OUR FAR-FLUNG CORRESPONDENTS

THE ICE RETREAT

Global warming and the Adélie penguin.

BY FEN MONTAIGNE

Litchfield Island is an outcropping of granite and diorite rising out of the Southern Ocean off the coast of the northwestern Antarctic Peninsula, which juts toward the tip of South America. With dark, snow-streaked ridges flowing into broad, pebbled beaches, Litchfield is picturesque, but amid the imposing Antarctic landscape the island—not quite three-quarters of a mile long and half a mile wide—hardly merits a second glance. To the north, on Anvers Island, the dome of the Marr Ice Piedmont—a glacier roughly forty miles long and twenty miles across at its widest point—dominates the horizon. To the east, forming the spine of the nine-hundred-mile-long Antarctic Peninsula, lies a towering mountain range of sheer black rockfaces and ice fields streaming to the sea. And to the south and west, stretching to the horizon, are innumerable icebergs, their shapes running from flat-topped slabs to whimsical, castle-like structures.

On an overcast January morning, with the temperature just below freezing, Bill Fraser, an ecologist and penguin expert, eased a rubber Zodiac boat onto Litchfield's shore. Grasping the bowline, I leaped onto the rocks and was quickly joined by Fraser, who lashed the rope around a boulder, flung an iridescent-orange flotation coat onto the stony ground, and began walking across the eastern third of the island. It had been two years since Fraser set foot on Litchfield, and he had come to see what remained of a once thriving rookery of Adélies—the classic tuxedoed penguin, and one of only two penguin species that breed exclusively in Antarctica. (The other is the emperor penguin.)

Fraser paused amid an expanse of pebbles, nearly the size of a football field, that were used by the few remaining Adélie penguins to construct their cup-shaped nests. "Everywhere you see these rocks, there used to be penguins," Fraser said. "All these areas used to be colonies. There was a colony here, there, over there."

Studies of Adélie bones buried under layers of guano have shown that penguins have nested on Litchfield Island since at least the sixteenth century. When Fraser first arrived in the region, in 1974, as a graduate student, the island's penguin rookery had nine hundred breeding pairs. Over the years, the number of Adélies had fallen to a few dozen breeding pairs, and a census conducted earlier that season by a birding team that Fraser led indicated that the rookery was on the verge of disappearing.

Still, he was not prepared for the scene

A steady loss of sea ice along the northwestern Antarctic Peninsula prevents Adélies reaching some of their richest feeding grounds.

PETER ESSICK/AURORA PHOTOS

that greeted him on Litchfield's southern shore: only five Adélie nests remained, containing seven fluffy chicks—no taller than a man's hand—and eleven adult Adélies, which reached a person's knee. They were huddled on an oval-shaped patch of stones, twenty-five feet across at its widest point. Some of the chicks had burrowed under their parents, seeking the warmth of the brood patch—a four-inch slit that covers the eggs with bare, blood-engorged skin. (The heat of the brood patch enables Adélies to incubate their eggs at 86 degrees Fahrenheit.) Other chicks, with light-gray down and black heads, stood and stretched their necks skyward, greedily accepting from a parent a meal of regurgitated krill, a shrimplike creature. This last Adélie redoubt on Litchfield Island was known as Colony 8.

Fraser shook his head and said, "This is unbelievable. Colony 8 used to have so many birds you could barely count them."

As we returned to the boat, Fraser said that a few dozen adults, some possibly as old as fifteen to twenty years, kept returning to their ancestral breeding grounds. But Adélies have evolved as an ice-dependent species, and, in the rapidly warming environment of the northwestern Antarctic Peninsula, many of the adults—and nearly all their chicks—were not surviving the winter.

"Litchfield is looking miserable," Fraser said. "When this colony goes, it will be the first time in at least five hundred years that there will be no Adélies on the island."

In the austral summer of 2005-06, I spent nearly five months as a member of Bill Fraser's birding team at Palmer Station, a scrap of civilization grafted onto a rocky spit of land. It is named for an early-nineteenth-century American seal hunter, Nathaniel B. Palmer, who at age twenty left Stonington, Connecticut, in command of a small sloop, the Hero, sailed the length of the planet, crossed the wild stretch of ocean known as the Drake Passage, and entered the foggy, iceberg-covered Antarctic waters in search of fur seals.

The U.S. government research station named in Palmer's honor is a cluster of half a dozen corrugated-metal buildings that, at peak times, house forty scientists and support staff. The tiny base—described by one early visitor as an "insolent blot" on the Antarctic landscape—is situated in the midst of numerous small islands that are home to Adélie-penguin rookeries.

One evening, soon after I arrived at Palmer, I hiked up the Marr Ice Piedmont, just behind the station. Though it was only three hundred feet above sea level, I gazed through the dust-free Antarctic atmosphere at mountain summits a hundred and twenty miles away. Close to shore, the sea ice was loosely packed, and the placid pools of water at the base of the Marr glacier reflected the pale-blue walls of the ice piedmont. Beyond the nearby islands, the sea ice was a cool, blue-white table that ran to the horizon. A closer look revealed that its surface was composed of small slabs of sea ice pushed together by persistent winds. A penguin had recently tobogganed across the glacier, its flippers slicing knifelike slits in the snow.

