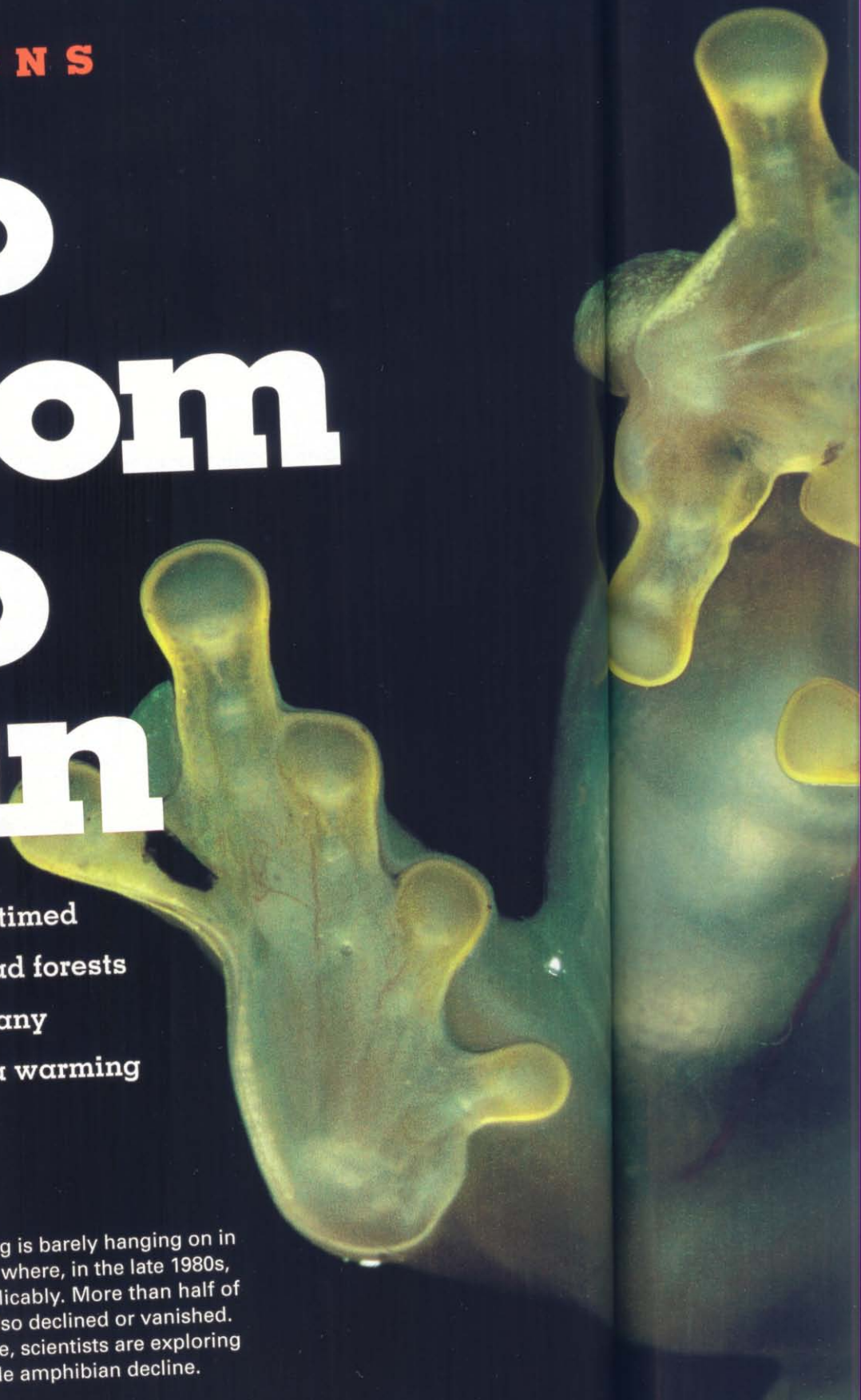


No Room to Run

Bleached coral, mistimed migrations, and dead forests count among the many complex effects of a warming global climate.

The Fleischmann's glass frog is barely hanging on in a tract of Costa Rican forest where, in the late 1980s, its numbers plunged inexplicably. More than half of that region's frog species also declined or vanished. As Earth's temperatures rise, scientists are exploring climate's role in a worldwide amphibian decline.





