

Antarctica is not protected from an influx of new species

Nonnative organisms have the unexpected potential to colonize the southern polar region, according to an interdisciplinary study that combined DNA analysis and ocean-current dynamics.

Life in Antarctica is different from anywhere else on Earth. In addition to its penguins, seals, and other large animals, the southernmost continent and its surrounding waters are home to a unique community of mosses, lichens, seaweeds, fish, and invertebrates that have evolved in apparent isolation, with almost no ecological interaction with the rest of the world since at least the Last Glacial Maximum, 18,000 years ago.

That degree of isolation is unusual. Antarctica is remote, to be sure, but so are many other land masses and small islands that aren't nearly so biologically insulated. Vast stretches of ocean aren't normally an impassable barrier to species migration; organisms have plenty of mechanisms to float, fly, or be carried across the water to new homes.

Unique to Antarctica, though, are the powerful winds and ocean currents that encircle the continent. They're known to provide a measure of protection against warmer waters from farther north, and they're thought to prevent organisms drifting by air or by sea from ever reaching Antarctic shores. (For more on currents in the Southern Ocean, see the article by Adele Morrison, Thomas Frölicher, and Jorge Sarmiento, *PHYSICS TODAY*, January 2015, page 27.) With such an unbreachable physical barrier to natural migration, the reasoning goes, the only way new organisms could colonize Antarctica is if they were brought there by humans. To forestall that possibility, all researchers and tourists traveling to Antarctica are subject to stringent measures to make sure they're not carrying any foreign mud, seeds, or insects.

Now Ceridwen Fraser, Adele Morrison



(both at the Australian National University), and their colleagues have shown that conclusion to be incorrect: Currents and winds notwithstanding, passive drifting of plants and animals from lower latitudes to Antarctica is not just possible but frequent.¹ The newcomers fail to settle because the inhospitable Antarctic climate kills them before they can take up residence. But as the global climate changes, so, too, could Antarctica's ecology.

Kelp drifters

In early 2017 marine biologist Erasmo Macaya of the University of Concepción in Chile traveled to Antarctica for a scientific mission. Unforeseen circumstances, however, left him on base for several weeks with nothing to do. While walking on the beach on King George Island, situated next to the tip of the slender Antarctic Peninsula, he came across a piece

FIGURE 1. SOUTHERN BULL KELP can float on the open ocean for thousands of kilometers over hundreds of days. It survives well in cold water, has colonized many remote islands in the Southern Hemisphere, and is now known to be able to reach Antarctica. (Courtesy of Erasmo Macaya.)

of southern bull kelp that had drifted ashore. Three weeks later, one of his colleagues found another one.

Southern bull kelp, shown in figure 1 and on the cover of this issue, grows throughout much of the Southern Hemisphere—but not, so far, in Antarctica. Macaya recognized that the plants were out of place, and he wrote to Fraser, who he knew was interested in the species.

For more than a decade, Fraser had been studying how southern bull kelp migrates from place to place and carries other species with it. The kelp grows on

rocks in intertidal zones, where waves and currents require it to withstand strong forces. When the host rock breaks and the kelp drifts away, its buoyancy and toughness can keep it afloat, alive, and reproductively viable for several years. At any given time, an estimated 70 million of the aquatic plants are adrift on Southern Hemisphere oceans, and more than a quarter of them carry some other species as a passenger. Mollusks and other shellfish attached to the kelp can survive and even reproduce at sea for several generations.

Southern bull kelp populations from Chile, New Zealand, and numerous small islands have subtle genetic differences that hold clues about how the species spread. "But it's hard to get good DNA from the kelps," says Fraser, "because their jellylike substances interfere with genetic reactions." Her work involved not only collecting kelp samples from everywhere they grow but also developing new lab procedures for extracting their DNA.²

By the time the specimens were found on King George Island, Fraser had a good database of the kelp's genetic variations. Analyzing 16000 DNA base pairs from each new specimen turned up clear matches to their geographical origins: One had come from the Atlantic island of South Georgia, due east of the southern tip of South America; the other had originated in the Kerguelen Islands in the Indian Ocean. They are the first objects found on Antarctic shores proven to have originated from the subantarctic.

Current crossing

But how did the kelps get to Antarctica? And was their arrival a rare fluke, or might more be washing up unnoticed elsewhere on the Antarctic coast? To investigate those questions, Fraser turned to Morrison, an experienced Southern Ocean modeler.

According to conventional models, the powerful eastward Antarctic Circumpolar Current has enough of a northward component to prevent any floating material from crossing north to south. But more detailed models can account for the ways that drifting objects might not move in tandem with underlying large-scale currents. As Morrison found, incorporating smaller-scale processes into simulations can qualitatively change the results.

One such process is turbulence in the form of eddies tens of kilometers across. "We thought that just including the eddies would be enough to simulate southward drift," says Morrison. "We were surprised that their effect was so small." As shown by the brown trajectories in figure 2a, simulated particles originating from South Georgia and floating under the influence of eddy turbulence still all drifted north. None of them even came close to Antarctica.

The answer to the puzzle lay in a second effect: Stokes drift, a nonlinear consequence of wave motion. The usual description of surface waves on water is that they carry energy but no mass; however, that's not quite true. Under Stokes drift, parcels of surface water move slowly but steadily in the direction of wave propagation.

Ocean models aren't detailed enough to resolve surface waves, and Stokes drift is usually considered to be negligible. But waves in the Southern Ocean are large—in stormy weather, heights of 10–15 m are typical—so Morrison decided to see what would happen if she accounted for them.