Aerial photographs taken in 1963 show that the Marr Ice Piedmont once engulfed nearly the entire point on which Palmer Station now stands. Since that time, however, the glacier has retreated roughly fifteen hundred feet. In the nineteen-seventies and eighties, Fraser and others used to climb the Marr Ice Piedmont and ski to places such as Biscoe Point, eight miles away. That is virtually impossible now, as the thinning glacier is riven by crevasses and is falling back from the coastline in large, scalloped chunks.

Fraser has spent most of the past thirty-five years working in Antarctica, more time than almost any other U.S. scientist. He and his fellow-researchers at Palmer are mainly engaged in studying the effects of the rapid warming on the formation of sea ice, on the phytoplankton and Antarctic krill that depend on the sea ice, and on the Adélie penguins that rely on the sea ice and the krill. Fraser's work is part of the Long Term Ecological Research Network, a program, launched in 1980 by the National Science Foundation, that chronicles environmental changes in twenty-six ecosystems around the world.

Much attention has been paid to the warming of the Arctic, where for three decades scientists have been tracking the rapid retreat of summer sea ice and

the melting of glaciers. But the northwestern Antarctic Peninsula has heated up faster than almost any other place on earth, as temperate air has streamed in from the north and warming ocean currents have swept along the peninsula. From 1951 to the present, the average annual air temperature in the region has increased by nearly five degrees. Winter temperatures have soared about eleven degrees over the past six decades—five times the global average.

For the moment, rising temperatures are only nibbling at the edges of Antarctica's repository of ice, a vast dome of frozen precipitation—three miles thick in places—covering an area one and a half times the size of the United States. But increasing warmth will likely penetrate more deeply into Antarctica; a recent study forecasts that the entire continent will heat up by more than five degrees this century.

"The poles are very sensitive barometers of warming, and what we're looking at here on the Antarctic Peninsula is an entire ecosystem that is changing," Fraser said. "And it's not changing in hundreds of years—it's changing in thirty to fifty years. To me, this is foretelling the future across major parts of the planet."

In the fall of 1975, Bill Fraser—then a twenty-five-year-old graduate student at the University of Minnesota—sailed from Ushuaia, Argentina, to Antarctica aboard a hundred-and-twenty-five-foot research vessel, the R.V. Hero, named in honor of Nathaniel Palmer's sloop. It was his second trip to the continent. After weathering a gale in the Drake Passage, the Hero approached the relatively tranquil waters of the Bransfield Strait, which is sheltered from the Southern Ocean by the South Shetland Islands, at the northern tip of the Antarctic Peninsula. Exhausted after several rough days of travel, Fraser went to sleep. The next morning, he awoke to unaccustomed stillness. The water was flat, and the only sound he heard was the drone of the Hero's diesel engine.

"I stepped out into this gray world," Fraser recalled. "It had been snowing heavily and the ship was moving through this three-to-four-inch layer of snow and slush on the water. There was snow all over the deck. It was incredibly foggy. And the ship was completely surrounded by snow petrels, one of the most beautiful birds in the world—absolutely white. When you see them, you know the ice is near."

After stopping at King George Island, in the South Shetlands, the Hero steamed toward Anvers Island, where Palmer Station is situated, at 64° S. The ship's progress was soon blocked by thick sea ice. Built for the National Science Foundation to supply Palmer Station and work along the Antarctic Peninsula, the Hero had an oak hull, overlain with a rock-hard layer of greenheart. The forward hull was sheathed in metal. But the Hero could not penetrate the sea ice surrounding the small American base. So Fraser disembarked and began heading toward Palmer Station on skis, carrying provisions and equipment behind him on a sled.

As Fraser glided swiftly over the surface, leopard seals—sleek, spotted predators that devour everything from krill to penguins—cruised under the ice, tracking his movements. Fraser could hear the leopard seals trilling low, droning calls beneath him, and occasionally a seal poked its head through an opening in the ice to observe the skiers. Leopard seals love ice, and they were a common feature around Palmer Station, lounging on floes, attacking Adélie penguins, trailing the rubber Zodiacs used by scientists, and occasionally biting a hole in one.

Fraser said of the peninsula, "It was completely remote and absolutely wild. The rawness and beauty of this place just cannot be described. It was a place where you could still feel inconsequential. You were part of a working system that paid you no mind."

Fraser spent thirteen months in Antarctica. Palmer Station had been in operation for only seven years, and the scientists and support staff lived in isolation, communicating with the outside world by ham radio. During the winter, Fraser and five other men manned the station, and no ships came or went. Fraser worked in the field, observing the behavior and foraging habits of one of the rare midwinter resident seabirds, the kelp gull. For recreation, he skied by himself into the frozen Southern Ocean. When the moon was full, bathing the ice in a ghostly blue light, Fraser skied for miles along the shore. He stopped from time to time and listened to the stillness, broken occasionally by the report of cracking ice.

"You start doing what you know you need to do to get through the winter," Fraser recalled. "You're taking care of your sanity. You knew you were there for the long haul. And the winters were a lot colder then."

