



MANY PLANT SPECIES around Oxford, England, bloomed earlier in the 1990s than they did from the 1954-to-1990 mean. Among the most dramatic changes was in *Lamium album*, also known as the white dead nettle: first flowering was January 23, compared with March 18.

As temperatures rise sooner in spring, interdependent species in many ecosystems are shifting dangerously out of sync

Spring Forward

By Daniel Grossman

Growing up in England in the 1950s, Alastair Fitter spent a lot of time wandering with his father through the countryside near their home.

The elder Fitter, Richard, now 90, is a noted naturalist (who has written almost three dozen books on flowers, birds and related topics). As a hobby, Richard jotted down the first flowering date of hundreds of plant species, the spring arrival time of scores of birds, the late-summer departure dates of butterflies, and other signs of the passing seasons. Richard, who insists that he is simply “an inveterate list maker,” never thought the records would serve any scientific purpose: “When I was 10, I read I should be keeping notes.”

Alastair grew up to be a naturalist like his father as well as a professor of ecology at York University. His father’s notes, he realized as an adult, were one of the few cases in which a single observer had systematically recorded the timing details of so many species in one place for so long. So in 2001, when the elder Fitter moved from his home, the locus of 47 years of systematic observations in one place, Alastair decided to take a closer look at the scribbles. By then, climate researchers had confirmed that the earth is getting warmer with stunning speed. The near-surface temperature of the plan-

et has risen about 0.6 degree Celsius (about 1.1 degrees Fahrenheit) in the past 100 years. The 1990s was the warmest decade on record. He thought his father’s data might confirm with plant life what researchers had shown with thermometers.

What Alastair Fitter discovered astonished him. An analysis of the records that he had done in the early 1990s had not shown a consistent pattern. But comparing flowering dates for the entire decade of the 1990s with those of the previous four decades, he found that 385 plants were flowering an average of 4.5 days earlier [see illustration on opposite page]. A smaller subset, 60 species in all, flowered on average two full weeks earlier, an astounding change for a single decade. It shows that, at least in the neighborhood of Oxford, England, “climate change is happening with extreme suddenness,” Richard Fitter says.

The research, which the Fitters published jointly in *Science* in 2002, was only one of the more startling of a number of recent studies showing rapidly occurring changes in the life patterns of the world’s plants and animals. Also in 2002 the Inter-

governmental Panel on Climate Change (IPCC) published an overview of this topic based on a review of 2,500 published papers. A number of these articles reported on the relation between species and temperature for at least the past 20 years. Of the more than 500 birds, amphibians, plants and other organisms studied in these publications, 80 percent had changed the timing of reproduction or migration, length of growing season, population size or population distribution in ways that might be expected from warming temperatures. The overview’s authors concluded that “there has been a discernible impact of regional climate change, particularly increases in temperature, on biological systems in the 20th century.”

As with the Fitters’ study of plant flowering, most of the studies reviewed by the IPCC did not investigate whether changes have been or will be harmful, but Alastair Fitter nonetheless believes adverse effects are inevitable: “When things flower may be relatively innocuous. Whether things go extinct is not, and that’s going to be the next stage.”

A small group of studies is taking up the challenge of looking into whether global warming is having an adverse effect on the relations among plants and animals within ecosystems. The research is proving that, in some cases, Fitter’s gloomy prophecy is already becoming a reality: rising temperatures are degrading the links of food chains and the fitness of some creatures to continue to live in their habitats. In at least one instance, a researcher predicts that global warming will extirpate one species from an entire region

Overview/*Ecosystems under Stress*

- The recent surge in warming at the planet’s surface has begun to alter the relationships among species in some ecosystems by weakening links in the food chain—between, for example, birds and the caterpillars they eat.
- Although the examples are not definitive, the signs are troubling, and many species could be at risk.
- Adding to the concern is research showing that the changing climate at the end of the last ice age tore apart existing ecosystems and created new ones, leaving no haven for species that no longer fit in.



