Lab # 1:

Please write a one-page essay (single-space typed with font size #12) on the potential impact of global warming on (1) glacier, (2) sea level, and (3) ecology on the basis of the attached two articles from National Geographic Magazine (due Thursday, April 27).

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GeoSigns: The Big Thaw

By Daniel Glick

If we don't have it, we don't need it," pronounces Daniel Fagre as we throw on our backpacks. We're armed with crampons, ice axes, rope, GPS receivers, and bear spray to ward off grizzlies, and we're trudging toward Sperry Glacier in Glacier National Park, Montana. I fall in step with Fagre and two other research scientists from the U.S. Geological Survey Global Change Research Program. They're doing what they've been doing for more than a decade: measuring how the park's storied glaciers are melting.

So far, the results have been positively chilling. When President Taft created Glacier National Park in 1910, it was home to an estimated 150 glaciers. Since then the number has decreased to fewer than 30, and most of those remaining have shrunk in area by two-thirds. Fagre predicts that within 30 years most if not all of the park's namesake glaciers will disappear.

"Things that normally happen in geologic time are happening during the span of a human lifetime," says Fagre. "It's like watching the Statue of Liberty melt."

Scientists who assess the planet's health see indisputable evidence that Earth has been getting warmer, in some cases rapidly. Most believe that human activity, in particular the burning of fossil fuels and the resulting buildup of greenhouse gases in the atmosphere, have influenced this warming trend. In the past decade scientists have documented record-high average annual surface temperatures and have been observing other signs of change all over the planet: in the distribution of ice, and in the salinity, levels, and temperatures of the oceans.

"This glacier used to be closer," Fagre declares as we crest a steep section, his glasses fogged from exertion. He's only half joking. A trailside sign notes that since 1901, Sperry Glacier has shrunk from more than 800 acres to 300 acres (324 hectares to 121 hectares). "That's out of date," Fagre says, stopping to catch his breath. "It's now less than 250 acres."

Everywhere on Earth ice is changing. The famed snows of Kilimanjaro have melted more than 80 percent since 1912. Glaciers in the Garhwal Himalaya in India are retreating so fast that researchers believe that most central and eastern Himalayan glaciers could virtually disappear by 2035. Arctic sea ice has thinned significantly over the past half century, and its extent has declined by about 10 percent in the past 30 years. NASA's repeated laser altimeter readings show the edges of Greenland's ice sheet shrinking. Spring freshwater ice breakup in the Northern Hemisphere now occurs nine days earlier than it did 150 years ago, and autumn freeze-up ten days later. Thawing permafrost has caused the ground to subside more than 15 feet (4.6 meters) in parts of Alaska. From the Arctic to Peru, from Switzerland to the equatorial glaciers of Irian Jaya in Indonesia, massive ice fields, monstrous glaciers, and sea ice are disappearing, fast.

When temperatures rise and ice melts, more water flows to the seas from glaciers and ice caps, and ocean water warms and expands in volume. This combination of effects has played the major role in raising average global sea level between four and eight inches (10 and 20 centimeters) in the past hundred years, according to the Intergovernmental Panel on Climate Change

(IPCC).

Scientists point out that sea levels have risen and fallen substantially over Earth's 4.6-billion-year history. But the recent rate of global sea level rise has departed from the average rate of the past two to three thousand years and is rising more rapidly—about one-tenth of an inch (about one-fourth of a centimeter) a year. A continuation or acceleration of that trend has the potential to cause striking changes in the world's coastlines.

Driving around Louisiana's Gulf Coast, Windell Curole can see the future, and it looks pretty wet. In southern Louisiana coasts are literally sinking by about three feet (about one meter) a century, a process called subsidence. A sinking coastline and a rising ocean combine to yield powerful effects. It's like taking the global sea-level-rise problem and moving it along at fast-forward.

The seventh-generation Cajun and manager of the South Lafourche Levee District navigates his truck down an unpaved mound of dirt that separates civilization from inundation, dry land from a swampy horizon. With his French-tinged lilt, Curole points to places where these bayous, swamps, and fishing villages portend a warmer world: his high school girlfriend's house partly submerged, a cemetery with water lapping against the white tombs, his grandfather's former hunting camp now afloat in a stand of skeleton oak snags. "We live in a place of almost land, almost water," says the 52-year-old Curole.