During the summer months, Fraser and his fellow graduate students travelled from island to island, taking a census of Adélie-penguin rookeries. One of the largest was on Torgersen Island, half a mile from the station. On a January evening, when many of the adults were on the island feeding their chicks, more than twenty thousand Adélies of all ages mobbed Torgersen, their raspy calls splitting the air with a din that could be heard miles away.

"You'd see thousands of Adélies walking to and from the sea," Fraser said. "It was like ants in the forest—there was a constant stream of birds. Torgersen was an absolute mass of life. It just manifested the incredible productivity of this ocean and its ability to support life."

One of the defining features of Antarctica is the great skirt of sea ice that spreads out from the continent each year. At the end of the Southern Hemisphere's summer, in February, the sea ice girding the continent is roughly a million square miles. By September, the circle of sea ice around the continent has expanded six times—more than doubling the size of Antarctica itself. (Although sea ice has declined markedly along the western Antarctic Peninsula, it is increasing in some regions of Antarctica, most notably in the Ross Sea, because of changing atmospheric patterns.)

Once, on a midwinter cruise in the Weddell Sea, Fraser went to bed as a severe cold snap set in and woke up the next morning to find that the ice edge had spread outward by several miles. On the infrequent occasions when the sun was out—for about two hours around noon—Fraser could stand on the bridge and, as temperatures dropped, watch the sea ice form before his eyes.

"Suddenly, you'd see what looks like grease on the water, and then that would

stop moving," Fraser said. "And, before you knew it, the sea was turning gray, gray, gray, and finally you would see an inch or so of ice just appear."

The Intergovernmental Panel on Climate Change has concluded that human-induced global warming began to clearly impact the planet at about the time that Fraser first came to Palmer Station. But in 1974 few scholars were linking human activity with rising global temperatures. One of Fraser's professors at the University of Minnesota did discuss climate change, but told his students that it was unlikely they would witness its effects in their lifetimes.

Fraser, who is fifty-eight, is a lean and handsome man of six feet, with light-brown hair, a ruddy complexion, blue eyes, thin lips, and a cleft in his chin. After three decades of working in Antarctica, he has perfected his field outfit, wearing clothes that protect him from the elements yet do not leave him overheated during swift hikes across the terrain. During my season at Palmer Station, he wore a fleece sweater covered by a royal-blue windbreaker that was faded by the sun and ripped in places by bird beaks and rocks; rugged black rain pants heavily stained by guano and crusty with sea salt; and ankle-high leather hiking boots, deeply scarred by years of scrambling over Antarctic rocks.

At the rookeries on Litchfield and other islands, the Adélies paid us little attention as long as we stayed ten feet away. If you moved closer, you would be subjected to an array of elaborate threat displays, all exhaustively studied by scientists—a walleyed stare, or the raising of the feathers on the head into something resembling a flat-top haircut. If you moved closer still, some Adélies would charge and jam a sharp beak into your leg. (One day, a belligerent penguin bounded up to me and plunged its beak into the flesh below my knee. Like an awl, it penetrated my rain pants, thick fleece pants, long underwear, and skin, drawing blood.)

While Fraser occasionally uses high-tech tools in his research—such as tracking penguins by affixing satellite transmitters to their backs—most of his work involves spending long days in the field performing decidedly low-tech, repetitive tasks. He and his birding team measure snow depth, count penguins and seabirds, and sample guano to check what's in their diets.

He is assisted by a team of five young field workers. Though nearly all of them have a background in biology, Fraser is looking primarily for people who are amiable—working five months in the field, often ten to twelve hours a day, tests a team's cohesiveness—and in excellent physical condition. The birders were an outdoorsy and collegial group who often came to a decision when one member looked at another and said, "Your call."

Fraser is fiercely loyal to his squad of birders; unlike many field biologists, he provides health insurance to his seasonal field-team workers and contributes to their pension plans. At Palmer, he was keenly attuned to the dangers of exhaustion. Once, lost in thought near season's end, I walked too close to some giant petrels and spooked them. A day or two later, I wandered near a group of elephant seals wallowing at the edge of an Adélie colony, prompting two of them to slither rapidly away in panic and nearly crush to death several penguin chicks. As we walked back to our boat, Fraser pulled me aside and said, "I think you're getting burned out. I've noticed it for a while. You came out of the boat yesterday with a rope wrapped around your legs."

I apologized and told him I felt fine.

"You don't even know it's happening to you," he continued. "I saw one person, after four months here, literally step off the boat right into the water. I had to talk to you because when someone is like this he can easily get hurt himself or

MY CHILDHOOD IN IRELAND

I never climbed the hill
or strolled to the end of the pier
to see what the walkers in rain
might be finding out there.

Nor did the book fall open
where Maeve had secretly signed it.
In fact, it never fell open.
Not that I minded: the world

streamed away
wherever the great ships
were going. Far away
there were ways beyond knowing.

I walked back to the house.
My sister's new child was chained
to her breast. She drifted
inside a dark forest.

My father opined while the dog whined.
The television did its best.
While my father opined
the dog licked itself.

