

Atlantic invertebrates are going the wrong way

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Why, as the oceans warm, are seafloor animals moving to even hotter waters?

Some species can save themselves from climate change simply by moving. Although organisms that are adapted to Earth's coldest climates may be left with nowhere to go in a warming world, those from temperate and tropical zones might find new homes in cooler regions: uphill for land species, in deeper water for aquatic ones, and toward the poles for both. Even if individual organisms, such as plants, can't migrate under their own power, their population as a whole can still shift, as offspring dispersed in cooler directions are more likely to survive.

But just because cooler homes exist doesn't mean species can or do reach them. Habitat destruction might obstruct their paths (see *PHYSICS TODAY*, September 2019, page 16). Or warming might be too rapid for a species to keep pace. Now Rutgers University's Heidi Fuchs and colleagues have identified yet another mechanism that not only blocks species from reaching cooler habitats but actually pushes them into warmer ones.¹

The Rutgers study concerned several dozen species of bottom-dwelling marine invertebrates—including the blue mussels shown in figure 1 and the starfish shown on the cover of this issue—that inhabit the continental shelf off the east coast of North America. Like plants, the seafloor species are mobile primarily between generations. Their adults are mostly or entirely sessile. The newborn larvae can swim, but not well, so they drift at the mercy of the current for a few weeks before settling into their permanent homes.

The patterns of currents along the Northwest Atlantic continental shelf haven't been altered much by climate change—at least not yet. But they do vary with the seasons just as they always have.² Ocean warming, Fuchs and colleagues concluded, is triggering the animals to spawn at the wrong time of year, when the larvae encounter currents they're not evolutionarily accustomed to and are swept into warmer and shallower waters.

Range shift

The Rutgers project grew out of a study of two aquatic snail species. Although



FIGURE 1. BLUE MUSSELS, seen here in Canadian waters, inhabit coastal regions around the world. In the Northwest Atlantic, they're among dozens of species now found to have a counterintuitive response to climate change.

the species are related, their larvae respond differently to waves and turbulence. Fuchs and colleagues wanted to see whether that difference influenced their distribution over time. "I noticed that one of the snails had shifted to shallower water," says Fuchs. "I was curious whether other species had done the same."

Information abounds about where marine animals have lived over the years. Censuses of marine life are important not just to scientists but to the commercial fishing industry. Decades of worldwide records are now compiled into a single open-access searchable source, the Ocean Biodiversity Information System (OBIS).

But it can be hard to infer from the data which way species are moving or why. Oceans overall are warming more slowly than Earth's land surface, and that warming isn't uniform in space or

time. The data are noisy, and species often seem to be shifting their ranges in unexpected ways: toward the Equator, east or west, or nowhere at all.

In 2013 Malin Pinsky (also at Rutgers, but not involved in the new research) and his colleagues showed that shifts in marine habitats were generally well explained by a concept called local climate velocity: Species go in whatever direction they need to, as far and as fast as necessary, to remain in a habitat of constant temperature.³ If a species seems to be going in a counterintuitive direction, it may just be responding to unusual local conditions.

But that's not what Fuchs and her colleagues observed. For an undergraduate project, team member Emily Chen mapped the OBIS records over time for 45 species of seafloor-dwelling invertebrates in the Mid-Atlantic Bight, a sub-region of the Northwest Atlantic. The rest

of the group cross-correlated the range shifts with a model of ocean-bottom temperature. Over the 60 years of available data, 31 of the species ended up in warmer regions than when they started, and 25 of them saw temperature changes even greater than the overall regional trend. Not only were they not keeping up with climate velocity, they were moving in the wrong direction.

To help figure out what was going on, Fuchs turned to her colleague Robert Chant for his expertise in marine currents and transport processes. Unlike the currents of the open ocean, which are dominated by the clockwise-turning North Atlantic Gyre, currents of the shallow waters of the continental shelf are heavily influenced by local river discharge and wind patterns.

The seasonality of those patterns is shown schematically in figure 2, looking northeastward along the purple line in figure 2a. Key to understanding the dynamics is the Coriolis force, which in the northern hemisphere deflects flows to the right. So when rivers flow southeastward into the ocean, they produce a current to the southwest along the continen-

