



NEWS

As the Seas Warm

Researchers have a long way to go before they can pinpoint climate-change effects on oceangoing species

At 400 kilograms, the leatherback turtle might seem tough enough to withstand the vagaries of the ocean. This endangered seafarer voyages annually from the Caribbean to the North Atlantic and back in search of food. Yet it takes just a few degrees' change in the ocean's temperature for it to turn off course, says Graeme Hays, a marine biologist at the University of Wales Swansea in the U.K., who has tracked this species up and down the Atlantic for 4 years.

In finding that the leatherback is sensitive to water temperature, Hays and his colleagues have taken the first step toward assessing the potential impact of global climate change on this turtle. They join a growing number of marine scientists beginning to track the effects of a warming ocean on marine migrants, including commercially important species, such as cod and salmon.

Shifting migratory routes for endangered species such as the leatherback turtle could complicate what are already tricky conservation challenges for wandering sea creatures, says Lee Hannah of Conservation

International in Washington, D.C.: "They're going to start turning up in places where there may not be conservation measures in place." Only by knowing the new routes and destinations of these animals, he adds, will protection measures be possible.

Researchers already know that for some migrating terrestrial species, birds in particular, climate change is making its mark. Systematic analyses of long-term data document shifting migration routes and earlier departures and arrivals, as well as suggesting a loss of synchrony between the migrant and its food source. Such hard evidence, however, has been lacking for the marine world. But with migrating sea animals showing up farther north than usual, "people are starting to ask, 'What [will happen] if the environment changes?'" says marine ecologist Patrick Halpin of Duke University in Durham, North Carolina.

On land ... and sea?

The current challenge for marine scientists is to make sense of largely anecdotal evidence

Giant migrant. In the Atlantic Ocean, leatherback turtles can travel 10,000 kilometers, taking routes that might be affected by a shifting climate.

about the effects of climate change on marine species. For example, in 1984, the northern boundary of migrating schools of jumbo squid (a smaller cousin to the giant squid) in the eastern Pacific was Point Conception off California; last year, the voracious predators were caught by Alaskan fishers. Similarly, marlins are appearing off the coast of Washington state, hundreds of kilometers north of their usual haunts. And sperm whales are frequenting the North Sea more than before. But are warmer global temperatures to blame?

For a growing number of species, mostly birds, the answer is yes. A 2003 meta-analysis of 1700 species—including some migratory species and a few marine animals—showed that warming temperatures have in recent decades moved species' range boundaries an average of 600 meters north per year. Behaviors are changing too. Warblers called blackcaps, for example, are wintering in the United Kingdom instead of Spain (*Science*, 21 October 2005, p. 419). Migrations are also happening sooner, with some European birds arriving 2 to 3 weeks earlier than 30 years before, and migratory bats are waking up from hibernation before their time. "For a while, it was a big deal" to have a documented impact of warming on a species, says ecologist Christopher Field of the Carnegie Institution of Washington, D.C. "Now there are examples all over."

Other studies have uncovered potentially serious consequences of such changes. In the 4 May issue of *Nature*, evolutionary ecologist Christiaan Both of the University of Groningen in the Netherlands showed that some populations of pied flycatchers flying from African wintering grounds to the Netherlands now arrive too late to catch their favorite local caterpillars. Warmer temperatures pushed their prey's peak emergence date up by 16 days, but the birds arrive only 1 week early, unaware that much of the food their young depend on will be gone.

Marine scientists have yet to find many similar examples of warming-induced changes, in part because they remain woefully ignorant about the distribution and movements of most sea creatures. "We don't know where these species are and what affects their migration, [and so we] don't know what impacts changes in temperature are going

CREDIT: GRAEME HAYS/INSTITUTE OF ENVIRONMENTAL SUSTAINABILITY

Migration and Dispersal

have on them,” says Duke University marine biologist Michael Coyne.