Well, you manage to find
what might make you happy.
I went on the Net. I wandered.
Asian bukkake.

—Bill Manhire

hurt someone else on the team. And it's no good for morale."

Although Fraser and his team study many seabird species around Palmer Station—including giant petrels, skuas, and kelp gulls—his work is heavily focussed on Adélies. In the thirty-five years since he first arrived at Palmer Station, the population of Adélie penguins on the seven islands that compose his main study area—Torgersen, Humble, Litchfield, Cormorant, Christine, Dream, and Biscoe Point—has declined from between thirty thousand and forty thousand breeding pairs to fifty-six hundred breeding pairs, a drop of more than eighty per cent. Meanwhile, the Adélie's cousin from warmer climes, the gentoo penguin, is moving in, following the heat as it travels down the Antarctic Peninsula. In 1993, there were no gentoo penguins in Fraser's study area. Today, there are twenty-four hundred pairs. As Fraser is fond of saying, "There goes the neighborhood."

Adélies are an easy bird to love, with their upright carriage and industrious demeanor. Their bonding displays are particularly charming: males daintily give gifts of nest pebbles to females, and couples greet each other by issuing full-throated honks and weaving their heads back and forth, in a kind of Adélie air kiss. After they've paired off, Adélie couples sometimes stand side by side, looking like partners at the start of a square dance. Occasionally, one penguin bows to its mate.

What most appeals to Fraser, though, is the Adélies' feistiness. Once, on Humble Island, I watched as an Adélie marched up to a fifteen-hundred-pound elephant seal that had moved too close to the penguin's chicks and jabbed the seal in the mouth. The seal retreated, shimmying back several feet even as it opened its bubblegum-pink mouth in a display of aggression.

Fraser once came across a female Adélie that had been grievously injured in a leopard-seal attack. "The seal had grabbed her by the head and ripped her breastbone off right at the neck and you could look down into her stomach cavity," he said. "You could actually see her lungs working in there. But she spent a few days recouping, hunched over, and I'll be damned if in less than a week she wasn't back in the water, feeding her chicks. She and her mate even pulled a brood off."

From time to time, the team affixed satellite transmitters to the backs of Adélies to determine where they were foraging. Fraser would approach a colony and slowly insinuate his arm among the penguins, some of which would hurl themselves at him and jab his legs or hands. Snatching an Adélie, he passed the bird to me. I grabbed it by the flippers and delivered it to the team members attaching the tags. The penguin's might was electric, its football-shaped body—a solid mass of muscle—rocking my arms as it struggled to free itself.

One evening, we travelled to Torgersen Island to do Adélie diet sampling. This entailed grabbing several penguins, pumping water into their stomachs through plastic tubing until they regurgitated, and then collecting their stomach contents in a white plastic bucket.

A team member, Brett Pickering, noticed drops of blood flowing into the bucket as one of the Adélies regurgitated krill. Pickering released the penguin, which stood for a few seconds, then lay down on the pebbles. It shook its head, spraying a combination of water, krill, and blood. The bird rose and tried to walk but couldn't. Blood-stained bubbles poured from its mouth. Fraser silently picked up the penguin, walked twenty-five feet away, knelt down, placed the Adélie between his legs, grabbed a rock, and ended its life with a blow to the head.

Several members of the team were on the verge of crying. We walked in silence back to the boat landing.

"Something has changed," Fraser said, as we neared the Zodiac. "I don't know what it is, but something has changed, and I want to find out what it is. We have done hundreds of these diet samples for years with no problems, and now in the last few years some birds have started dying.

"I know that it's very likely that the bird we're diet sampling is probably an old animal, because chick recruitment is so poor now. And it really bothers me that here's a bird that's survived thick and thin and gone through hell and it's an old bird and I come along and it dies because of me."

Like many earlier explorers, Fraser seems happiest in the Antarctic. ("Once you have been to the white unknown, you can never escape the call of the little voices," Frank Wild, Ernest

"I'm getting red fruits, earth tones, and oak. Amen."

Shackleton's second-in-command on the Endurance expedition, said.) I once asked Fraser if he could live in a city, and he replied, "When I have to spend four or five days at a conference in a big city, I wither away. I become lethargic. It drives me insane. I hate it when I can't see the horizon."

Fraser's many years in the field have been instrumental in helping him understand how a warming climate has decimated the region's Adélies.

"It always seemed intuitive to me that the only way to really understand something is to live in it, to spend a tremendous amount of time in the field, collecting the same data year after year," Fraser told me. "You develop a sense for what the rhythms should be, the flow of things. And that's what has allowed me to pick up things that don't make sense, the anomalies. The anomalous years really cue you in as to how this system is operating."

For eighteen years, beginning in 1987, Fraser spent from three to five months every year in Antarctica—and occasionally seven or eight—as his wife and two daughters stayed at home in the U.S. The marriage ended in divorce, and relations with one of his daughters have been strained. (Once, as he was preparing to depart for another season at Palmer, one of the daughters told him, "Mommy says you love penguins more than you love me.")