ECOLOGIST Alastair Fitter (below) and his father, Richard, documented that first flowering dates for hundreds of plants in England have shifted in recent years. Although many plants now bloom significantly earlier, a few, such as this butterfly bush (*Buddleja davidii*, left), are delayed.



within 15 years. Although the data are insufficient so far to prove that many ecosystems are coming apart, the findings already point in a disturbing direction.

Earliest Birds and the Worm

IN A SMALL OFFICE at the Netherlands Institute of Ecology, not far from Arnhem, Marcel E. Visser is crawling under a table. Visser is the head of the institute's animal-population biology department. Right now he is stalking a small chickadeelike bird that entered the room through an open window. But before the scientist can grab the bird or shoo it out, the frightened animal takes flight and leaves of its own accord.

Coincidentally, the intruder was a great tit, the subject of a long-term study that Visser heads. The study was not designed to investigate global warming. When Visser's predecessors instituted the research in the 1950s, it was intended to contribute to the general understanding of bird populations. Under Visser's leadership, however, the research has become one of the only studies in the world examining the cascading effects of global warming on a food chain.

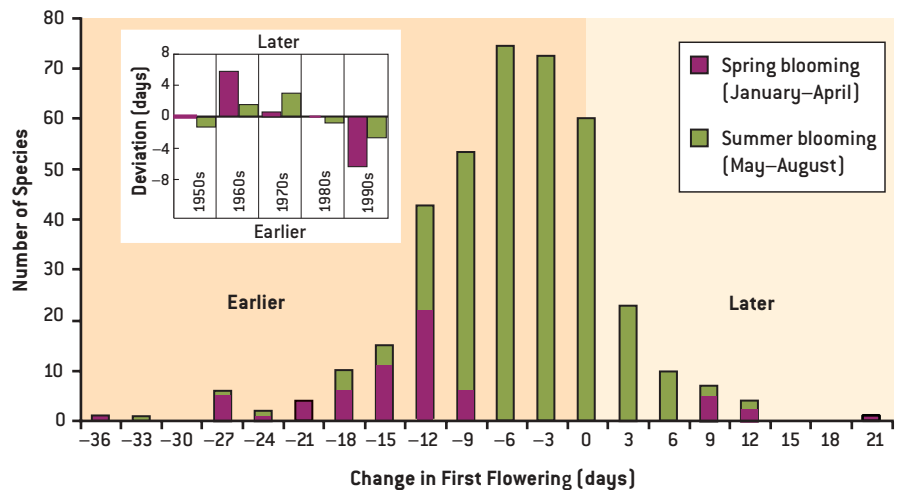
Great tits at De Hoge Veluwe National Park, a large wooded area near Visser's office, engage in their annual nesting rituals in April and May. At the same time, Visser engages in his own rites of spring, monitoring these birds and their offspring. The scientist and a crew of assistants record the activities and health of every breeding pair in about 400 wooden birdhouses in the park. One mid-May morning, carrying a short aluminum lad-

der on his shoulder, the ornithologist mounts a sturdy yellow bike and sets off over the park's unpaved paths.

After several minutes of pedaling, he parks his bike by a nest box mounted a few feet above eye level in a spindly oak. With help from the ladder, he scales the tree, installs a metal trap in the box and waits a short distance away. Within moments the trap catches one of the two adults that nest in the box. Visser carefully swings the top open and removes the bird. It has a gray back, a black-and-white head and a pale yellow breast with a black stripe and weighs only about as much as a AA battery. Gently he locks the bird's head between his pointer and middle finger and makes some measurements with a ruler. He weighs the tiny animal in

a sandwich bag. Multiplied thousands of times a season, these statistics are critical raw material for Visser's research. He and his colleagues visit each box weekly except as hatching (and, later, fledging) approaches, when they make daily checks.