In work begun in 2002, Hays took a stab at answering this question by outfitting nine leatherbacks with radio recorders that transmit position, water temperature, and other data to satellites. He confirmed observational records that they are venturing higher into the North Atlantic compared to historical trends. Hays had presumed that the turtles migrated northward as far as it took to find rich reservoirs of jellyfish and other foods. But the work, which is reported in the July issue of *Global Change Biology*, shows that these lumbering beasts go north only until they hit 15°C water, regardless of where their prey are. He calls that “a total surprise.” Leatherback migration limits, he says, “are driven by temperature, not food.”

Critics point out that nine turtles are very few upon which to base a theory, and that the temperature-migration link says little about how climate change might ultimately affect the survival of the leatherback species. Still, the work “is certainly pointing in the right direction as to where the field has to go,” says behavioral ecologist Julian Metcalfe of the British Centre for Environment, Fisheries, and Aquaculture Science in Lowestoft, U.K.

Adrift with data

Until recently, finding and following an oceangoing migrant was a big stumbling block for marine scientists. Today, better, cheaper technology is slowly allowing marine migration work, such as Hays’s, to come into its own (see sidebar, p. 777). A satellite tag for a sea turtle still costs the same \$5000 it did years ago but now lasts months longer, transmits several times a day instead of once every few days, and records data that include dive times and pressure, says ecologist Brendan Godley of the University of Exeter, U.K. Coin-sized data recorders log months of complex data for fish and are retrieved when fishers catch the animals, and new tags that provide coordinates from the Global Positioning Satellite network offer better spatial resolution and battery life.

However, the flood of data from these improved instruments is “raising more questions than answers,” Godley says. He used

satellite tags in 2004 to figure out where loggerhead turtles foraged after leaving their Cape Verde, Africa, home. Godley says he was amazed to learn that 7 of 10 tagged turtles stayed out at sea for the whole foraging season—a then-unknown behavior that may or may not change as the oceans warm.

Other tagging studies are showing that the actions and preferences of captured or lab-reared animals don’t always reflect



Heat is on. Field and lab studies disagree about the ability of cod to thrive in warming temperatures.

behavior in the wild. In the lab, for example, the ideal water temperature for Atlantic cod is between 13° and 15°C. But cod surgically implanted with data recorders and released back into the ocean have revealed that the fish actually live for months in shallow water warmer than 17°C, according to recent unpublished work by Metcalfe. Researchers might be underestimating certain species’ environmental flexibility, another important consideration for determining whether climate change is harmful, he says.

Another significant challenge for researchers hoping to assess the impact of climate change on migrating marine animals is that historical records are sparse. There are storerooms full of fishers’ catch records, but those “are only loosely related to real changes in population size,” says population biologist Camille Parmesan of the University of Texas, Austin. Fishers tend to be inconsistent in how they calculate their catches and sometimes fail to record when and where certain fish were caught, she explains.

Where long-term data exist, climate change seems to be proving important. The Continuous Plankton Recorder survey, started in 1946, maintains population records on these key microorganisms at the bottom of the ocean’s food chain. The plankton are collected in screens towed voluntarily by merchant ships in the North Atlantic and North Sea. A 2003 analysis of the 5 decades’ worth of data, by researchers from the Sir Alister Hardy Foundation for Ocean Science in Plymouth, U.K., suggested that rising North Atlantic temperatures were linked to a change in plankton distribution, leading to what amounted to a northward shift in the southern boundary of salmon.

“Historic records are so valuable when you start thinking about [climate] change,” Halpin says. “There are so many things like that we wish had been done.”

As their analyses are getting more sophisticated, marine ecologists considering the impact of climate change are seeking more interdisciplinary approaches and combining different kinds of data more extensively. Godley has recruited a climate modeler to help him come up with realistic scenarios with respect to physical changes predicted for the marine environment. Duke University marine scientists are helping other researchers take a more comprehensive approach to migration studies by compiling marine mammal, seabird, and sea turtle data in a geographically organized database, complete with data on climate and ocean-floor topography. The database will be part of the new online Ocean Biogeographic Information System, which will be publicly accessible.