On the Rocks

Hunched against the elements along the Antarctic Peninsula, ecologist Bill Fraser counts Adélie penguins amid rocky nests red with guano. This colony dwindled from 320 breeding pairs to 54 between 1990 and 2004. Average winter temperatures here have increased nearly 9°F over five decades, and sea ice has retreated by a fifth since the mid-1970s, depriving Adélies of an important feeding platform from which they hunt krill. "The Adélies are the canaries in the coal mine of climate change in the Antarctic," says Fraser.

BY FEN MONTAIGNE

PHOTOGRAPHS BY PETER ESSICK

Biscoe Island is a small outcropping of rock and ice lost amid the epic landscape of the western Antarctic Peninsula. Looming above the island is the Marr Ice Piedmont, a massive glacier cleaved by 9,000-foot Mount Français. To the east, a few miles away, the sheer, jagged peaks of the peninsular chain—a checkerboard of black granite and broad glacial fields—plunge into the ocean. The blue waters of the Bellingshausen Sea are studded with icebergs and streaked



with sea ice. On a clear summer day the entire landscape—water, ice, rock—sparkles.

Ecologist Bill Fraser has been coming to the Antarctic Peninsula, an 800-mile finger of land that pokes upward toward South America, for 23 of the past 30 years. He can attest that the only thing that remains unchanged is the magnificent vista. In this corner of Antarctica, the land, the sea, and the creatures that inhabit them are all in flux as a result of some of the most rapid warming on Earth: Average winter temperatures have risen nearly 9°F in the past half century.

The most noticeable change has been the retreat of the Marr glacier, but most unsettling to Fraser—who came to Antarctica for adventure, solitude, and a Ph.D. on polar

birds—has been the effect of the warming on Adélie penguins, his life's work. One day in January, at the height of the Antarctic summer, Fraser and I hiked to a promontory on Biscoe to census a nearby Adélie colony, a patch of pebble nests stained brick red with guano. Adélies commuted to and from the ocean in single file, transporting shrimplike krill to feed hundreds of downy, peeping chicks on shore.

Twenty years ago Biscoe was home to 2,800 breeding pairs of Adélies, one of only two ice-dependent polar penguin species (the other is the emperor) in Antarctica. Today the number of Adélie breeding pairs on Biscoe has dropped to about a thousand, mirroring a 66 percent Adélie decline on nearby islands, where numbers have plummeted in 30 years from 32,000 breeding pairs to 11,000. As Fraser's work has documented, the disappearing Adélies are being replaced by gentoo penguins, a subantarctic species that has begun migrating toward the Pole from more temperate climes, such as the Falkland Islands. A dozen breeding pairs of gentoos arrived on Biscoe in the early 1990s. Since then, their numbers have increased to 660 pairs.

Surveying Biscoe's western ridgeline, where gentoo numbers had risen by about a hundred since the last breeding season, Fraser looked like a person watching his block mutate into a slum.

"Man, oh, man, this is absolutely unbelievable," said Fraser, who works out of Palmer Station, a U.S. research base. "This whole area used to be Adélie colonies. Now the gentoos are using the same nesting sites. I think Biscoe will soon be Adélie free. These birds are doomed."

Just behind us, the Marr Ice Piedmont calved with a thunderous rumble, sending a wall of blue ice cascading into the ocean. This continual booming, I was beginning to understand, was the soundtrack accompanying the disappearance of Bill Fraser's Adélies.

"A century ago this was basically a polar environment," he said. "The area embodied Antarctica. Now we have this subantarctic system impinging. I've watched the confrontation over the past 30 years, and the polar system has really disintegrated at Palmer. I'm in awe that it has taken such a short time to happen. Lesson number one for me has been the realization that ecology and ecosystems can change"—he snapped his fingers—"like that. In geologic time it's a nanosecond."



Uphill Climb

Daniela Hohenwallner of the Global Observation Research Initiative in Alpine Environments (GLORIA) takes samples of mosses above 10,000 feet on Schrankogel, a peak in Austria. Rapid warming in high mountains may be forcing alpine flowers like *Helianthemum alpestre* (above) to compete with taller plants inching up from below. GLORIA has set up more than a hundred sites globally to document this upward shift.

AUSTRIAN ALPS (LEFT);
SWISS ALPS (ABOVE)



“Ecology and ecosystems can change—like that. In geologic time it’s a nanosecond.”