Though he worked for several years as an associate professor at Montana State University, Fraser's decision to run a field operation for nearly half the year made it virtually impossible for him to hold a traditional academic job. In 2002, he married one of his team members, Donna Patterson, who shares his commitment to the work at Palmer Station. The couple now run the Polar Oceans Research Group, a non-profit based in their home, a thirty-four-acre farm in southwestern Montana's Ruby Valley. The modest, century-old house owned by Fraser and Patterson sits at five thousand feet and has mountain views in all directions. Madison County, where they live, is half the size of New Jersey but has no stoplights and not quite eight thousand inhabitants.

"He's part of a generation of scientists we won't see again," Polly Penhale, a former program director of Antarctic biology and medicine at the National Science Foundation, told me. "How many people would give up their personal lives for four to five months a year for all those years?" Since having a son in 2004, Fraser has spent less time at Palmer and more time in Montana with his family, increasingly leaving the field work to his team.

Over the past two decades, Fraser and his colleagues have gradually identified two main culprits in the decline of the region's Adélie penguins. One is the steady loss of sea ice along the northwestern Antarctic Peninsula. The second is a related increase in snowfall, which has primarily interfered with the ability of Adélies to successfully breed and incubate their eggs.

"There's this gigantic puzzle and you have all these pieces and it has taken twenty years to figure it out," Fraser said. "The most dangerous thing you can do is assume it is one factor that is causing these changes, when in fact many factors are playing a part."

The decline in sea-ice duration has been dramatic. Satellite imagery shows that sea ice now blankets waters off the peninsula three months less than it did in 1979. On average, sea ice forms fifty-four days later in the autumn and retreats thirty-one days sooner in the spring.

"The whole system revolves around the freezing point, so a slight change in the positive direction has major implications for the entire food web," Fraser said. "The freezing point is truly a threshold."

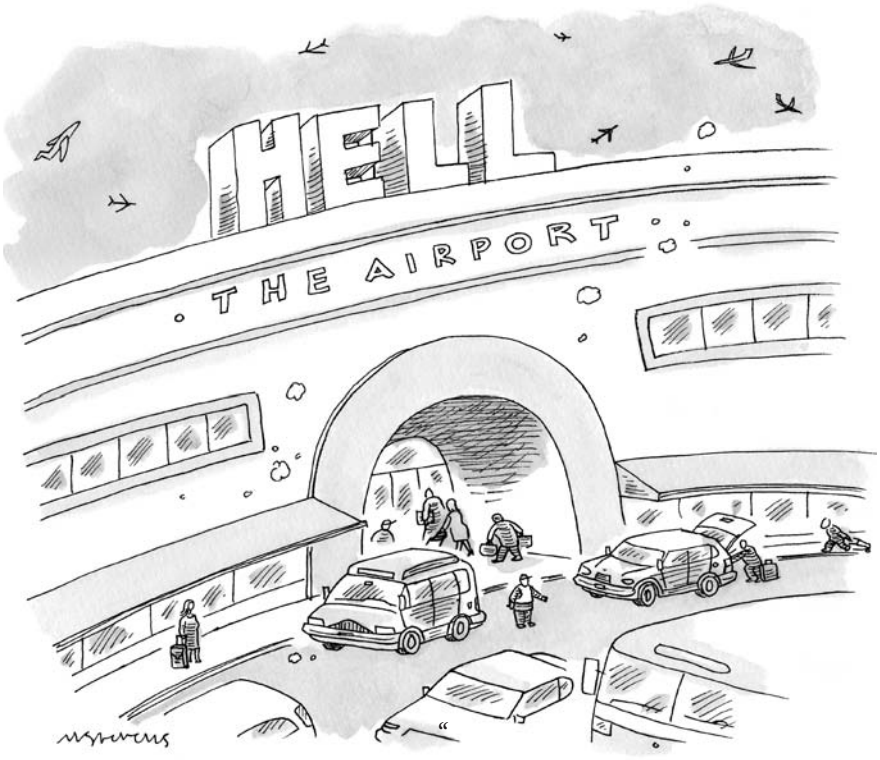
The importance of sea ice to Adélies first became clear to Fraser during a government-funded cruise in 1988. Fraser was aboard a Coast Guard icebreaker in the Weddell Sea, east of Palmer Station, on the other side of the Antarctic Peninsula. As the cruise unfolded in bitterly cold conditions, with temperatures sometimes plunging to minus 40 degrees Fahrenheit, Fraser noticed tens of thousands of Adélies on the pack ice and the absence of chinstrap penguins. A second research vessel, to the north, in the largely ice-free Scotia Sea, found almost exclusively chinstrap penguins, whose numbers were growing in the region.

The widely accepted explanation for the increase in chinstrap penguins was the decimation of baleen whales in the Southern Ocean by large-scale commercial whaling operations, which continued into the nineteen-eighties. Scientists believed that, with these voracious krill consumers largely removed from the sea, krill populations had rebounded, sparking a resurgence by creatures that ate krill, including chinstrap penguins.

If that hypothesis was true, Fraser wondered, then why were Adélies, which also ate krill, declining in number in some places? Not long after the cruise, he attended a conference in Hobart, Tasmania, during which several papers discussed growing evidence of global warming. "And that is when I sort of put these stories together," Fraser said. "It reeked of habitat change due to a warming climate."

