyone (Figure 2B). This means that the people who are in charge of the policies for activities on land not only talk to the people who live and work on land, but also to those who live and work along the streams and in the sea. The people making the policies for the people

Figure 2

Can you spot the differences between **(A)** and **(B)**? **(A)** Here, the people making decisions may not talk to the people who suffer the consequences of the decisions. **(B)** Here, people are working together. More land is set aside for native trees and there is less impact from human activities like deforestation, farming, and factories. This means less pollution and erosion of soil into the water, so aquatic ecosystems are clean and have more fish. Some fish can migrate, maintaining healthy connections across land, freshwater, and sea. More people are enjoying the environment.

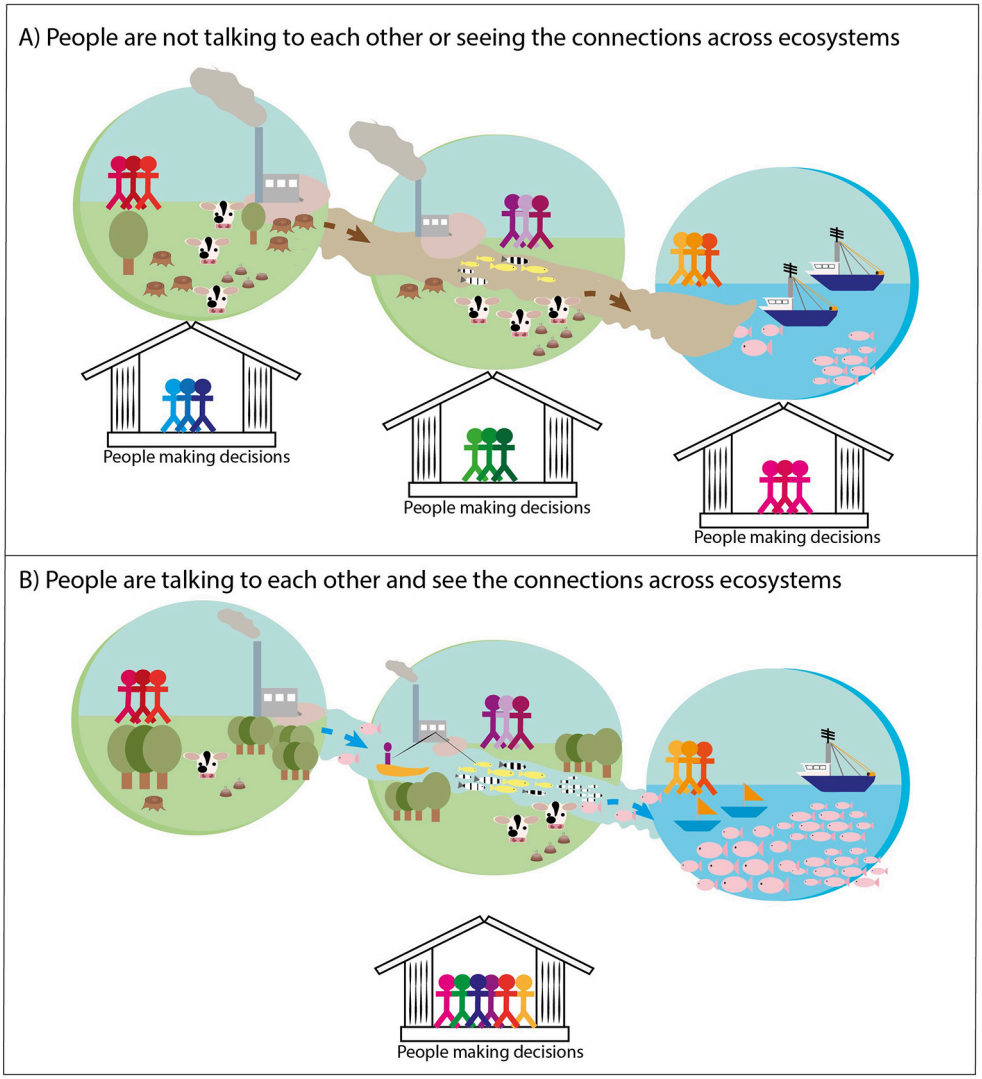

Figure 2

fishing in the sea talk to the people making the policies for activities on land.

