POLAR SCIENCE

Taking a Bottom-to-Sky "Slice" of the Arctic Ocean

Robie Macdonald had trouble catching fish this summer. Then again, Macdonald had picked a tough spot to fish: the deck of an icebreaker crunching through the frozen Arctic Ocean on the way to the North Pole. In those ice-locked waters, nets and a variety of other methods were ineffective, says Macdonald, a researcher from the Institute of Ocean Sciences (IOS) in Sidney, British Columbia, who wanted to study pesticide contamination in Arctic fish.

Then Macdonald and colleagues noticed that, as the icebreaker pounded out a path, it occasionally bounced a hapless cod up onto the broken ice blocks bobbing in its wake. "We got them by blowing them out of the water," laughs Macdonald. What the researchers on board called "Arctic roadkill" supplied Macdonald's group with a specimen from almost every degree of latitude on the journey north, providing one of most complete wildlife contamination samples ever collected in the Arctic Ocean.

The "ones that didn't get away" is just a single example of the stories from an ambitious Canadian–U.S. scientific expedition that, during July and August, traveled on the first surface ships to explore the Amerasian basin, which comprises two thirds of the Arctic Ocean, the world's least studied ocean. "This is the last area of ocean about which nothing is known," says Oregon State University biologist Evelyn Sherr, an expedition member. That's an ignorance that scientists are strongly motivated to change, because they think the ocean's remote position makes it a particularly sensitive indicator of global change, such as warming trends. Such change is hard to detect without a baseline of data, however.

That baseline began to take shape by the time the expedition's two icebreakers—the Canadian Coast Guard ship *Louis St. Laurent* and the U.S. Coast Guard's *Polar Sea*—completed their voyage in early September. The ships, which after crunching through 1700 nautical miles of ice became the first North American surface vessels to reach the North Pole, carried more than 70 researchers pursuing 50 different research programs. And on their trip, the scientists completed the first "section" of the Amerasian basin: a comprehensive look at the biology, physics, and chemistry of the ocean floor, waters, ice, and atmosphere above. As IOS oceanographer Ed Carmack, Canada's senior scientist on the trip, put it, researchers took "a full cut of the Arctic, from the top of the sky to the bottom of the ocean."

Such a section is "something that people have wanted to do for years and years. Nobody's ever been out there with a major scientific expedition. It's quite an accomplishment," says Robert Rutford of the University of Texas, Dallas, chair of the National Academy of Science's Polar Research Board. Although the mission's major goal was baseline data for predicting and monitoring future changes in the Arctic, there have been more immediate scientific payoffs. Some of the early results point to an unforeseen bonanza of biological activity on the frozen wastes, ranging from polar bears to plankton, and some unexpectedly warm water quite a bit further north than it was supposed to be.

Warmth in the cold. The surprisingly warm water layer—at least for the Arctic Ocean—is one example of how the northern region can apparently experience dramatic changes in environment. Water samples taken during the cruise show that a layer of the Arctic Ocean, from 100 to 2000 meters deep, originated in the warmer, salty waters of the North Atlantic. The water temperatures in these intermediate Arctic layers, compared to a few years ago, are warmer by about 1 degree Celsius. "There is clear evidence the Arctic is warming," says Carmack.

Carmack and others hasten to add that this may be a normal, sporadic phenomenon and not necessarily a sign of global warming, although he says he can't rule out the latter possibility. "We really don't have a theory yet why this is occurring. We're welcoming any suggestions," says Carmack. The take-home message, adds expedition leader Knut Aagaard, an oceanographer from the University of Washington, is "that you can have large changes in the Arctic, much larger than I would have thought credible."

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Unexpected presence. The Arctic expedition saw polar bears hundreds of miles out on the ice-locked ocean; biologists previously thought the animals stayed closer to shore.

Another crucial mystery explored on the cruise was the area's albedo, a measurement of how much of the sun's radiation—and thus its heat—is reflected back into space by the Arctic surface. "The climate models have become so sophisticated that they need to know the albedo at specific wavelengths," explains Terry Tucker of the U.S. Army's Cold Regions Research and Engineering Laboratory in New Hampshire. Past albedo measurements, he says, had only touched the edges of the Arctic Ocean basin. On this voyage, Tucker and other researchers took ice samples to study their optical properties, noted snow depth, and measured incoming and outgoing radiation. Helicopter reconnaissance also provided the best survey yet of the abundance of melt ponds, areas that unfreeze during the summer, forming puddles that absorb more light than normal ice. One finding that surprised the albedo researchers was the extent of sediment-laden ice, "dirty ice," which reflects less than cleaner ice. "I was shocked to see it all the way across the Arctic" and to the North Pole, says Tucker. Researchers hadn't thought the sediments, largely derived from shoreline areas, could be transported that far away from their origin.

While the albedo can determine how much solar radiation bounces away from Earth, it isn't the only factor affecting the warmth of our planet. Cloud cover is a major influence on the amount of radiation that gets through to Earth's surface in the first place, and one project examined the role algae may play in cloud formation. "We're trying to understand the link between biological sulfur production and clouds," says Leonard Barrie, an atmospheric chemist at Canada's Atmospheric Environment Service in Ontario. Phytoplankton—microscopic algae—reside in the Arctic waters, he explains, and employ a unique organic molecule, called DMSP, to help them adapt to the frigid temperatures. When the plankton die and their cells burst, DMSP is released into Arctic water, quickly degrading into molecules of insoluble dimethylsulfide, which can escape into the air. There they may form nuclei for condensed water droplets, "seeds" for a cloud. Initial data from the cruise provide the first confirmation that this algae-to-cloud pathway may play a significant, if small, role in the overall amount of cloud formation over the Arctic waters. Summer blooms of these algae might therefore have to be taken into account in the climate models of the region, researchers suggest.