As shown in figure 2b, Stokes drift by itself isn't enough to drive drifting particles southward past the Antarctic Circumpolar Current. But with eddies and Stokes drift together, as shown in figure 2c, many of the simulated particles started reaching Antarctica. In relative terms, the numbers were small: just 0.2% of the particles released from South Georgia and 0.0001%–0.01% of the ones released from the Kerguelen Islands and two other subantarctic sources. But millions of southern bull kelps are set adrift in the ocean every year. A fraction of a percent of them, added up over time, is a significant number.

Furthermore, those fractions could still be underestimates. "We didn't consider windage, the direct force of the wind to push a floating object along like a sailboat," says Morrison. The effect of windage is probably not large, because floating kelps are mostly submerged. But because wind and surface waves usually move in the same direction, any effect windage did have would serve to enhance the Stokes drift—that is, to push even more particles south to Antarctica.

An uncertain future

By Morrison's rough estimates, on the order of 100 pieces of kelp—one for every

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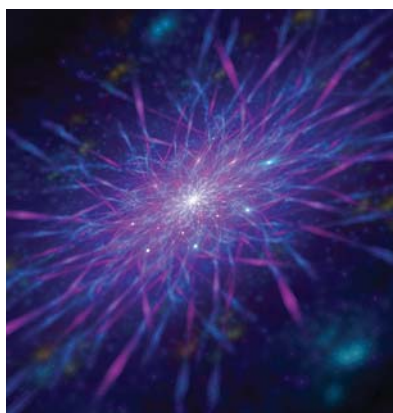


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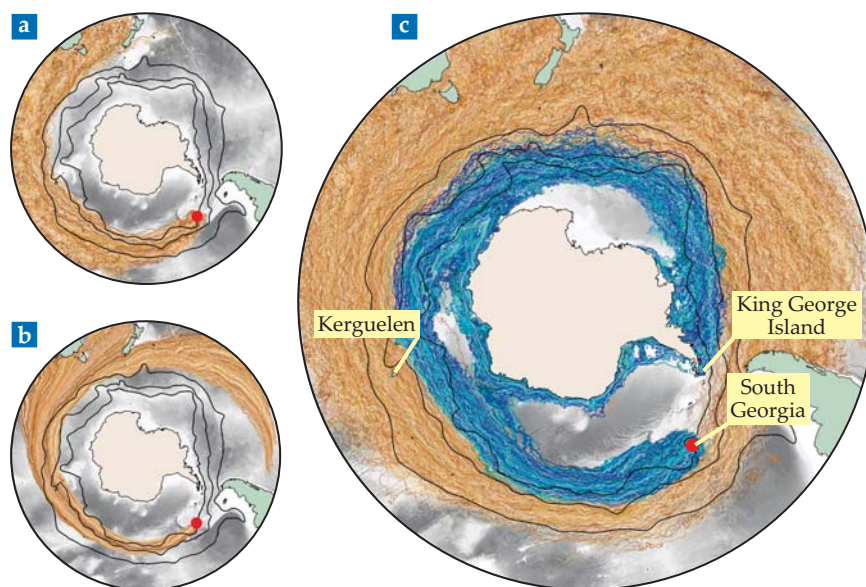


FIGURE 2. OCEAN-CIRCULATION SIMULATIONS test whether passively floating material can travel from the Atlantic island of South Georgia to Antarctica. Brown trajectories represent simulated particles that don't reach Antarctica; blue trajectories represent ones that do. The three panels show the results of simulations that incorporate (a) eddies but not Stokes drift, (b) Stokes drift but not eddies, and (c) both eddies and Stokes drift. (Adapted from ref. 1.)

200 km of coastline—could lie on Antarctic shores at any given time. That's more than enough to start an ecological colonization but still sparse enough to have gone largely unnoticed. "Interestingly, the kelp last year was not actually a one-off find," says Fraser. "A few days after our paper was published, we were contacted by a researcher at the herbarium of the University of California, Berkeley. He let us know that they have a southern bull kelp specimen in their collections, found in Antarctica in 1989. It's just that at the time, the significance of the finding was not recognized."

That so much kelp is arriving in Antarctica without establishing a population there is best explained by environmental factors. The kelp, along with all the passengers it carries, just isn't well adapted to such a cold climate. That insight has implications for both Antarctica's past and its future. The continent's unique plants and animals evolved the way they did not because they lacked contact with other species, as previously thought, but because they're uniquely adapted to Antarctic conditions.

But Antarctica is one of the fastest warming areas of the planet, and as conditions there change, its plants and animals could face a double threat. They'll have to contend with not only the rising temperatures themselves but also com-

petition from newly arriving species that are better suited to the warming conditions. Particularly significant change may be in store for the Antarctic intertidal zone. Right now, not much lives there, and the rocks are scrubbed clean by ice. If southern bull kelp were to move in, it would provide food and shelter for numerous other species and dramatically reshape the ecosystem.

Importantly, Fraser, Morrison, and colleagues' results are descriptive, not predictive, and many unknowns remain. "We've modeled what is happening now," says Fraser, "but we're waving our hands when we say what it will mean for the future." For example, the study says nothing about which species are most likely to establish new populations in Antarctica, or which Antarctic species will be most vulnerable. The winds, currents, and storms of the Southern Ocean will themselves be altered by climate change, and it's not clear whether southward drift will become more or less likely. Answering those questions should offer a clearer picture of Antarctica's ecological future.

Johanna Miller

References

1. C. I. Fraser et al., *Nat. Clim. Change* **8**, 704 (2018).
2. C. I. Fraser et al., *Mol. Ecol.* **25**, 3683 (2016).