The western Antarctic Peninsula has warmed so drastically because of a combination of rising global temperatures and regional shifts in ocean and air currents. Worldwide, temperatures have warmed far more slowly—an average of 1°F over the past century—yet even that relatively small change is rippling through the natural world. Fraser’s painstaking studies on the Antarctic Peninsula provide clues to how rising temperatures can profoundly affect ecosystems all over the planet, where animals, plants, and insects are already

adapting to moderate climate change by shifting their ranges, advancing migration dates, and altering times of mating and flowering.

A study of 35 nonmigratory butterfly species in Europe found that in recent decades about two-thirds have expanded their ranges northward by 20 to 150 miles. Many plants in Europe flower about a week earlier than they did 50 years ago and shed their leaves in the fall five days later. British birds breed an average of nine days earlier than in the mid-20th century, and frogs mate up to seven weeks sooner. Tree



swallows in North America migrate north in spring 12 days earlier than they did a quarter century ago. Red foxes in Canada are shifting their ranges hundreds of miles toward the Pole, moving into the territories of Arctic foxes. Alpine plants are edging uphill and beginning to overrun rare species near mountain summits.

Although the Earth's climate has always been subject to natural variation, with shifts between cold and warm, the current warming trend has ecologists worried for several reasons. This is the first instance in which humans appear to be accelerating the change, and warming could take place so quickly that species will not have the time to adapt and avoid extinction. And since different species react to climate change in different ways, the natural cycles of interdependent creatures—such as birds and the insects they feed on—may fall out of sync, causing population declines.

Pests and Pathogens

Four million acres of Alaska spruce, like these Sitkas by the Kachemak Bay, stand dead, victims of the spruce bark beetle. "We went into overdrive, climate-wise," says ecologist Ed Berg of the warmer summers since 1987. The warmth has boosted the numbers of mature beetles.

Monte Deatrick of metro Denver's Tri-County Health Department (right) tests a chicken for West Nile virus, which exploded in Colorado in 2003. Some suspect that a six-year drought concentrated migratory birds and virus-carrying mosquitoes at water sources, where the disease spread fast.

For now, as much of the world warms, animals and plants can try to beat the heat by retreating to higher latitudes and elevations. But such escape routes have limits, some of them imposed by humans. Unlike in past millennia, flora and fauna must cope in a world that is not only warming but is also home to 6.3 billion people.

"During past major climate changes, there wasn't a lot of human disturbance," says Camille Parmesan, an ecologist at the University of Texas at Austin. "Species could shift around. Now if they try to shift, they may be driven into a cornfield—or Chicago."

Parmesan conducted a study highlighting the pressure that species face when squeezed between a warming world and habitat destruction. In a 300-mile swath of territory between northern Mexico and southern California, the Edith's checkerspot butterfly has become extinct in 80 percent of its historical range. The



KENAI PENINSULA, ALASKA (LEFT); DENVER, COLORADO (ABOVE)

major cause, Parmesan showed, has been rising temperatures, which have led to the early desiccation of host snapdragon plants, depriving the butterfly larvae of crucial nutrition. Most of the southern populations, in otherwise prime Mexican habitat, are now extinct. And to the north, San Diego sprawl is gobbling up cooler sites that could support healthy colonies of the Edith's checkerspot.

At some point, as temperatures continue to rise, species will have no more room to run. Such is Bill Fraser's worry about the Adélies. Today only the 300,000 pairs that live on the Antarctic Peninsula seem to be at risk from climate warming. Another 2.2 million pairs are doing well elsewhere in Antarctica, in the far colder, more southerly (Continued on page 46)

Coral Necropolis

A heat-damaged reef in the Indian Ocean offers poor habitat for passing fish. Increasingly the planet's coral is in hot water, parboiled in periods of calm, sunny weather. Heat triggers coral to shed the algae that nourish it—a bleaching event that leaves coral white. Some reefs recover from bleaching while others become briny boneyards. In 1998 the world's coral suffered its worst year on record, which left 16 percent bleached or dead.