He began to believe that changing penguin populations had less to do with krill abundance than with a warming winter habitat. Adélies were denizens of sea ice, while chinstraps preferred open water. The temperature record showed a steady decrease in the frequency of the cold years that led to extensive sea-ice formation along the Antarctic Peninsula, which occurs when the mean annual air temperature falls below 24 degrees Fahrenheit. At mid-century, roughly four out of five years saw temperatures below that mean. But by the nineteen-eighties the frequency of such winters had fallen to one or two out of every five years.

Some of Fraser's colleagues were skeptical of his thesis about the central role played by declining sea ice. Fraser spoke with scientists at NASA, which had begun using satellites to monitor sea ice along the peninsula. NASA researchers told him that there were no discernible trends in sea ice. Within a few years, however, satellite data clearly



showed that sea ice was swiftly disappearing in the region. In 1991, Fraser and three colleagues wrote a paper on the subject, but the prestigious journals *Science* and *Nature* rejected it. A year later, he and his collaborators published the paper in *Polar Biology*, arguing that shrinking sea ice was leading to the growth of chinstrap populations and the decline of Adélies. That year, John Croxall, a prominent scientist with the British Antarctic Survey, published a paper questioning Fraser's thesis, saying that it was "certainly premature" to conclude that changing environmental factors, such as declining sea ice, were the reason behind shifting penguin populations. Croxall, who has retired, now says that, given the accumulated evidence of the last two decades, there is "no doubt" that declining sea ice has been a crucial factor affecting penguin populations.

As his research on the peninsula continued, Fraser became convinced that shrinking sea ice was depriving Adélies of a crucial platform that allowed them to reach rich feeding grounds. In winter, Adélies throughout Antarctica must have access to open water, which on the peninsula is typically at the heads of undersea canyons, where upwelling brings nutrients—and krill—to the surface. Those foraging areas must also be above the Antarctic Circle in midwinter, so that the penguins have sufficient light to see their prey. If a lack of ice prevents the Adélies from easily reaching these feeding grounds, their winter survival rates plummet.

"Without enough sea ice, these birds can't reach what must be very productive areas of the ocean," Fraser said. He had placed satellite tags on Adélies along the northwestern Antarctic Peninsula, which showed that they were foraging in three main locations, at the heads of the large undersea canyons.

One way to look at the Adélies' plight, Fraser said, is through the prism of an old ecological concept: "match-mismatch dynamics." More recently, some scientists and writers have taken to calling it "global weirding." On the most basic level, it means that a species has fallen out of sync with its environment.

In the field one afternoon, Fraser said, "What we're looking at here is an entire ecosystem that is changing, and it's not changing in hundreds of years, which is what we used to be taught. It's changed so quickly that it has encompassed the research lives of a few people who have spent a lifetime here."

The loss of sea ice has also taken a toll on ice-dependent krill—juvenile krill eat phytoplankton embedded in the underside of the ice—and on phytoplankton that bloom when sea ice melts in summer. Recent studies have shown drops in populations of both species along the northwestern Antarctic Peninsula. In addition, populations of ice-dependent Antarctic silverfish—which thirty years ago made up nearly half the diet of Adélie penguins around Palmer Station—have also fallen in the region, meaning that Adélies are overwhelmingly dependent on krill.

Hugh Ducklow, the director of the Ecosystems Center at Woods Hole and the head of the Palmer Long Term Ecological Research Network, said, "As sea ice begins to decline and then fails to form, as is now happening very rapidly, all these populations that depend on the timing and the existence and the extent of sea ice for their successful feeding and breeding will be high and dry."

Fraser has noticed from radio-transmitter data that Adélie penguins have been spending more time foraging at sea in recent years. Average foraging times appear to have increased from roughly eight to thirteen hours per trip, an indication that the Adélies are having a harder time finding the krill they need to feed their chicks—and themselves.

In the early nineties, Fraser began focussing on the impact of increasing snowfall on Adélie penguins. Working one November on Torgersen Island, Fraser walked to the top of the low, rocky ridge that bisects the island. He recalls, "I looked to my right, and that area was almost snow-free and there were thousands of Adélies there. Then I looked to my left—the south side—and it was under a metre of snow, with fewer than a thousand Adélies sitting on the snow, having a hell of a time trying to breed." Adélies have scant success nesting on snow or in snowmelt, as their eggs often become addled—and newly hatched chicks sometimes drown—in meltwater ponds.

Fraser realized that the abundant snow on the south side had to be related to the state of Adélie populations there, which were declining far more

rapidly than on the north side of the island. As he stood on the ridge, it also became clear to him why the south side was snowier than the north: this relatively modest crest of crumbling, lichen-covered rocks was still high enough to create a wind barrier that prevented the prevailing northerly winds from blowing the snow off the south side.

