numbers). A number, Langlands realized, is just a 1-by-1 matrix in disguise. Just as shifts can be represented by a single number or 1-by-1 matrix—the distance shifted—he hypothesized that the transformations behind more general reciprocity laws could be represented by matrices. The link has remained conjectural, but the confirmation of one special case led to disproportionately large consequences. The seed of Andrew Wiles's monumental work on Fermat's Last Theorem was his proof of Langlands's conjecture for 2-by-2 matrices whose entries are all 0, 1, or 2.

Lafforgue's tour de force is unlikely to have such dramatic consequences, because function fields lack the éclat of number fields and Fermat's Last Theorem. However, other mathematicians say that its significance will likely become apparent in time. "Lafforgue has proved that two very different-looking things are the same," says Nicholas Katz, an algebraic geometer at Princeton University. "When you do that, it's almost always the case that there are some properties that are very easy to see one way, and incredibly obscure the other way. … It's too soon to predict exactly how it's going to work, but I feel strongly that it's very important."

–DANA MACKENZIE

ECOLOGY

How Climate Change Alters Rhythms of the Wild

The more scientists look, the more connections they see between shifts in climate and changes in animal behavior and populations

Each year for 31 years, biologist Jerram Brown has trekked into the Chiricahua Mountains of southern Arizona to chronicle the rites of spring for a population of Mexican jays. Brown adheres to his own ritual: The biologist from the State University of New York, Albany, notes on which date the females lay their first clutch, then several weeks later he shinnies up 15-meter-tall Chihuahua pines to band each and every chick. His perseverance has paid off with an intriguing observation: The jays are laying their eggs earlier and earlier each season. By 1998, the first eggs of the season arrived 10 days earlier than in 1971.

Early bird. Warmer nights seem to be why Mexican jays become parents sooner.

Brown blames global warming for turning the hands forward on the jays' reproductive clock. Although Arizona hasn't necessarily gotten hotter, it has grown less cool. In the months leading up to the breeding season, Brown found, average daily minimum temperatures have nudged up 2.7 degrees Celsius in 27 years. A narrower temperature range probably encourages earlier breeding by allowing birds to conserve energy on cold nights, when they can burn off about 10% of their weight just to stay warm, Brown says. The warmer air may also roust insects earlier, which would likewise provide extra calories for females to funnel into the energetic business of egg production. Strengthening the case against warming, Brown says, is the fact that many other species in the Northern Hemisphere, from birds to frogs, are also breeding earlier than they were years ago. "While no one study can prove that earlier breeding is caused by global warming," he says, "it all fits in."

For more than 2 decades, climate modelers have warned that global warming may transform our environment by pushing corn belts north, expanding deserts, and melting ice caps. Now biologists are getting in on the action, compiling an impressive array of data suggesting that climate changes big and small can have profound effects on species. Climate's fingerprints are turning up in observations compiled over years and decades.

The sheer complexity of ecosystems makes biologists reluctant to start predicting the fate of individual species based on various climate-change scenarios. But with some models forecasting that average global temperatures could rise as much as 4.6 degrees Celsius in the coming century, the new observations "give us a handle to think about where things will be in 2100," says biologist Camille Parmesan of the University of Texas, Austin.

Dippers take a dive. The latest observation of a species' response to climate change involves Norway's national bird, the dipper. On page 854 of this issue, a team led by Bernt-Erik Sæther and Jarle Tufto of the Norwegian University of Science and Technology in Trondheim reports that while the number of dippers in a population in southern Norway fluctuated between 1978 and 1997, it followed an upward trajectory. The trend—based on an analysis of more than 20 years of observations by amateur bird watchers—was closely associated with the gentle touch of an atmospheric pressure system called the North Atlantic Oscillation (NAO) and the milder winter temperatures it brought.

Warm-weather dipper. A gentle NAO boosts populations of this bird.

The NAO, which embraces much of the Northern Hemisphere, delivers warm, wet winters to northern Europe during its high phase. (When it flips to low gear, bitter cold usually sets in.) For much of the past 3 decades, the high phase has dominated, and for the dipper, "a warm year is a good year," Sæther says. Because the bird dives for its food on stream bottoms, it has little to eat if streams ice over. The researchers found that the bird's ranks swelled after warm years, thanks to increased immigration and a higher birth rate in the local population. A long-term warming of 2.5 degrees Celsius, Sæther's team estimates, should boost dipper numbers by 58%.

The team's mathematical model, which takes into account random population fluctuations and temperature changes, can be applied to other species as well, says Peter Kareiva, a biologist with the U.S. National Oceanic and Atmospheric Administration in Seattle. Unlike previous models, Sæther's teases apart the effects of climate change from those of density dependence, a phenomenon in which mortality rates tend to rise, and birth rates fall, as a population's size increases.

Also in tune with the NAO, it would appear, are grazing mammals. Eric Post and Nils Chr. Stenseth of the University of Oslo in Norway analyzed 15 years of data on northern mammals. They found that 9 of 11 ungulate populations—including caribou, musk ox, moose, feral goats, and Soay sheep—declined following warm NAO winters. But the effects varied by location. In maritime areas, the survival rates of Soay sheep and feral goats improved during mild winters,

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spurring increased competition for food and population declines the following spring. Farther from the coast, high NAO years were not only warm but extra snowy, making it harder for the animals to forage and making them easier prey. Thus it is no surprise that they fared poorly during NAO highs, says Post, whose team's results appear in the June 1999 issue of *Ecology*.