MALDIVES, INDIAN OCEAN

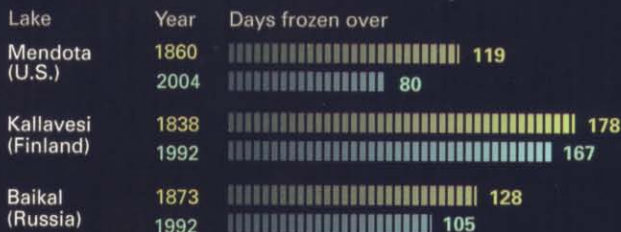


Shorter winters

Lake-ice freeze
and breakup dates >>>>>

■ Less ice

Many lakes are freezing later in the fall and thawing earlier in the spring than in the 19th century.

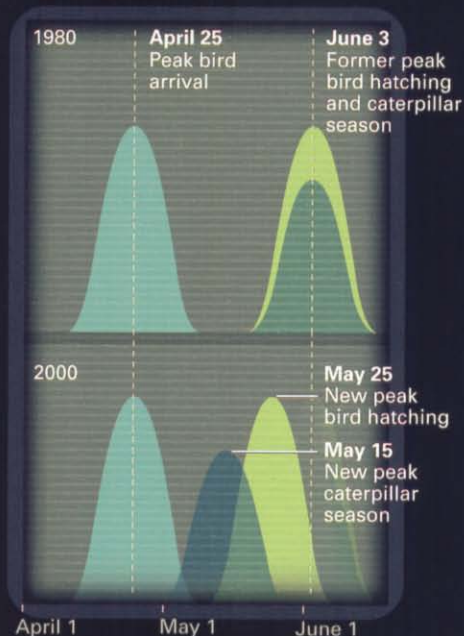


Nature changing its habits

Cycles
out of sync >>>>>>>>>>>

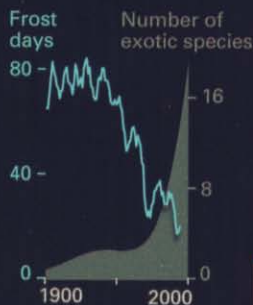
■ Off schedule

Flycatcher birds that migrate from Africa to the Netherlands to nest still arrive at the same time now as they did two decades ago. But because of warming, moth caterpillars on which nestlings feed emerge two weeks earlier than before. The birds' peak hatching date has shifted too, but not enough. Nestlings now miss peak caterpillar hatching and may go hungry.



■ Plants shift

Warming in the mountains of southern Switzerland (thus fewer days of frost) has forced some plants upslope and allowed exotic plant species to invade.



■ A Shift in Seasons

Life out of killer As temperatures rise, seasonal cues are altered, and life is shifting in space and time. Habitats are changing along with the timing of annual processes like flowering, leaf coverage, migration, and

birth. Species that depend on each other—plants and the insects that pollinate them, for example—don't always adapt to changes at the same time. In some cases they are slipping dangerously out of sync.



(Continued from page 41) parts of their range. But how many more decades, Fraser wonders, will that last?

Standing on the fringes of an Adélie colony on Humble Island, Fraser surveyed more than a hundred nine-pound, knee-high spheres of solid muscle. Packed tightly together, the penguins pecked at neighbors that infringed upon their territory. An incessant honking and trumpeting rose from the colony. Smearing with a gumbo of urine and guano, pear-shaped gray chicks hovered close to their nests, awaiting the arrival of a parent that would regurgitate several ounces of krill down their throats.

I remarked on the overpowering stench, but Fraser—tall and slender, dressed in a sun-bleached green parka, beige baseball cap, and black rain pants splattered white and red with

bird excrement—seemed to take no notice. “Smells like life,” he said.

Fraser was searching for a penguin on which to affix a satellite transmitter, a three-inch, waterproof device that would let him know where the Adélies were foraging. Crouching, he took a few steps into the colony, setting off a frantic chorus of alarm. He snatched a bird by the flipper and brought it, flailing and squawking, to the waiting lap of biologist Cindy Anderson, who taped the transmitter to its back.

The transmitter would tell Fraser and Anderson that the Adélies were feeding within ten miles, as there was an abundance of krill close to shore this year. Such foraging information is an important part of the ecological puzzle Fraser and his colleagues are piecing together about the Antarctic Peninsula. Sea ice is a nursery for krill, and krill are the key link in a food chain that supports penguins, whales, and many other

BUCK ISLAND, CARIBBEAN SEA



animals. If sea ice keeps retreating, then krill—and everything that eats them—could be in trouble.