"As counter-intuitive as it may sound, Adélie penguins are a snow-intolerant species," Fraser told me. "They evolved in a polar desert. And these birds' life histories are so finely tuned to the environment that tiny differences can affect their survival. If they don't have snow-free habitat by the end of November, their breeding success is catastrophic. You would think the Adélies would delay their breeding a bit because of the snow, but they can't. The birds are just hardwired and they don't adjust. They are hard-wired into oblivion."

Snowfall had been increasing along the western Antarctic Peninsula, according to ice-core records and meteorological data from a nearby British base. More snow was consistent with a marine Antarctic environment that was experiencing an influx of warmer air and seeing sea ice shrink—thus exposing more open water, leading to more evaporation, which then formed as precipitation.

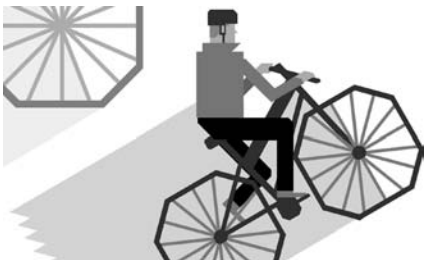
The main impact of increased snowfall on Adélies, according to Fraser, is that more eggs are being lost as colonies have to cope with melting snow. I witnessed that on Torgersen Island, where half a dozen eggs in Colony 19-A rested at the bottom of two murky ponds of snowmelt, about six inches deep. The water was a putrid brown color, and under the surface the eggs looked like large golf balls resting in a shallow water hazard. Adélies were standing belly-deep in the water, dunking their heads under the surface to try to move their eggs or rebuild their collapsed nests. Several penguins had managed to rebuild their nests high enough so that they just poked above the ponds, looking like castles in the middle of a lake. One or two even had succeeded in placing an egg atop the pile, after which they attempted to brood the eggs. That colony has since disappeared.

By monitoring the penguins from hatching to fledging, Fraser determined that pairs of Adélie penguins in his study area successfully raised, on average, 1.3 chicks to fledging. This rate is roughly twice as high as the success rate at some other colonies on the continent. Fraser soon realized that the reason Palmer's Adélies were so good at rearing chicks was that the breeders were almost all older, experienced adults, which have more success raising chicks than younger Adélies. Fraser said, "This high breeding success is actually an indicator of just how bad recruitment of new penguins into the population is, because new breeders always screw up."

Survival rates for fledged Adélie chicks that head to sea are low—by one estimate, between ten and fifteen per cent—so environmental factors that cut down on those odds can push a population of Adélies over the edge.

In February, I spent many days on Torgersen Island watching Adélie chicks plunge tentatively into the Southern Ocean. Looking half-panicked and half-playful, these fledging penguins dog-paddled in the shallows, splashed wildly with their flippers, and honked to their fellow-swimmers. Within a minute, the stronger chicks began heading out to sea. Most travelled in packs, but some headed out alone. I saw a young Adélie struggle through three-foot waves and then, as it cleared the surf, scramble onto a passing ice floe in a desperate attempt to find some semblance of terra firma. The chick then floated away, its ice platform rocking in the swells.

Biscoe Point, on the southeastern corner of Anvers Island, sits in the shadow of Mt. William, a fifty-two-hundred-foot peak whose ridges are cloaked in ice and whose gray face is etched with snow-filled draws. A dozen miles away, on the peninsula, looms a line of tombstone-shaped mountains that plunge into the Southern Ocean. These days, however, Biscoe Point is in need of rechristening. As recently as twenty years ago, the Marr Ice Piedmont covered part of Biscoe. But the retreat of the glacier has revealed that what once looked like a peninsula is actually an island, now separated from the glacier by more than fifty feet of open water. The warmer weather has brought other changes to Biscoe: As Adélie-penguin populations have declined, gentoo penguins—with their fondness for higher temperatures—have arrived in force.



Fraser and I went to Biscoe in mid-January. He had not been there in two years, and as we puttered to our landing site he noted that gentoo-penguin colonies had spread across a series of terraces, all the way to the highest ridge. "Is that a gentoo colony way the hell up there on the ridge?" he asked. "This is just amazing." There were seven hundred and sixty-one nesting pairs of Adélies—down from twenty-eight hundred pairs in 1984—and they were relegated to a few ridges close to the sea. For the first time, more gentoos—nine hundred and two pairs—were nesting on Biscoe than Adélies. As we ranged across the terraces where the gentoos had built their round, high-sided nests, they filled the air with donkey-like braying.

We walked to the end of the point, next to the terminus of the Marr glacier. For two hundred yards, we traversed gradually sloping terrain of smoke-colored stone and shattered rocks, some frost-fractured into thin slices. In the seventies, the area we walked across was buried under a hundred feet of ice. Now the ice patch, the size of a football field just two years before, had been reduced by half, and seemed to be only a few dozen feet thick. On the surface of the ice, fist-size rocks had been heated by the sun, boring holes in the remnant of the glacier. We dipped our hands into these little wells, drinking the sweet water. I could hear, beneath the plate of ice, the trickling of meltwater flowing to the sea. Patches of Antarctica's two vascular plants—a short, tufty, pale-green hair grass, *Deschampsia antarctica*, and a mossy-looking pearlwort, *Colobanthus*

quitensis—were colonizing new territory amid the glacial till.