That the NAO influences so many species "throws up a red flag," says Post, who estimates that about 5 million caribou and reindeer, 16 million white-tailed deer, and 2 million moose now graze in high latitudes. But the NAO could be a harbinger of grander changes. "With global warming we might see declines of some large mammals throughout the Northern Hemisphere," says Post, who points out that many northern species perished during the last major episode of global warming, at the end of the last ice age.

Butterflies on the wing. Whereas extreme climate, like extreme sports, weeds out the meek, a gradual warming seems to weave a more subtle spell on species. Warming sends butterflies, for instance, fluttering into terra nova. In the last century, Europe has warmed by 0.8 degrees Celsius, and its isotherms (bands of average temperature) have drifted north—roughly in sync with the shifting ranges of many butterflies.

Parmesan analyzed distribution patterns of 57 nonmigratory butterfly species across Europe. In the last century, about two-thirds of the species have shifted their ranges northward as much as 240 kilometers, she reported in the 10 June 1999 issue of *Nature*. "We ruled out all other obvious factors, such as habitat change, that could alter distributions," Parmesan says. "The only factor that correlated was climate." New populations are popping up in regions such as Finland and Sweden that were previously too cold for comfort, she says.

Although a shifting range suits some populations fine, for others, Parmesan says, it means moving "out of good habitat into fragmented landscapes where they can't survive." Some European butterflies are declining as a result. The same is true in North America, where the Quino checkerspot butterfly has mostly abandoned the southern edge of its range in Mexico. There, warming temperatures cause larvae to hatch early and their snapdragon host plants to bloom early. But the plants are also drying and dying sooner, starving caterpillars before they are able to wait out the winter in their cocoons. Meanwhile, habitat in suitable regions farther north, where the butterfly thrived previously, has mostly been swallowed in the urban sprawl of Southern California.

While Parmesan has tracked range shifts of closely related species across an entire continent, Alan Pounds, an ecologist at the Monteverde Cloud Forest Preserve in Costa Rica, has documented disturbing changes in three disparate groups—amphibians, reptiles, and birds—on a tropical mountain. Pounds and biologist Michael Fogden have correlated population extinctions in 20 of 50 frog species, as well as range shifts in all three groups, to a broad climatic pattern: more mist-free days. Clouds usually hug the upper reaches of the mountains, and their mists bring moisture even without rain. The increasing frequency of dry days corresponds to rising Pacific Ocean surface temperatures, Pounds reported in the 15 April 1999 issue of *Nature*. The warmer ocean warms the air, which ultimately pushes the cloud ceiling higher up the mountain.

"We never would have predicted that the climate change we've seen up till now would have caused the collapse of the amphibian fauna," Pounds says. The higher clouds, he believes, triggered several chains of ecological events—including one that culminated in an outbreak of chytrid fungus, a frog pathogen—that contributed to extinctions.

Like a football game without any huddles, a change in how key species interact can destabilize, or even bring down, an entire ecosystem. "If interactions are very sensitive to temperature, then small shifts could have rapid effects, cascading through the community," says community ecologist Eric Sanford of Stanford University. To test this idea, Sanford went tide pooling. He worked with a well-known system: a rocky intertidal habitat ruled by the starfish predator *Pisaster ochraceus*. Along the Pacific beaches of Oregon and Washington states, *P. ochraceus* feasts on mussels, its prime competitor for space. In the starfish's absence, the mussels take over, literally crushing all other invertebrates beneath them, until the only species remaining is the mussel itself.

Observing eating habits of the starfish as colder water upwelled and subsided, Sanford noted that a cooling of 3 degrees was enough to transform *P. ochraceus* from a glutton into a finicky eater. This suggests that a change in upwelling patterns along the West Coast—as some climate models predict—could decimate communities by altering one key species interaction, says Sanford.

The findings pouring in could have huge implications for conservation. "Strategies for protecting land or species could be thwarted by substantial climate change," Kareiva says. Cordoning off a preserve for an endangered species may work in the short term, but climate change could render the habitat unsuitable for the target species. Coping with climate change, Kareiva says, will mean maintaining genetically diverse populations capable of adaptation.

If you can't beat climate change, you may as well learn from it. "We can analyze [climate fluctuations] as if they are experiments and learn a lot about how ecological systems function," Stenseth says. Like it or not, he says, the changes are "happening anyway." —BERNICE WUETHRICH

Bernice Wuethrich writes from Washington, D.C.

A PUNISHING CLIMATE
(SELECTED SPECIES)

Species	Location	Change	Proposed climate link
Frogs, toads, lizards	Costa Rican cloud forest	Population declines leading to extinction, late 1980s to 1996	General warming: high ocean temperatures linked to drier conditions
59 bird species	Southern U.K.	Expansion of range north by an average of 18.9 km	General warming
34 butterfly species	Europe	Range shifted north by 35–240 km	General warming
Mexican jay	Southeastern Arizona	Earlier breeding by 10.1 days, 1971–1998	General warming: increase in daily minimum temperature
Reindeer, white-tailed deer, moose, caribou	Canada, Norway, Greenland, U.K., U.S.	Population declines	NAO: heavy winter snows
Dipper *Cinclus cinclus*	Southern Norway	Increasing population, 1978–1997	NAO: warm winter temperatures
Several coral species	Caribbean Sea, Indian Ocean, and Pacific Ocean	Bleaching and mass mortalities, 1998	El Niño: high ocean temperatures; possible pathogen
Wolves, moose	Isle Royale, Michigan	Declines in moose, 1959 to present	NAO: increased snowfall alters predator-prey dynamics
Starfish *Pisaster ochraceus*	Pacific shore in Oregon and Washington	Fluctuating starfish predation of mussels, August 1998	Predation decreases with upwelling of cold water