Fraser first came to Antarctica in 1974 as a graduate student at the University of Minnesota. He was based at Palmer Station, on the west side of the peninsula. Palmer is accessible only by boat, and back then almost nothing was known about the wildlife there. So Fraser began censusing seals and seabirds, noting the dates of their arrival, hatching, and fledging. He gave scant thought to global warming, but the data he steadily compiled would eventually prove crucial to his future work on climate change.

“I fell in love with the sheer wildness that existed here,” recalls Fraser, who is now president of the nonprofit Polar Oceans Research



Four species threatened by global warming in polar or mountain regions:

- polar bear
- gelada baboon
- pygmy possum
- monarch butterfly

Group in Montana. “This was virgin territory. It was the sheer power of the Earth—ice and rock. It was a place where you could still feel inconsequential. You were part of a working natural system that paid you no mind.”

Fraser remembers an early encounter with the Adélies. He spotted a female, her breastbone ripped away from her neck by a leopard seal. Fraser could look inside the wound and see her lungs. The Adélie hovered around her chicks, scarcely moving for a week while her mate foraged for food. Then, her wounds partly healed, she headed to sea and resumed feeding her offspring.

“Adélies are the toughest animals I’ve ever encountered,” says Fraser. “They’re 18 inches tall and they can’t fly, but they can swim 3,500 miles in a winter migration. They thrive in what has to be the harshest environment on the planet.”

Beginning in 1983, Fraser spent springs and summers at Palmer, and after seven years he began to unravel the mystery of the Adélies’ decline around the region. In December 1990 Fraser stood on a rocky ridge that bisects Torgersen Island. He looked at the northern half of the island, which was largely snow free, and saw thousands of nesting Adélies. Then he looked to the south and saw Adélies struggling to nest in deep snow.

The western Antarctic Peninsula has received more snow in recent decades, a phenomenon linked, oddly enough, to rising temperatures: Less ice covering the ocean means greater evaporation of seawater, which at Palmer translates into increased snowfall. Around Palmer storms generally blow from the northeast. Snow piles up on the sheltered lee, or south, sides of ridges. And it is the Adélie colonies on the south sides of promontories that have been experiencing precipitous population drops.

“All of a sudden this lightbulb went on,” recalls Fraser. The Adélies, hardwired to nest in the same place at the same time year after year, were trying to incubate eggs in snow or snowmelt, where they failed to hatch. As a result, the colonies were withering away. The Adélie population on Litchfield Island, where the colonies were all on the lee side of a ridge, has experienced a collapse in numbers from 884 breeding

Gender Gap

Biologist Zandy Hillis-Starr sheds light on endangered hawksbill sea turtles newly hatched in the Virgin Islands. Scientists have long known that hot weather during the middle third of incubation causes the turtles’ eggs to yield more females. Now they have detected more females among sea turtles worldwide, with unknown long-term consequences for the species. Storms amplify the trend, shearing away trees that provide cooling shade to nests on beaches. “Severe weather events,” says Hillis-Starr, “really knock the socks off in favor of the females.”



At some point, as temperatures continue to rise, species will have no more room to run.

pairs in 1974 to 47 today. Fraser knew the Adélies had not migrated elsewhere, as his team had banded 20,000 penguins, only a few of which were found in other locations.

But Fraser also knew that Adélies were being affected by more than local conditions, for even colonies in relatively snow-free spots were shrinking. Larger forces were at work, and sea ice—vital to the Antarctic ecosystem—was at the heart of the matter. Adélies depend on sea ice as a feeding and resting platform. The gentoo penguins that are replacing them thrive in open water. Sea ice on the western Antarctic Peninsula has declined by about 20 percent, depriving the Adélies of important jumping-off points for rich winter feeding grounds.

Fraser continues to make important field observations. He discovered recently that Antarctic silverfish—once an important food for Adélies—have disappeared from the Palmer Station area and are now found only in colder waters farther south. He also has documented an invasion of fur seals, a subantarctic mammal, from areas such as South Georgia Island, 1,400 miles to the northeast. In 1974 Fraser counted six fur seals on the islands surrounding Palmer Station. Last summer he and his team saw 3,000.

In effect, over three decades, Fraser and his colleagues have recorded the retreat of an Antarctic ecosystem. In Fraser's words: "It has gone to hell."