What Visser has found sounds harmless enough: the tits laid their eggs at almost the same time last year as they did in 1985. But over this same period, spring temperatures in the area have climbed, especially during the mid-spring (between April 16 and May 15), which has seen a warming of two degrees C. And although the chronology of the tits has not changed with this warming, that of winter moth caterpillars—which (along with other less abundant species) tits feed their chicks—has [see illustration on page 89]. Cater-



FIRST FLOWERING DATES of 385 plant species from 1991 to 2000—the warmest decade on record—were an average of 4.5 days ahead of the 1954-to-1990 mean. For clarity, two species with extreme deviations, *Lamium album* [−55 days] and *Buddleja davidii* [+36 days] are omitted. A graph of the first flowering for each decade compared with the long-term mean (1954–2000) underscores the change that occurred in the 1990s (inset).



GROWTH RECORDS (above) made of the great tit, repeated thousands of times a season by Marcel E. Visser (left) and his team at the Netherlands Institute of Ecology, shed light on the local ecosystem's reaction to climate change. The research, begun in 1955 to help understand the species' population dynamics, has become one of the best examples of how climate change can disturb the links of a food chain.

pillar biomass—or the total meat available to the birds—peaks two weeks earlier today than it did in 1985. Back then, it occurred almost precisely when the tit hatchlings needed it most. Now, by the time most chicks have hatched, the caterpillar season is on the wane and food is becoming scarce. Only the earliest chicks get the worms.

It is not just the birds and the moths in this food web that are getting out of synchrony, or “decoupled,” as Visser likes to say. The scientist also looks lower down

the food chain to the relation between the moth and its food—young, tender oak leaves. To survive, the moth's caterpillar must hatch almost precisely at “bud burst,” when the oaks' leaves open. If the insect hatches more than about five days before bud burst, it will starve. It will also starve if it hatches more than two weeks too late, because oak leaves become infused with inedible (to the caterpillar) tannin. Visser has discovered that at the De Hoge Veluwe park, oak bud burst now occurs about 10 days earlier than it did 20 years ago. Caterpillars hatch 15 days earlier, overcompensating by five days for the change in the oaks. The caterpillars were already hatching several days before bud burst in 1985, so now they must wait on average about eight days for food.

Visser's research shows that the winter moth population at De Hoge Veluwe is declining, but he has not collected moth numbers long enough to be sure this is not

part of a natural cycle. The gap between the schedules of the caterpillars and the birds has had no demonstrable effect so far on tit numbers. The scientist says that could be because normal year-to-year fluctuations caused by various factors such as the availability of winter food are greater so far than the impact of warming. In a system where “timing is everything,” however, Visser observes that the decoupling between links in the food chain cannot continue growing without consequence. “It's only a matter of time before we see the population come down,” he says of the birds.

According to Visser, what is most worrisome about his research is not that tits at De Hoge Veluwe could be on the verge of a decline but that the decline suggests that many other species are also in danger. “I'm sure if we go to other food chains we'll find the same thing,” he states. His findings suggest vulnerabilities to climate change that are universal to all

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DANIEL GROSSMAN

Organisms have come to synchronize their life cycles using certain cues. But old rules do not work anymore.

ecosystems. Some scientists say that these weaknesses are best understood using a vocabulary invented in the 1960s by marine biologist David Cushing, formerly the deputy director of the Fisheries Laboratory in Lowestoft, England.

Match and Mismatch

IN ATTEMPTING to explain year-to-year variations in herring stocks, Cushing looked at phytoplankton, the food of the herring larvae. He showed that when the hatching of the herring larvae coincided with phytoplankton blooms, a high proportion of that year's offspring survived to adulthood. This happy state of affairs, which leads to elevated larvae numbers, he called a match. A mismatch, in contrast, is when larvae hatchlings are out of sync with their food, causing a poor year.

The conceptually simple match-mismatch hypothesis is now being applied by a number of researchers to explain the impact of climate warming. The power of the idea comes in part from the fact that a match can refer to different kinds of relationships. For instance, it can describe temporal relationships between predator and prey—as in the case of the tits and the caterpillars—or animal and plant, as in the case of the caterpillars and the oaks. It can be applied to the temporal relationship between different plants. For example, the Fitters found that recent changes in the flowering times of plants are not uniform across species.