"Nature's contributions to people" (e.g., food, clean water, clean air to breathe) can be lost if tipping points are reached (like in Figure 2A) [5]. This happens because, for example, the people benefitting from cutting down forests are separated from and do not see the consequences for people downstream, who rely on shellfish for food. These types of consequences are often felt by **Indigenous people** and less privileged people, leading to an unequal society. Other activities that can have negative consequences for connected ecosystems and "Nature's contribution to people" are pollution and plastic litter from towns and cities, factories and farms, and too much fishing or hunting.

INDIGENOUS PEOPLE

Ethnic groups whose ancestors lived on and had connections with the lands, natural resources, and ecosystems of a place and consider themselves distinct from other people occupying the area.

WORKING TOGETHER WITH NATURE TO PROTECT ECOSYSTEMS

Our research shows that we need to work with nature by taking notice of the "good" connections (e.g., migrating fish) and the "bad" connections (e.g., flow of pollutants) between land, freshwater, and sea. We need to show the governments who make policies, and the local/regional people (who make individual decisions based on those policies) that ecosystems are connected and that working together across land, freshwater, and sea will result in faster actions and a healthier environment. To work together, we will need to encourage a new culture for people who make the rules, people who are doing the activities (e.g., building cities and harvesting forests), and people who suffer the consequences of other people's activities in the environment. We need more research that connects land, freshwater, and sea ecosystem science with **social sciences** (science about people and how they behave). For centuries, Indigenous people worldwide have been guardians of the natural world, understanding connections between ecosystems. To protect Earth's ecosystems and connections for future generations we need to get better at combining science, Indigenous knowledge and people's values and behaviors so that we can improve the way we manage the environment.

SOCIAL SCIENCES

The scientific study of human society, behaviors, and relationships.

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YOUNG REVIEWERS

AYAT, AGE: 12

I am a 12-year-old with a big passion for sketching and painting, especially when nature sparks my creativity. My favorite books, like "Amari" and "The Magicians of Paris", along with other fantasy stories, fuel my imagination. I love cycling, playing chess and badminton, and hiking to uncover nature's hidden treasures. Along the way, I enjoy taking notes and drawing detailed sketches of the plants and animals I encounter!

GERMOGLIAMO, AGES: 9–10

The Sprouts group of Young Reviewers is composed byEdoardo, Ilyan, Yuri, Flavio, Ernesto, and Lorenzoand Mattia. They attend their 4th-5th year at the primary outdoor parental school GermogliAmo in Colonna (nearby Rome, Italy).

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Johanna Yletyinen is a senior researcher at the University of Jyväskylä, Finland. She investigates the resilience and sustainability of natural resource systems, such as fisheries and forests. She often uses modeling to better understand the complex interactions between people and the environment. Her work aims to find solutions for improving the wellbeing of both people and the environment.

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Emily Douglas is a marine ecologist at the National Institute of Water and Atmosphere (NIWA) in Aotearoa New Zealand. Her research focuses on coastal seafloor ecosystems, and how those ecosystems change with climate change and other human-made stressors. She uses field experiments and modeling to investigate what happens to ecosystem functioning and biodiversity when stressors like heatwaves and nutrient pollution occur.

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Conrad Pilditch is a professor in marine science at University of Auckland in Aotearoa New Zealand. His research focuses on marine soft sediment ecosystems, one of the most extensive habitats on the planet. He explores how these ecosystems are impacted by human activities and climate change. Conrad and his team of students and collaborators have generated new knowledge that underpins better environmental management.

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Dr. Ewa Siwicka has over 10 years of experience exploring how nature contributes to human wellbeing. Ewa's mission is to make nature restoration an integral part of the economy. Ewa's work helps businesses and organizations navigate their transition toward nature-positive.

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