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.

CREDIT: JORGE RODRIGUES

Continued from page 779

different types of movements. Ecologist Peter Smouse of Rutgers University in New Brunswick, New Jersey, says scientists might glimpse a hitherto unseen "bigger picture" of, say, rare colonization events, if provided with a data set that brings together varied examples of this phenomenon, such as an exotic plant that had been transported by freighter across the ocean, or pollen from a genetically engineered plant that was blown to a new field. Nathan says scientists will then use such data sets to test new ideas about the role of physiology, evolution, behavior, and environmental forces in shaping when and how organisms move.

Modern technology is providing the flood of information necessary for the birth of movement ecology. Advances in the analysis of stable isotopes of common elements now allow researchers to tell where a bird has been since its last molt because the isotopes—variants with different atomic weights that are specific to particular latitudes—get into the food chain and eventually show up as chemical geographical signatures in feathers. Better genetics techniques are helping clarify the dispersal history of populations of many different species. Global positioning systems and the miniaturization of animal-tracking tags are making it possible to collect migration and dispersal data in unprecedented detail over long periods (see p. 780).

Stubborn. Milk thistle won't yield to just any puff.

And thanks to greater computing power and prowess, researchers can manipulate these data in new ways. As a result, scientists can "start to make what now seem to be impossible comparisons," says Nathan. Princeton University mathematician Simon Levin, who looks at the movements of a wide variety of organisms—from phytoplankton to locusts—and of the influenza A virus, says the approach will lead to rules that govern movement "across scales of space, time, and organizational complexity."

Levin and Iain Couzin of the University of Oxford, U.K., who is moving to Princeton University in the fall, have already used data on several species of fish and insects to build a generic model that describes group movements. The model shows that only a tiny number of "informed" individuals—that is, those familiar with a food source or migration path—are required to bring around the whole group, they reported in the 3 February 2005 issue of *Nature*. These few are somehow able to get "naïve" members to "reconcile the tendency to clump together" with the tendency to follow those in the know, says Couzin.

The researchers found that the larger the group, the smaller the proportion of leaders required. In the case of bees, this behavior likely evolved as a more efficient way to transfer information: Only a few individuals need to take the time to observe the waggle dance, and the rest just follow along. The duo also figured out rules by which a group reaches consensus when the informed individuals differ with one another on the course to take. They are now testing these ideas with data on other fish species as well as on human groups.

In some cases, the models employed by movement ecologists are coming from other disciplines. In one study, Couzin, with Jerome Buhl of the University of Sydney in Australia, turned to theoretical physics. They used a model that predicts the behavior of magnetic particles to forecast the behavior of marching locusts (*Science*, 2 June, p. 1402).

Couzin and Buhl filmed a band of locusts circling a dome in the lab, which gives the locusts the impression they are in an endless swarm. When the marching locusts reach a certain density, their movements change from a chaotic to a highly ordered state, and they suddenly align with the paths of their nearest neighbors, the researchers reported. At densities of 24.6 per square meter, the insects began to march together, behaving like magnetic particles, which also start to align at increased densities. But the group still occasionally made rapid, spontaneous changes in direction without losing group cohesion. By the time densities surpassed 73.8 per square meter, however, the locusts surged along as one, with no direction changes.

While some researchers push movement ecology's frontiers forward in the lab and at the computer, Nathan has his students out in the field. For example, graduate student Nir Sapir marked bee-eaters and tracked their spring migration along the Negev and the Arava Valley in southern Israel. He mounted tiny radio transmitters on birds' backs, followed them in a car, and trapped the birds along the way. In all, he and his team recorded the paths of 11 birds, showing that even for a bird of the bee-eater's nimble flying abilities, courses and distances depend strongly on wind conditions—reminiscent of windswept seeds. In both the seeds and the bee-eaters, there's a "relative lack of control of their movements and [a] clear dependence on external conditions," Nathan says.

In other work, graduate student Ana Trakhtenbrot and colleagues put milk thistles in a wind tunnel to see exactly what force it would take to dislodge the seeds. Unlike a dandelion, the milk thistle is not at the mercy of the lightest puff—it resists all but stiff winds. The results show that the thistles, like birds, have some, but not total, control over how the wind affects them. Cataloging similarities in the movements of plants and animals such as bee-eaters and thistles can open doors to new ways of looking at the natural world, says Nathan.

Couzin points out that once movement ecologists hammer out common principles among diverse types of motion, their efforts may prove relevant to other fields, even reaching into the social sciences. For example, the way many viruses spread—accelerating as the number of individuals infected increases—in some respects resembles the way information is disseminated. In fact, Couzin says, one of his colleagues tried putting short-range sensors on people at dinner parties to work out social networks and the potential spread of information.

But for biologists, the relevance of this approach is in how it will influence their thinking, says Janzen: Movement ecology "might make it more fashionable or legitimate to try to add the movement part [back] into biology."

–CONSTANCE HOLDEN

CREDIT: RAN NATHAN