Alastair Fitter says that this kind of discrepancy means, among other things, that competition for sunlight, nutrients and water will be altered, with, as he and his father wrote in *Science*, “profound ecosystem and evolutionary consequences.” Finally, the match-mismatch concept can be applied to the relation between animals or plants and their physical surroundings. One example is research in Colorado showing that American robins that migrate to high-altitude summer habitats arrive early and wait longer for the winter snow to melt before mating.

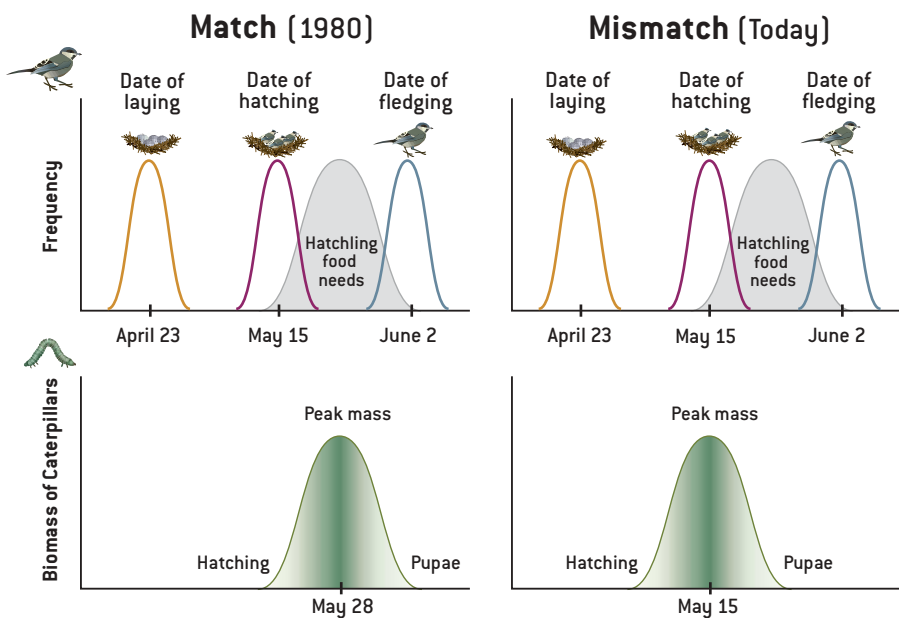
Because matches often require syn-

chrony between disparate species, it is no surprise that climate change creates mismatches. Some species are influenced by average temperatures, whereas others respond only to extremes, such as cold snaps.

Tits, oaks and moths, for instance, all seem to respond to temperature in some fashion, though each in a different way. The hatch date for tit eggs appears to be determined about a month earlier, when the eggs are laid. Visser says the birds base the laying date at De Hoge Veluwe on early spring temperatures, which, in contrast to late spring temperatures, have not changed in the past 30 years. Visser has discovered that the hatch date of moth eggs appears to be related to a combination of two factors: the number of winter and early-spring frost days (days when temperatures dip below freezing) and temperatures in late winter and early spring. The winter and early spring temperatures at De Hoge Veluwe have increased in recent decades, although there has been no change in frost days. Finally,

the oaks appear to adjust the timing of bud burst depending in part on late spring temperatures, which have risen by two degrees C since 1980. Over thousands of years of evolution, these three organisms have come to synchronize their life cycles using these cues. But climate warming has decoupled the cues so that the old rules do not work anymore.

Long-distance migrants face special challenges. They may need to use cues in one habitat to determine when to depart for another. In the case of migrating birds, arrival at the summer breeding site may require precise timing of departure from wintering grounds. But wintering-site cues will not necessarily shift in synchrony with changes in nesting areas, especially if summer and winter sites are separated by thousands of kilometers, as is the case with many birds. One reason is that climate is not changing uniformly across the globe. Compared with temperate regions, for example, the tropics are hardly warming at all. The varied effects



INTERDEPENDENT SPECIES can be “uncoupled” under stress from global warming. In De Hoge Veluwe National Park in the Netherlands, changes in weather patterns have caused oak buds to burst into leaf sooner. As a result, winter moth caterpillars—an important food that great tit chick hatchlings need to reach fledging size—peak in total biomass earlier today (right) as compared with two decades ago (left). Egg-laying time has not shifted.