Rising sea level, sinking land, eroding coasts, and temperamental storms are a fact of life for Curole. Even relatively small storm surges in the past two decades have overwhelmed the system of dikes, levees, and pump stations that he manages, upgraded in the 1990s to forestall the Gulf of Mexico's relentless creep. "I've probably ordered more evacuations than any other person in the country," Curole says.

The current trend is consequential not only in coastal Louisiana but around the world. Never before have so many humans lived so close to the coasts: More than a hundred million people worldwide live within three feet of mean sea level. Vulnerable to sea-level rise, Tuvalu, a small country in the South Pacific, has already begun formulating evacuation plans. Megacities where human populations have concentrated near coastal plains or river deltas—Shanghai, Bangkok, Jakarta, Tokyo, and New York—are at risk. The projected economic and humanitarian impacts on low-lying, densely populated, and desperately poor countries like Bangladesh are potentially catastrophic. The scenarios are disturbing even in wealthy countries like the Netherlands, with nearly half its landmass already at or below sea level.

Rising sea level produces a cascade of effects. Bruce Douglas, a coastal researcher at Florida International University, calculates that every inch of sea-level rise could result in eight feet of horizontal retreat of sandy beach shorelines due to erosion. Furthermore, when salt water intrudes into freshwater aquifers, it threatens sources of drinking water and makes raising crops problematic. In the Nile Delta, where many of Egypt's crops are cultivated, widespread erosion and saltwater intrusion would be disastrous—since the country contains little other arable land.

In some places marvels of human engineering worsen effects from rising seas in a warming world. The system of channels and levees along the Mississippi effectively stopped the millenniaold natural process of rebuilding the river delta with rich sediment deposits. In the 1930s, oil and gas companies began to dredge shipping and exploratory canals, tearing up the marshland buffers that helped dissipate tidal surges. Energy drilling removed vast quantities of subsurface liquid, which studies suggest increased the rate at which the land is sinking. Now Louisiana is losing approximately 25 square miles (65 square kilometers) of wetlands every year, and the state is lobbying for federal money to help replace the upstream sediments that are the delta's lifeblood.

Local projects like that might not do much good in the very long run, though, depending on the course of change elsewhere on the planet. Part of Antarctica's Larsen Ice Shelf broke apart in early 2002. Although floating ice does not change sea level when it melts (any more than a glass of water will overflow when the ice cubes in it melt), scientists became concerned that the collapse could foreshadow the breakup of other ice shelves in Antarctica and allow increased glacial discharge into the sea from ice sheets on the continent. If the West Antarctic ice sheet were to break up, which scientists consider very unlikely this century, it alone contains enough ice to raise sea level by nearly 20 feet (6 meters).

Even without such a major event, the IPCC projected in its 2001 report that sea level will rise anywhere between 4 and 35 inches (10 and 89 centimeters) by the end of the century. The high end of that projection—nearly three feet (0.9 meters)—would be "an unmitigated disaster," according to Douglas.

Down on the bayou, all of those predictions make Windell Curole shudder. "We're the guinea pigs," he says, surveying his aqueous world from the relatively lofty vantage point of a 12-foot-high (3.7 meter) earthen berm. "I don't think anybody down here looks at the sea-level-rise problem and puts their heads in the sand." That's because soon there may not be much sand left.

Rising sea level is not the only change Earth's oceans are undergoing. The ten-year-long World Ocean Circulation Experiment, launched in 1990, has helped researchers to better understand what is now called the ocean conveyor belt.

Oceans, in effect, mimic some functions of the human circulatory system. Just as arteries carry oxygenated blood from the heart to the extremities, and veins return blood to be replenished with oxygen, oceans provide life-sustaining circulation to the planet. Propelled mainly by prevailing winds and differences in water density, which changes with the temperature and salinity of the seawater, ocean currents are critical in cooling, warming, and watering the planet's terrestrial surfaces—and in transferring heat from the Equator to the Poles.

The engine running the conveyor belt is the density-driven thermohaline circulation ("thermo" for heat and "haline" for salt). Warm, salty water flows from the tropical Atlantic north toward the Pole in surface currents like the Gulf Stream. This saline water loses heat to the air as it is carried to the far reaches of the North Atlantic. The coldness and high salinity together make the water more dense, and it sinks deep into the ocean. Surface water moves in to replace it. The deep, cold water flows into the South Atlantic, Indian, and Pacific Oceans, eventually mixing again with warm water and rising back to the surface.

