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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.

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.

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.

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.

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

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.

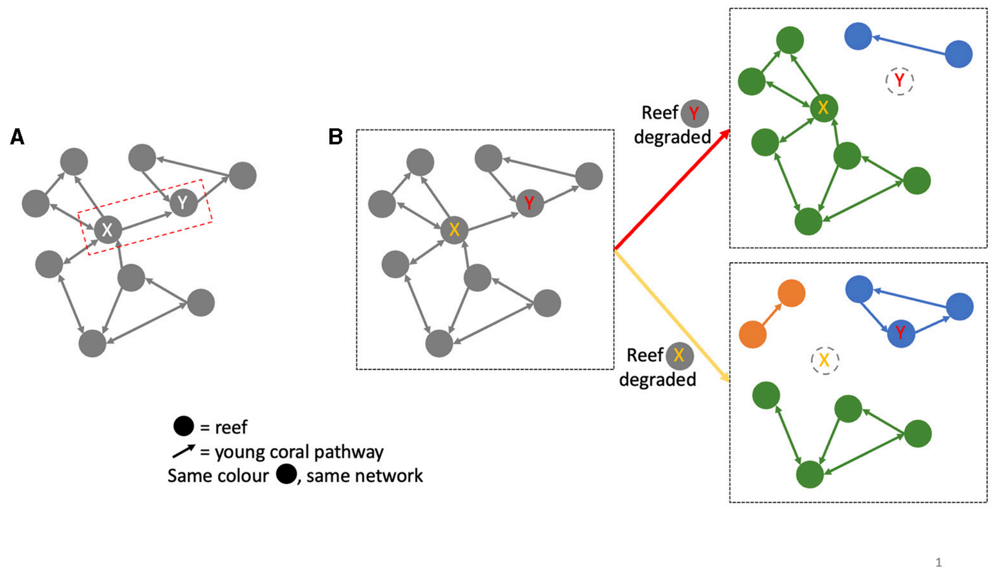

Figure 1

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.

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).

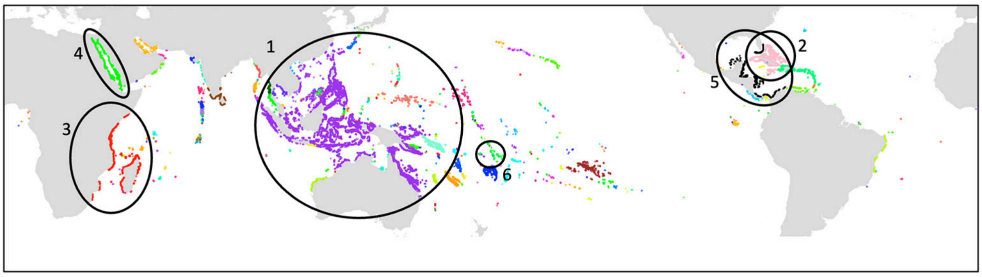

Figure 2

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.

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.

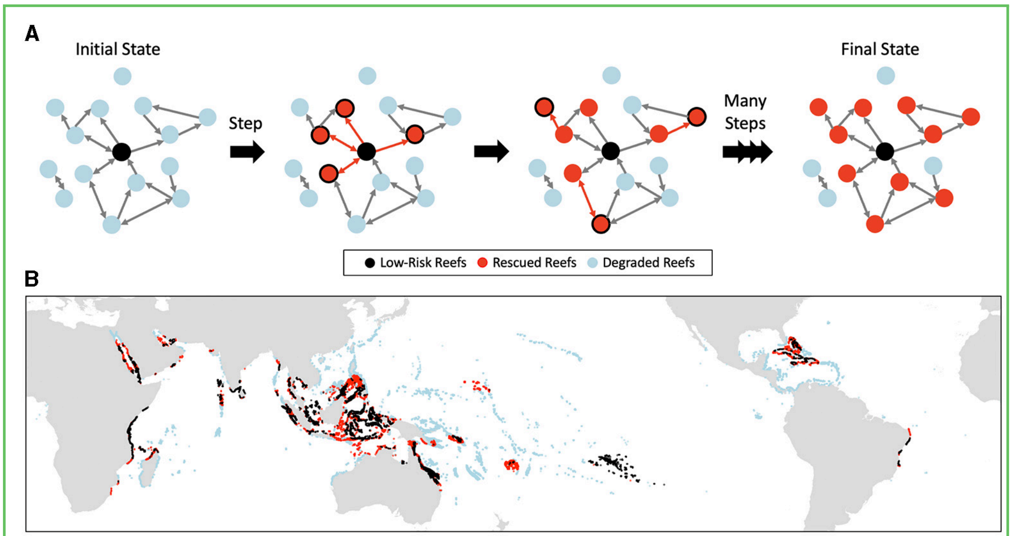

Figure 3

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.

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ORIGINAL SOURCE ARTICLE

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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.

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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

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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.

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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.