SOURCE: MARCELE VISSER, CHRISTIAAN BOTH AND MARCEL M. LAMBRECHTS; NADIA STRASSER

Many species are already responding to global warming by moving their ranges. Less nimble ones will be left behind.

of warming on El Niño and other such climate phenomena confuse the picture further. Moreover, because temperatures in the tropics are not strongly correlated with those of temperate regions, many birds do not even use climate cues to decide when to depart tropical wintering sites. Instead they regulate their travels by the length of the day. Of course, global warming has no influence on day length. Thus, such birds are now in danger of arriving at temperate breeding grounds on a date that no longer makes sense.

Christiaan Both of the University of Groningen in the Netherlands says that the pied flycatcher, which migrates 5,000 kilometers from tropical West Africa to De Hoge Veluwe, appears to be suffering from such a mismatch between nesting and wintering-site conditions. Like great tits, the flycatchers feed their hatchlings caterpillars, which reach peak abundance half a month earlier than they did 20 years ago. But the flycatchers are arriving on virtually the same date today as they did in 1980. In a 2001 *Nature* article, Both and his co-author, Marcel Visser, observe that the flycatchers' cue to leave Africa is day length, which explains why the arrival time has not changed. "They have a decision rule that has become maladaptive," Both notes.

The birds have compensated for their late migration by shortening their rest time after they reach the Netherlands. The interval between arrival and breeding has shrunk by 10 days since 1980. But even that is not enough to produce hatchlings in synchrony with the caterpillar peak. Today only the earliest flycatchers have healthy chicks. The rest have underweight offspring, most of which do not return to breed the following year. The birds have stopped nesting in forests with the earliest caterpillar season. Both says that to date, flycatcher numbers do not appear to have dropped off, but that could change if warming continues, because the birds probably cannot reduce the time between arrival and mating any further: "Now they have used up all the

safety margin." Both and Visser speculate in *Nature* that the same mechanism that is affecting the pied flycatchers may be one of the factors behind why a number of other European migrants have declined in recent years.

Penguin in a Coal Mine

THERE ARE VARIOUS warning signs but so far few cases in which a mismatch caused by climate change has actually had a serious impact on a plant or animal population. Montana State University ecologist William Fraser, however, says that he has evidence that climate change is causing the extinction of Adélie penguins living on the western coast of the Antarctic Peninsula. Over the past 30 years, Fraser has documented a startling 70 percent decline in the number of Adélie penguins nesting on a number of islands in the vicinity of Palmer Station, one of three U.S. research bases in Antarctica. He believes that climate change is affecting the birds through a mechanism not previously suspected, proving the difficulty of anticipating how nature will respond to warming temperatures.

The Antarctic Peninsula has experienced more warming than almost any

other place on the earth. In the past 50 years, winter temperatures in this part of the Antarctic Peninsula have climbed by almost six degrees C. Counterintuitively, this warming has increased snowfall. That is in part because sea ice, which forms an impermeable cap on the ocean, has decreased with rising temperatures, permitting more moisture to escape into the air. That moisture falls down as snow. Fraser says that colonies sustaining the worst losses are located on the southern slopes of hillsides in the rocky nesting grounds. These areas, he has discovered, are also sustaining the greatest impact from the extra snow falling along the Antarctic Peninsula. Southern slopes, in the lee of the prevailing winds of this region's winter storms, are the last to melt in the spring because they collect snowdrifts in winter and receive relatively little of the sun's warmth (southern slopes are sunniest in the Northern Hemisphere; the opposite is true in the south). But Adélies are "hardwired," Fraser explained in an interview at Palmer Station, "to need the timing of conditions to occur in a very precise chronology," and the extra snow is altering that chronology.