Changes in water temperature and salinity, depending on how drastic they are, might have considerable effects on the ocean conveyor belt. Ocean temperatures are rising in all ocean basins and at much deeper depths than previously thought, say scientists at the National Oceanic and Atmospheric Administration (NOAA). Arguably, the largest oceanic change ever measured in the era of modern instruments is in the declining salinity of the subpolar seas bordering the North Atlantic.

Robert Gagosian, president and director of the Woods Hole Oceanographic Institution, believes that oceans hold the key to potential dramatic shifts in the Earth's climate. He warns that too much change in ocean temperature and salinity could disrupt the North Atlantic thermohaline circulation enough to slow down or possibly halt the conveyor belt—causing drastic climate changes in time spans as short as a decade.

The future breakdown of the thermohaline circulation remains a disturbing, if remote, possibility. But the link between changing atmospheric chemistry and the changing oceans is indisputable, says Nicholas Bates, a principal investigator for the Bermuda Atlantic Time-series Study station, which monitors the temperature, chemical composition, and salinity of deep-ocean water in the Sargasso Sea southeast of the Bermuda Triangle.

Oceans are important sinks, or absorption centers, for carbon dioxide, and take up about a third of human-generated CO_2. Data from the Bermuda monitoring programs show that CO_2levels at the ocean surface are rising at about the same rate as atmospheric CO_2. But it is in the deeper levels where Bates has observed even greater change. In the waters between 250 and 450 meters (820 and 1,476 feet) deep, CO_2 levels are rising at nearly twice the rate as in the surface waters. "It's not a belief system; it's an observable scientific fact," Bates says. "And it shouldn't be doing that unless something fundamental has changed in this part of the ocean."

While scientists like Bates monitor changes in the oceans, others evaluate CO_2 levels in the atmosphere. In Vestmannaeyjar, Iceland, a lighthouse attendant opens a large silver suitcase that looks like something out of a

James Bond movie, telescopes out an attached 15-foot (4.6 meter) rod, and flips a switch, activating a computer that controls several motors, valves, and stopcocks. Two two-and-a-half-liter (5.3 pint) flasks in the suitcase fill with ambient air. In North Africa, an Algerian monk at Assekrem does the same. Around the world, collectors like these are monitoring the cocoon of gases that compose our atmosphere and permit life as we know it to persist.

When the weekly collection is done, all the flasks are sent to Boulder, Colorado. There, Pieter Tans, a Dutch-born atmospheric scientist with NOAA's Climate Monitoring and Diagnostics Laboratory, oversees a slew of sensitive instruments that test the air in the flasks for its chemical composition. In this way Tans helps assess the state of the world's atmosphere.

By all accounts it has changed significantly in the past 150 years.

Walking through the various labs filled with cylinders of standardized gas mixtures, absolute manometers, and gas chromatographs, Tans offers up a short history of atmospheric monitoring. In the late 1950s a researcher named Charles Keeling began measuring CO2 in the atmosphere above Hawaii's 13,679-foot (4,169 meter) Mauna Loa. The first thing that caught Keeling's eye was how CO2 level rose and fell seasonally. That made sense since, during spring and summer, plants take in CO2 during photosynthesis and produce oxygen in the atmosphere. In the fall and winter, when plants decay, they release greater quantities of CO2 through respiration and decay. Keeling's vacillating seasonal curve became famous as a visual representation of the Earth "breathing."

Something else about the way the Earth was breathing attracted Keeling's attention. He watched as CO2 level not only fluctuated seasonally, but also rose year after year. Carbon dioxide level has climbed from about 315 parts per million (ppm) from Keeling's first readings in 1958 to more than 375 ppm today. A primary source for this rise is indisputable: humans' prodigious burning of carbon-laden fossil fuels for their factories, homes, and cars.

Tans shows me a graph depicting levels of three key greenhouse gases—CO2, methane, and nitrous oxide—from the year 1000 to the present. The three gases together help keep Earth, which would otherwise be an inhospitably cold orbiting rock, temperate by orchestrating an intricate dance between the radiation of heat from Earth back to space (cooling the planet) and the absorption of radiation in the atmosphere (trapping it near the surface and thus warming the planet).