Clouds of another sort—clouds of pollutants—also drew the attention of researchers interested in global change. "What we don't know from the Arctic is the distribution of contaminants in the ocean," says IOS's Macdonald, who headed a program to look at pesticides and radionuclides. Canada is particularly interested in what happens to pesticides used in Europe and Asia, as wind and current patterns tends to bring this material to the Arctic Circle, where it can be taken up by plants and enter the food chain, eventually working its way to the native people of the region who eat the local animals. On the trip, researchers were measuring the concentrations of pesticides such as lindane in the Arctic air, ice, and water. These pesticides are fat-soluble, which means that their concentration is magnified as they move up the food chain into larger animals such as seals, polar bears—and cod. That's one reason why Macdonald was chasing his Arctic roadkill. "We have to advise the natives whether to eat the stuff," says Macdonald, who expects it may be a year before the contamination studies are done.

A whole lot of life. Macdonald's catches of the day were just one sign of a surprisingly abundant amount of life in the Arctic Ocean. "From bacteria to polar bears, there was a lot more activity than anyone expected to find," says Sherr. For example, the amount of plant material, largely algae in the water and on the ice, was two to four times higher than measurements back in the 1950s had suggested, notes Oregon State University's Pat Wheeler. And those plants are quite active, it seems. The primary production rate for the region, a measure of the photosynthetic activity among the plants, was 10 times higher than expected, says Wheeler.

The Arctic's unanticipated liveliness was also reflected at the top of the food chain. The polar bear researchers that went on the trip, notes Ed Carmack, had been told by their colleagues that the voyage was a waste of time because they would find no bears on the floating ice pack that covers the Arctic Ocean. Yet the ship's scientists directly observed seven polar bears, including a mother and two cubs that were 700 miles from the nearest land, an indication that they lived on the ice pack itself. Tracks and seal remains also pointed to a significant polar bear presence on the pack. "There was evidence of bears all the way across the Arctic," says Carmack.

These results "changed our perspective in a very significant way as polar bear ecologists. [The Arctic] may not be the marginal habitat we thought," says Françoise Messier of the University of Saskatchewan in Saskatoon. In order to study these polar bears further, researchers tagged a number with radio collars to allow satellite observations of their migration patterns across the ice.

First surface passage. Starting near Alaska, the icebreakers traveled across the pole, finishing the journey at Iceland. Dots indicate stops made to perform experiments.

Boring in. Present-day life, however, wasn't the only aspect of the Arctic investigated on the trip; the past was also the subject of several explorations into the sediments covering the ocean floor. Elizabeth Osborne of the Wood's Hole Oceanographic Institution (WHOI) and others aboard the *Polar Sea* collected "box core" samples of floor sediments throughout the voyage. The box cores amass less than a meter of sediment, but those layers date back almost 50,000 years and contain clues to the past climate and biological activity of the region. "No one had culled box cores from the very center of the Arctic," says Glenn Jones, a WHOI paleoceanographer.

Only a few of the *Polar Sea*'s box cores have been analyzed so far, says Jones, but early results support the belief that the Arctic Ocean and northern land masses were a connected massive block of ice relatively recently. In today's Arctic Ocean, the ice cover is only a few meters thick, allowing the ice to crack and open water to form, which provides an opportunity for life-sustaining nutrients and light to penetrate into the ocean. But when studying the box core sediments for evidence of biological life, researchers found nothing in the layers dated to between 13,000 and 26,000 years ago. This abiotic zone, says Jones, suggests that during that glacial period the Arctic Ocean was covered by an ice shelf hundreds of meters thick that killed off all life in the waters below. "I think the Central Arctic was locked up," he says.

Other attempts to penetrate the Arctic sea floor were not quite as successful. Arthur Grantz of the U.S. Geological Survey (USGS), senior scientist aboard the *Polar Sea*, led a group whose goal was to study Earth's crust below the Arctic Ocean. To that end, USGS had brought along an instrument that sends acoustic waves into the crust and receives faint echoes in return. Because the density and composition of the material through which the waves travel affects their speeds, the echoes yield a "seismic profile." "You get a series of reflections showing layers in the Earth," says Grantz, explaining that such profiles can also provide clues to deposits of gas, oil, and water.

None of that information was gained in the Arctic, however. Once on board, says Grantz, the icebreakers' captains and Aagaard changed the scientific agenda. Arguing that heavy ice prevented them from easily reaching the areas Grantz wanted to profile, they made the decision to defer the work until the return trip, when the ships planned largely to retrace their route. But near the pole, the *Polar Sea* broke a propeller blade, and for safety reasons the return expedition was aborted. Escorted by the *Saint Laurent* and a nuclear-powered Russian icebreaker the expedition had encountered, the *Polar Sea* took the shortest route away from the pole and out of the ice—through the top of the North Atlantic. The route skipped the sites Grantz wanted to profile and effectively canceled his seismic program. "We got nothing. I thought it was a breach of faith and horrible waste of taxpayer money," says Grantz, who asserts that reaching the North Pole became a larger goal for the expedition than its scientific objectives.

Aagaard sympathizes with Grantz's disappointment, but points out that 49 of the 50 scientific programs were carried out. He also defends the decisions of the ships' captains. "We had more difficult ice conditions than I expected. I felt everyone made a bona fide effort to satisfy the needs of a very complex scientific program," he told *Science*.

Indeed, most participants in the expedition have given it rave reviews. "If we have drastic changes in the polar region, at least now we have some good baseline data," says Lisa Clough of East Carolina University, who studies sea floor biology. The trick may be getting back to the Arctic to take a look. "Given the logistical difficulties, I'm not sure we'll get up there again soon," Clough says.

–**John Travis**