Shortly after they arrive at these islands to breed in October, the birds need bare ground to build their pebble nests. If the snow does not melt in time, they will occasionally try nesting on top of it, but that does not work. When the snow eventually melts, the eggs in such nests become waterlogged, yielding "addled" eggs, not live chicks. Actual precipitation varies from year to year, but over time increased snow has gradually cut the number of new members added to the colonies, which are dying by attrition. Fraser calls the penguins' dilemma a "mismatch between physics and biology." He predicts that as the process continues, more of each island will be affected, extirpating Adélies from the region within 15 years. He says that the Adélies are "extremely sensitive indicators of climate-induced perturbations," suggesting that important changes may be afoot elsewhere. They are



ADÉLIE PENGUIN is from a population near the U.S. research base at Palmer Station in Antarctica that has dropped 70 percent in three decades.



NESTING ADÉLIE PENGUINS suffer from increased snowfall, a consequence of climbing temperatures on the Antarctic Peninsula's western coast. Melting snow "addles" eggs, so they do not hatch.

"one more piece of evidence that our planet is changing."

Researchers say that in many cases, plants and animals will be able to adapt to changing conditions, avoiding the fate of Fraser's Adélie penguins. Christiaan Both is doing genetic studies of pied flycatchers to see if certain families migrate earlier, raising the possibility that evolution will produce an early migrating subspecies. In at least some instances, however, it is unlikely that an evolutionary trick will be able to solve the problem climate warming has created. For example, it might seem that evolution could produce an early-laying great tit that could remain in synchrony with caterpillars in the oak trees in the De Hoge Veluwe park.

But there is a catch: before adult female tits can produce eggs, they must nourish themselves. They do so by foraging for insects in a different group of trees, primarily larch and birch, which open their leaves before the oaks. These trees have not changed the date of bud burst nearly as much as the oaks have. If this trend continues and if the insects in these trees remain in sync with larch and birch bud burst, the tits could not possibly be ready to breed any earlier in the season.

Many species, such as certain birds and insects, are already responding—and

will most likely continue to respond—to global warming by moving their ranges farther north or, in mountainous areas, to higher elevations. Less nimble species, such as trees, will be left behind. Terry L. Root, a biologist at the Center for Environmental Science and Policy at Stanford University, warns that these differential responses will cause existing ecosystems to be "torn apart," leaving altered, more impoverished ones in their place. The problem is compounded by human uses of land, such as cities, farms and highways, which fragment the landscape. Root published a paper in *Nature* last year with evidence of "fingerprints" of global warming on wild plants and animals. She says pollen studies of the end of the last ice age suggest what might happen. Such research shows that as the ice sheet that covered most of North Ameri-

ca retreated north, forests were not far behind. But complete communities did not simply move north in synchrony with rising temperatures. Instead the blend of plants and animals changed as the forests moved. Root fears that global warming could produce similar results, creating ecosystems unknown today and casting off species that no longer fit in.

There is, of course, much more research left to do to determine how serious and widespread the problem is. Certain conundrums will also need to be resolved. For example, why are the great tits in the De Hoge Veluwe park failing to remain in sync with winter moth caterpillars, while birds of the same species at a research site near Cambridge, England, just 400 kilometers away, have altered life cycles in step with the same insects? One thing, says Alastair Fitter, is clear: "The natural world is paying attention to what's going on in the climate." And, he adds, "It's going to get worse." SA

MORE TO EXPLORE

How Climate Change Alters Rhythms of the Wild. Bernice Weuthrich in *Science*, Vol. 287, No. 5454, pages 793–795; February 4, 2000.

Adjustment to Climate Change Is Constrained by Arrival Date in a Long-Distance Migrant Bird. Christiaan Both and Marcel E. Visser in *Nature*, Vol. 411, pages 296–298; May 17, 2001.

Climate Change and Biodiversity. Edited by Habiba Gitay, Avelina Suárez, Robert T. Watson and David Jon Dokken. IPCC Technical Paper, 2002. Available at www.ipcc.ch/pub/techrep.htm

Rapid Changes in Flowering Time in British Plants. A. H. Fitter and R.S.R. Fitter in *Science*, Vol. 296, pages 1689–1691; May 31, 2002.

Wildlife Responses to Climate Changes: North American Case Studies. Edited by Stephen H. Schneider and Terry L. Root. Island Press, 2002.