Tans and most other scientists believe that greenhouse gases are at the root of our changing climate. "These gases are a climate-change driver," says Tans, poking his graph definitively with his index finger. The three lines on the graph follow almost identical patterns: basically flat until the mid-1800s, then all three move upward in a trend that turns even more sharply upward after 1950. "This is what we did," says Tans, pointing to the parallel spikes. "We have very significantly changed the atmospheric concentration of these gases. We know their radiative properties," he says. "It is inconceivable to me that the increase would not have a significant effect on climate."

Exactly how large that effect might be on the planet's health and respiratory system will continue to be a subject of great scientific and political debate—especially if the lines on the graph continue their upward trajectory.

Eugene Brower, an Inupiat Eskimo and president of the Barrow Whaling Captains' Association, doesn't need fancy parts-per-million measurements of CO2 concentrations or long-term sea-level gauges to tell him that his world is changing.

"It's happening as we speak," the 56-year-old Brower says as we drive around his home in Barrow, Alaska—the United States' northernmost city—on a late August day. In his fire chief's truck, Brower takes me to his family's traditional ice cellars, painstakingly dug into the permafrost, and points out how his stores of muktuk—whale skin and blubber—recently began spoiling in the fall because melting water drips down to his food stores. Our next stop is the old Bureau of Indian Affairs school building. The once impenetrable permafrost that kept the foundation solid has bucked and heaved so much that walking through the school is almost like walking down the halls of an amusement park fun house. We head to the eroding beach and gaze out over open water. "Normally by now the ice would be coming in," Brower says, scrunching up his eyes and scanning the blue horizon.

We continue our tour. Barrow looks like a coastal community under siege. The ramshackle conglomeration of weather-beaten houses along the seaside gravel road stands protected from fall storm surges by miles-long berms of gravel and mud that block views of migrating gray whales. Yellow bulldozers and graders patrol the coast like sentries.

The Inupiat language has words that describe many kinds of ice. *Piqaluyak* is salt-free multiyear sea ice. *Ivuniq* is a pressure ridge. *Sarri* is the word for pack ice, *tuvaqtaq* is bottom-fast ice, and shore-fast ice is *tuvaq*. For Brower, these words are the currency of hunters who must know and follow ice patterns to track bearded seals, walruses, and bowhead whales.

There are no words, though, to describe how much, and how fast, the ice is changing. Researchers long ago predicted that the most visible impacts from a globally warmer world would occur first at high latitudes: rising air and sea temperatures, earlier snowmelt, later ice freeze-up, reductions in sea ice, thawing permafrost, more erosion, increases in storm intensity. Now all those impacts have been documented in Alaska. "The changes observed here provide an early warning system for the rest of the planet," says Amanda Lynch, an Australian researcher who is the principal investigator on a project that works with Barrow's residents to help them incorporate scientific data into management decisions for the city's threatened infrastructure.

Before leaving the Arctic, I drive to Point Barrow alone. There, at the tip of Alaska, roughshod hunting shacks dot the spit of land that marks the dividing line between the Chukchi and Beaufort Seas. Next to one shack someone has planted three eight-foot (two-meter) sticks of white driftwood in the sand, then crisscrossed their tops with whale baleen, a horny substance that whales of the same name use to filter life-sustaining plankton out of seawater. The baleen, curiously, looks like palm fronds.

So there, on the North Slope of Alaska, stand three makeshift palm trees. Perhaps they are no more than an elaborate Inupiat joke, but these Arctic palms seem an enigmatic metaphor for the Earth's future.

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EcoSigns: No Room to Run

By Fen Montaigne

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 (2,740-meter) 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 (1,290- kilometer) 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 (-27°C) 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."

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 (-31°C) 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 (30 to 240 kilometers). 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.

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 (480-kilometer) 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 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 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 (four-kilogram), 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. Smeared 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 spattered 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 (8-centimeter), water-proof 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 Ander-son 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 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 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 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 (2,250 kilometers) 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 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 (one kilometer) 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 (78 kilograms) and the mother 542 pounds (245 kilograms). 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.

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."

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 mani-fested the incredible productivity of this ocean."

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.

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