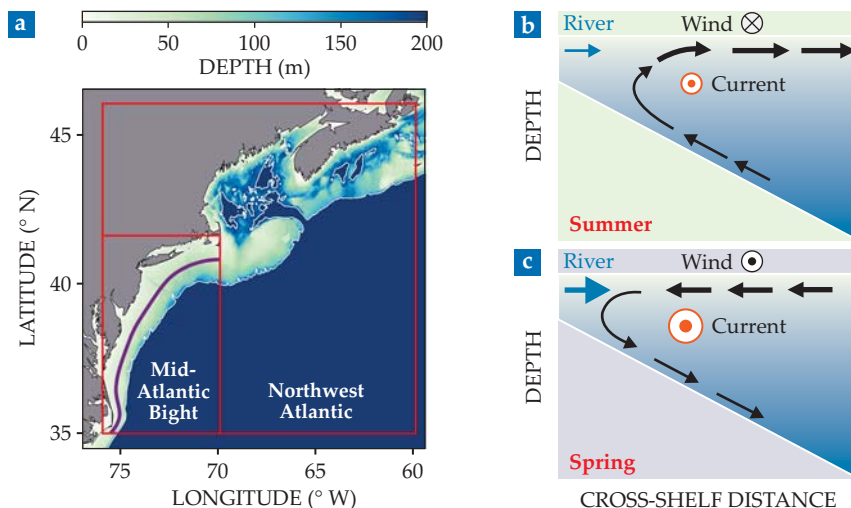


FIGURE 2. OFF THE EAST COAST OF NORTH AMERICA, the continental shelves of the Northwest Atlantic and the Mid-Atlantic Bight (a) are affected by seasonal wind, river, and current patterns. In the summer (b), the southwestward current (orange, out of page) is modest and wind-driven surface waters (black arrows) flow away from the shore. But in the spring (c), the current is stronger and surface waters flow toward the shore. When shellfish spawn too early in the year, their larvae are thus swept into warmer, shallower waters. (Adapted from ref. 1.)

tal shelf, parallel to the shore (and out of the page in figures 2b and 2c, as shown by the orange symbols). Because river discharge is strongest in the spring, the current is too.

Wind-driven current works similarly. A process called Ekman transport, also related to the Coriolis effect, drives surface waters at a 90° angle to the prevailing wind (see the article by Adele Morrison,

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Thomas Frölicher, and Jorge Sarmiento, *PHYSICS TODAY*, January 2015, page 27). In summer, winds in the Northwest Atlantic blow to the northeast, and the surface waters are pushed away from shore. In spring, southwestward winds push the waters toward shore. In both cases, the flow at the surface is compensated by a deeper flow in the opposite direction.

Out of time

Seafloor invertebrates usually spawn in the summer, when food for the larvae is plentiful. If spawning is triggered by temperature, then warming could push the spawning season earlier in the year—perhaps early enough for the larvae to get caught in the strong springtime current. If the larvae drift near the water's surface, then the springtime winds could also push them closer to shore.

The exact effect depends on the depth a species originally inhabited, the temperature at which it spawns, and whether its larvae occupy waters nearer the surface or the bottom. Those factors vary by species and aren't always known, so Fuchs and colleagues considered an array of possibilities. For most combinations of location and spawning temperature, ocean warming between 1960 and 2010 was sufficient to trigger spawning at a time when the larvae would encounter a significantly different current than their ancestors did.

The cycle reinforces itself: After one generation spawns too early, its offspring get swept southward and closer to shore, where they spawn earlier still. And shallower waters are not just warmer overall than deeper ones; they also warm up faster in the spring. All told, some species may be spawning up to a month too soon, and they're getting pushed to the limits of the temperatures they can tolerate. Continuation of that pattern could spell doom for the populations. Transporting them back to cooler regions would be difficult, expensive, and only a temporary solution.

Much remains unknown. Fuchs and colleagues' analysis is specific to the geography of the Northwest Atlantic; are similar feedback loops at work in other regions? The researchers found no evidence that the current patterns had changed over the half century they studied; will that constancy persist as the planet warms further? Could any of the species develop an evolutionary adapta-

tion—perhaps spawning at a higher temperature—in time to save themselves?

The work highlights the complexity and fragility of the ecosystems currently being disrupted by climate change, as well as their interconnection with physical systems. "These species' complex life cycles mean they have to adapt to two completely different environments: the seabed where they spend their adult lives, and the water column they occupy as larvae," explains Fuchs. If either of those life stages becomes

maladapted to its environment—due to too high a temperature, too strong a current, or anything else—the population as a whole suffers. And finding a new home in a warming world is not so simple.

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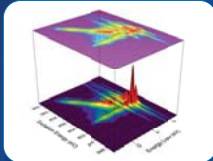
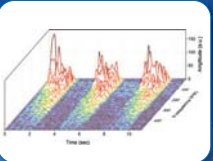
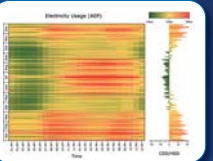
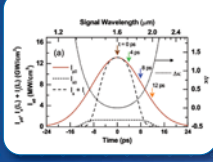
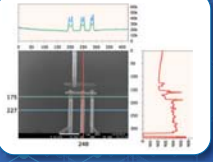
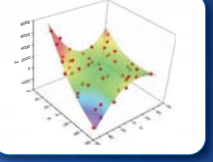
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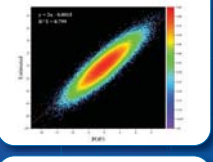
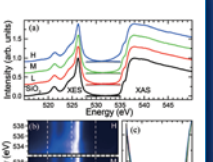
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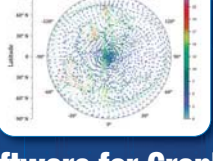
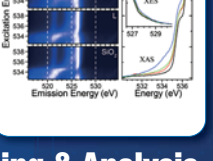


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