At the top of the world, in the Arctic, climate change is occurring swiftly as well, and animals and birds appear to be feeling the effects. As temperatures have risen across the Arctic, permanent sea ice has declined by 9 percent per decade since 1978, when satellite monitoring of the ice cover began. In Hudson Bay the summer sea ice breakup now generally occurs two to three weeks earlier than it did during the mid-20th century. For animals that spend most of their year living and feeding on the ice—notably

polar bears and ringed seals—the continuing loss of sea ice could be disastrous.

Last September I joined Martyn Obbard, a wildlife research scientist with the Ontario Ministry of Natural Resources, on the shores of southern Hudson Bay. An estimated 1,000 polar bears inhabit this region at the southern edge of the species' range in North America. Obbard, accompanied by veterinarian and fellow biologist Marc Cattet, was in the final year of a four-year project to weigh, measure, and take physiological samples from roughly 300 bears.

Obbard would compare his measurements with those taken by biologists in the same region two decades ago. If polar bears are being forced to abandon the ice two to three weeks earlier than in the 1980s—departing at a time when they traditionally gorge on ringed seal



UTAH (ABOVE); EL ROSARIO PRESERVE, MICHOACÁN STATE, MEXICO (RIGHT)

Heights of Vulnerability

Freezing temperatures and more precipitation proved a lethal combination for millions of monarch butterflies in Mexico's mountains in early 2000. More such weather is projected. Cold-loving pikas in North America could face extinction if temperatures keep rising, driving the heat-sensitive mammals uphill to summits that effectively become shrinking islands of habitat.





Cloud Forests in Flux

MONTEVERDE, COSTA RICA (ALL)



Of the world's already diminished rain forest, less than 2.5 percent is considered cloud forest—a fragile environment blanketed by mist between 6,600 feet and 9,800 feet in tropical mountains. Mist is critical to the health of a *Pleurothallis* orchid (left), a tree-dwelling species from Costa Rica's Monteverde forest. Scientists have detected an increase in clouds in the forest (bottom), but the clouds are forming at higher altitudes. These warming-induced changes are forcing some species to move upslope. Biologist Debra Hamilton, who is studying the shifts, extracts an orange-billed nightingale thrush from a research net (below).



pups—then the loss of a crucial feeding period should, Obbard hypothesized, be taking a measurable toll on their health.

On a gray, windy day we lifted off from the village of Peawanuck in a five-seat helicopter, following the Winisk River north toward Hudson Bay. Flying over tundra occasionally broken by stands of pine and larch, we soon spotted polar bears along the shoreline, where they spend the summer months fasting as they wait for sea ice to form in the fall. Obbard saw a mother and cub a half mile ahead, and we descended. Leaning out of the helicopter, Obbard fired an anesthetic-filled dart into the mother. Within five minutes she was motionless on her side in the grass.

Landing nearby, we approached the bears. The nine-month-old cub straddled its mother's body, swinging its head from side to side. Biologist Lyle Walton worked his way to the rear and jabbed the cub in the neck with a syringe attached to a long pole. Soon the cub, too, was out, its head resting in the crook of its mother's arm. For the next two hours, the scientists took blood and fat samples and weighed the bears using a stretcher and pulley. The cub weighed 172 pounds and the mother 542 pounds. Both appeared healthy.

But while they may be healthy, they're not as hardy as the bears of two decades ago. Obbard has found that since the mid-1980s, the ratio of body mass to length among polar bears in southern Hudson Bay has dropped about 15 percent. In short, the bears are getting skinnier.

Polar bear biologist Ian Stirling has found similar body-mass declines among 1,200 bears in western Hudson Bay. Stirling, a researcher with the Canadian Wildlife Service, has also detected other trends indicating polar bears may not be getting enough food these days. Several decades ago in western Hudson Bay, triplet polar bear cubs were common. Now they're virtually nonexistent. Once, up to 40 percent of the cubs were weaned by 18 months, finding food for themselves. Today fewer than 5 percent of them are.

Stirling is convinced that the regression of sea ice is the culprit. And he fears that Hudson Bay's several thousand polar bears—part of an estimated worldwide population of 25,000—will vanish if, as climatologists have forecast, sea ice disappears from the bay by 2070.

Herd on Its Heels

Caribou from the Porcupine herd hoof it across northern Canada on their summer migration from birthing grounds in and around Alaska's Arctic National Wildlife Refuge. Their numbers declined from 178,000 in 1989 to 123,000 at last count in 2001. Scientists suspect that climate warming is a cause. The spring greening starts and ends earlier, and vegetation may die back before calves can gain enough weight to survive the winter.