Such interdisciplinary approaches are paying off. By analyzing the locations of hake, a commercially harvested Pacific fish, with respect to a subsurface Pacific current called the poleward undercurrent, fisheries oceanographer Vera Agostini of the Pew Institute for Ocean Science at the University of Miami in Coral Gables, Florida, has found that schools of this species may vary their migration patterns depending on the strength of the current. During an El Niño year, when the northward current was robust, the hake were “getting on the highway,” by concentrating in the strong flow’s edge, says Agostini. But in 1995, a

non-El Niño year with a weaker current, the fish were found within the current less frequently, she will report in the *Canadian Journal of Fisheries and Aquatic Sciences*. Because climate change is expected to affect ocean flow and the frequency of El Niño, Agostini predicts it might in turn affect the hake's migration behavior.

There's a natural tendency to assume that climate change will have negative impacts on

marine species, but some scientists caution that that might not be the case for every creature. If cod can thrive at higher-than-expected temperatures, for example, they may adjust just fine to a warming ocean, at least for a while. Turtles may have greater access to one of their favorite foods, adds Hays, noting that his 3-year aerial study of the Irish Sea found huge assemblages of jellyfish, ready for the picking by leatherbacks should that water get

warm enough—above the proposed 15°C cutoff—for the turtles' liking.

Whether turtles, salmon, or other sea creatures will fare better or worse in a warming world is unanswerable at this point, admit marine scientists. But Halpin urges his colleagues to take on these questions. Determining how climate change affects marine migrants, he says, "is the next horizon."

—ELI KINTISCH

NEWS

Inching Toward Movement Ecology

With ever more data coming out on migration, dispersal, and other movements, a few researchers say it's time for some synthesis

For centuries, researchers have sought to understand when, why, and how various species crawl, swim, fly, float, or hoof it to new locales. That work has led to maps of migration routes and details about dispersals.

But few biologists have tried to fit these data into a big picture of movement in general, says Ran Nathan of Hebrew University in Jerusalem. Under the auspices of a new discipline called "movement ecology," he and others are beginning to derive testable hypotheses about the mobile behaviors of animals, microbes, and even the seeds of plants. Their goal is to join empirical work to theories and to build models that fill in gaps in our understanding of movement—be it over millimeters or continents or by groups or individuals—in the natural world.

Nathan and his students, for example, have been analyzing how birds fly and seeds disperse, looking for common ways that both plants and animals react to wind. Colleagues elsewhere are building computer models showing how very different species of animals, such as guppies and bees, may follow similar rules while on the go. These researchers are also looking at how laws of physics can help explain group behavior.

Movement ecologists contend that their work will have practical applications. Wayne Getz, an applied mathematician at the University of California, Berkeley, says new, more fine-

grained methods for studying movement will help researchers understand the spread of bovine tuberculosis in moving buffalo herds in South Africa. Or conservation biologists may find that the proliferation of invasive species, be they viruses, weeds, or goats, is governed by some common rules that, once understood, could be used to quash an invasion. "This is an important emerging field," says Paul Barber, a marine biologist at Boston University.

At first glance, Nathan and colleagues seem to be simply applying a new label to what some researchers have been doing for years. Yet they may succeed in drawing attention to an underappreciated component of

ecology, says Daniel Janzen, a tropical ecologist at the University of Pennsylvania. "Practically every field biologist I know deals with movement ecology all the time," he explains. "But an awful lot of biologists conveniently trim that out of their way of thinking to make their problems simpler." For instance, he says, when researchers can't find a particular butterfly where they expected, they tend to assume that the species is dormant or has declined and don't consider that its members may have simply moved on.

Nathan is hoping to create new sets of assumptions. With a grant from his university's Institute for Advanced Study, he has invited a group of scientists, with expertise in areas as

diverse as zebra migrations and the mathematical and genetic analysis of pollen flow, to spend all or part of the next academic year in Jerusalem hammering out the new field.

Defining it is difficult at this point, says Marcel Holyoak, an environmental scientist at the University of California, Davis, and one of Nathan's recruits. "The core of movement ecology is seeking a unified theoretical framework for studying movement, and such a framework is not yet available." The thinkfest in Jerusalem is supposed to create that framework, then move on to develop data sets that integrate information collected on different species, at different scales, and on

Continued on page 782



Frequent flier. Even the versatile bee-eater is at the mercy of winds.