We sat on rocks and gazed at the glacier's face, which was several stories high. Its luminous front was honeycombed, and much of it slumped forward, looking like melted wax. The noise coming from the glacier was constant—sharp cracks, deep rumbles like the sound of furniture being moved across a floor, and from time to time the showering of ice inside a hidden crevasse. The snapping sounds intensified and then, just in front of us, a twenty-five-foot chunk of the glacier calved into the narrow channel separating the Marr and Biscoe. The cascading pieces of the glacier sent waves lapping against nearby rocks. Thousands of ice shards from this and previous calvings hissed as they were buffeted by the waves. The newly exposed face of the glacier was a heavenly shade of blue, attained over thousands of years as the ice was compressed and air pockets were eliminated.

Eighty-seven per cent of the glaciers along the Antarctic Peninsula are in retreat, according to a study by the British Antarctic Survey and the U.S. Geological Survey. Along the peninsula, eight ice shelves have fully or partially disintegrated in the past three decades. The largest collapse was the Larsen B Ice Shelf—once the size of Connecticut—which in March, 2002, shattered into millions of pieces after several summers of unusually high air temperatures in the customarily frigid Weddell Sea. Many glaciers in west Antarctica are now sliding more rapidly to the sea, most notably the Pine Island Glacier, a river of ice—a hundred and ninety miles long and thirty miles wide—moving toward the Amundsen Sea at the rate of a foot an hour. If that glacier and the neighboring Thwaites Glacier unload their mass into the Southern Ocean, sea levels could rise as much as five feet.

"If someone had taken you here ten or twenty years ago and said, 'This will all disappear in ten years,' you would have said, 'You're fucking crazy,'" Fraser said. "The ice cap on Biscoe has been here for thousands of years, and now it's almost gone. What you're seeing here is what you would have seen if you had been standing in Wisconsin fifteen thousand years ago as the glaciers retreated. This is what these landscapes must have looked like as the ice melted. It's the sheer power of the earth—ice and rock. Lesson No. 1 for me has been the realization that ecology and ecosystems can change like that," he said, snapping his fingers. "In geological time, it's a nanosecond."

In all likelihood, the fate that has befallen Adélie penguins around Palmer Station awaits ice-dependent penguins breeding farther south in Antarctica. Two and a half million pairs of Adélie penguins still breed throughout the continent, and some Adélie populations in colder Antarctic regions are actually growing. Such is the case with a rookery of Adélies that Fraser's team monitors on Avian Island, in Marguerite Bay, two hundred and fifty miles south of Palmer Station. Fifty years ago, much of the ocean around Avian Island was covered year-round in ice, making it difficult for large numbers of Adélies to nest there and gain access to the open water needed for foraging. But the warming of the bay region has melted sea ice and provided an optimal mixture of ice and open water. As a result, Fraser estimates that the Adélie-penguin population on Avian Island has doubled in the past thirty-five years, to between fifty thousand and seventy-five thousand pairs. But he believes that the Avian Island population is probably nearing its peak, and that, as sea ice continues to disappear, the rookery will decline.

David Ainley, a penguin expert, who studies Adélie populations on the Ross Sea, recently led a study funded by the National Science Foundation and the conservation group W.W.F. Ainley and his colleagues predict a dire impact on polar penguins if global temperatures rise 2 degrees Celsius (3.6 degrees Fahrenheit) above pre-industrial levels, which now seems inevitable. The researchers conclude that Adélie- and emperor-penguin colonies north of 70° S—comprising half of Antarctica's emperor-penguin colonies and three-quarters of the continent's Adélie colonies—"are in jeopardy of marked decline or disappearance."

Within several decades, Fraser believes, Adélie penguins will disappear from the northwestern Antarctic Peninsula. As he put it, "They're on a decline that has no recovery."

In late January, two members of the birding team and I returned to Litchfield Island to see if any Adélie chicks remained. Walking across the many abandoned colonies, I strained to catch a glimpse of chicks, but as we neared the other side of the island it was clear that the young Adélies were gone. Lacking the protection of a larger colony, they had presumably been eaten by brown skuas.

Brett Pickering, the field-team member, said, "Litchfield is officially over."

"It's the total lack of any life whatsoever on these quite large rookeries that just keeps going through my mind," Fraser said after I returned from Litchfield.

"I have real affection for Adélies, but everything seems to be working against them," Fraser had told me earlier. "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, and they're dying because of it. And that's the sad side of that story for the Adélies. It's such a long-distance effect. The industrial nations to the north are having an impact that Adélies are being subjected to down here. That's what sort of pisses me off 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."

Several days later, Fraser returned to Litchfield, wanting to see for himself the end of the island's Adélie rookery. A lone adult stood staidly in Colony 8, flippers at its sides, scarcely noticing us. The penguin seemed to be sleeping, the white rings around its eyes closing to a slit and gently pulsating. The late-summer sun turned the Bismarck Strait a shade of deep indigo. Except for the gentle slosh of the surf and the occasional cry of a brown skua, the island was silent. ♦

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Slide show: Fen Montaigne on penguins.