YUKON TERRITORY, CANADA



The natural cycles of interdependent creatures may fall out of sync.

Obbard and Cattet say the link between retreating sea ice and declining bear body mass, though likely, has yet to be conclusively proved. The pair agrees with Stirling on a key issue: If temperatures keep climbing and sea ice continues to melt, the bears of Hudson Bay face a bleak future.

“No doubt if these trends continue for the next 50 years, Hudson Bay polar bears will never make a living,” says Cattet. “They’re toast. They’ll either have to learn to hunt caribou or head up to the high Arctic.”

TOOLIK LAKE, ALASKA

In late January, near the end of my stay at Palmer Station, Bill Fraser and I set out in a Zodiac boat to make the short trip to Torgersen Island. In the four weeks I’d been on the Antarctic Peninsula, I’d seen the Adélie chicks grow from fuzz balls to full-fledged seabirds weighing nearly as much as their parents. Most of the chicks had crèched, wandering away from their nests and hanging out in large packs, not unlike the students at any high school. The chicks hounded their parents continually, begging for food.



But Adélie adults have an intriguing way of dealing with annoying adolescents. Unable to keep feeding the chicks, the parents leave and don't come back. After a few days the chicks grow hungry and head to the sea in droves. At last, as their hunger grows by the day, they plunge in, flail around, and begin to pursue krill.

Though Torgersen Island has experienced a free fall in Adélie numbers—from 9,000 breeding pairs to 3,200—enough penguins still breed on the north side to remind Fraser of the abundance of the 1970s. Then, in the lingering summer evenings, Fraser would take in the sight of 30,000 adults and chicks squawking and feeding on the beaches.

"There was a constant stream of birds, two to five penguins wide, walking to the ocean," recalls Fraser. "It was like ants in the forest. Torgersen was an absolute mass of life. It manifested the incredible productivity of this ocean."

Greenhouse Effect

A forecast of Alaska's likely future grows 360 miles north of Fairbanks. Birch takes over from tundra in a greenhouse where nitrogen and phosphorus added to the soil mimic the effect of faster decomposition in a warmer climate. Temperatures inside average 6.3° F higher than outside. That's more warming than is predicted for the near future, concedes ecologist Gus Shaver, "but we're hitting the system with a hammer to see what direction it takes."

We walked to the snowy south side of the island, where the number of breeding pairs has fallen most drastically—from 1,200 to 99. In all directions lay fields of gray pebbles that Adélies had carried in their beaks to now abandoned nest sites. Once a colony dips below about 30 pairs, the scarcity of adults watching for danger makes eggs and chicks easy prey for the gull-like brown skua, and Fraser ticked off the damage at the south side's four most recent colonies: Colonies two and three abandoned, all of colony one's eggs and chicks, ten total, eaten by skuas this season, and 48 chicks still standing in colony four. He predicted that south Torgersen would soon be Adélie free.

"It's pretty pathetic," he remarked. "I've seen it time and again, same scenario. You remember the colony filled with Adélies, and you watch it dwindle until you actually see the last few survivors."

"It's as though the life of this place is slowly being drained away. They're so tough, but everything seems to be working against them. If there's a human footprint attached to this [warming], and there probably is, here you have this unbelievably tough little animal, able to deal with anything, succumbing to the large-scale effects of our activities. And that's the one thing they can't deal with. That's what angers me about the whole picture, that these incredible animals have to take it in the neck because a bunch of humans can't get together to decide what to do about the planet."

Later, Fraser and his team returned to Torgersen Island to pump the stomachs of Adélies and see what they were eating. As the scientists worked, I turned around to watch scores of penguins marching to the sea. Clouds hovered low above the Marr glacier, and the evening breeze was light. Extending their flippers for balance, the Adélies walked across gray stones polished over centuries by the passage of their ancestors. The birds' steps were delicate, and the padding of their pink, webbed feet on the rocks made one of the loveliest sounds I've ever heard—a gentle clink, clink, clink, reminiscent of wind chimes. □

FORCED TO SEEK NEW HABITATS Have you noticed any signs of climate change in flora and fauna around you? Report in our forum, then test your climate smarts with an interactive quiz at nationalgeographic.com/magazine/0409.

