record, which leans more heavily on data from some longitudes than others, and offset poles would appear when none existed.

The inner core's influence would show through most clearly, however, when the field is reversing. Just how the field behaves during reversals is controversial; Hoffman argues that some wandering poles spent much of their time in one of two patches centered south of South America and around western Australia, while other researchers say those "preferred patches" are segments of larger "preferred paths" within which the wandering poles tend to be confined. Still other researchers doubt the reality of either pattern, but Clement and Stixrude see increasing support for such behavior in some, although not all, reversals.

Hoffman had suggested that enrichments of electrically conductive iron at the bottom of the mantle might be guiding the reversing poles into preferred patches (*Science*, 21 June 1991, p. 1617), but Clement and Stixrude propose that the observed pattern is the work of the inner core. During the 8000 years or so of a reversal, the main field weakens and becomes distorted as the rapid convective currents of the dynamo reorganize. The slow-responding field of the inner core, however, could remain unaffected for thousands of years—able to capture the wandering main field poles at its own poles, creating preferred patches, or guide them along preferred paths.

Clement and Stixrude's colleagues aren't ready to believe that some of their knottiest problems can be solved so neatly. "I would like to see some hard numbers before I believe anything," says geomagnetist Jeremy Bloxham of Harvard University. "There's also the problem that you still have to get any inner-core magnetic field through the 2200 kilometers of the outer core, which is convecting and distorting and twisting the field. I think that is going to be the hard part."

But neatness is just what delights Clement about this proposed role for the inner core. "You've got three very complicated aspects of field behavior that might be explained by one simple mechanism," says Clement. "That's why I'm really excited." And he thinks that if the inner core's role in the magnetic field is widely accepted, the insights may eventually flow the other way. "The magnetic field could help us figure out the properties of the inner core," he says, finally bringing it a little closer to home.

–Richard A. Kerr

Additional Reading

B. M. Clement and L. Stixrude, "Inner core anisotropy, anomalies in the time-averaged paleomagnetic field, and polarity transition paths," *Earth and Planet. Sci. Letts.* **130**, 75 (1995).

R. Hollerbach and C. A. Jones, "Influence of the Earth's inner core on geomagnetic fluctuations and reversals," *Nature* **365**, 541 (1993).

ECOLOGY

Pacific Warming Unsettles Ecosystems

California surfers, used to shivering in bone-chilling breakers that average 13°C, might rejoice at news that the cold current washing their coastline seems to be warming up. From San Diego north to about San Francisco, ocean temperature records show a gradual upward trend beginning in the early 1950s—a trend that has accelerated since about 1976 as an unusual parade of El Niño warmings in the tropical Pacific pumped warm water northward. But the permanent residents of the California Current may be finding the 1.2 to 1.6°C warming less agreeable.

Earlier this month, researchers from the Scripps Institution of Oceanography in La Jolla announced that populations of zooplankton—tiny shrimp, larvae, and other drifting animals—in the California Current have declined 80% over the past 40 years, apparently because of the warming (*Science*, 3 March, p. 1324). Other ecologists say repercussions of this plankton loss seem to be rippling up the food chain and may help explain recent declines in fish and seabird populations. "There are tantalizing indicators out there," says Thomas Powell, an oceanographer at the University of California, Berkeley, "of food-web changes caused by changes in the ocean's physical environment."

Now Powell and other scientists are trying to decide whether the warming is a natural, decades-long fluctuation or a longer term trend toward warmer oceans, perhaps driven by greenhouse warming. For the moment, both possibilities seem plausible. "If it's part of a natural cycle, then it'll reverse itself," says Scripps' John McGowan, who with his colleague Dean Roemmich reported the plankton loss. "If this is man-caused ... then we're in serious trouble." Either way, he and his colleagues think the California Current could offer an early look at the changes that might be in store elsewhere in the oceans if global warming takes hold.

The California Current, which flows from Oregon southward down the coast, is particularly sensitive to temperature changes because of the upwelling that takes place along its path. The prevailing winds that drive the current also sweep surface water offshore, dragging up cold, nutrient-rich water from the depths. The upwelling supports dense plankton blooms that in turn feed other marine life. But when surface waters warm, explains McGowan, "the increased temperature ... puts a density cap on the upper layers," preventing cold, deep water from reaching the surface. As a result, the upwelling comes from shallower depths and carries less nutrients, and biological productivity decreases.

That is just what has happened over the last 4 decades off southern California, according to McGowan and Roemmich's plankton studies. And there are hints, they say, that the plankton crash is taking a toll farther up the food web. For example, McGowan says, total commercial landings of fish in the California Current, including anchovy, sardine, mackerel, and squid, have gone down by some 35% since the 1950s.

Commercial catches are only a rough measure of fish populations, however, and many other factors besides a plankton shortage can drive them down. But Stephen Ralston, a fisheries biologist at the Tiburon Laboratory of the National Marine Fisheries Service, has evidence that populations of at

G. LASLEY/VIREO

BATES LITTLEHALES/ANIMALS ANIMALS

BRUCE WATKINS / ANIMALS ANIMALS

In hot water. Three plankton-eating species—the sooty shearwater, the Cassin's auklet, and the rockfish (*top to bottom*)—have all declined in the last decade as a warming of the California Current reduced zooplankton numbers.

least one group of fish, the rockfish, do respond to water temperature and zooplankton abundance. Ralston has been part of a team studying juvenile rockfish off the central California coast since 1983. Rockfish feed on zooplankton in their first year of life, Ralston says, and in years of unusually warm water these young fish seem to die before they can reproduce. "We have a major reduction in the abundance of young-of-the-year rockfish in El Niño years," he says. "It's pretty much a disaster in terms of [reproductive success]."

Zooplankton eaters with feathers may be suffering even more than those with fins. Richard Veit, an ornithologist at the University of Washington, has been monitoring seabirds off the coast of southern California, and they seem to be in serious trouble. Four times a year between 1987 and 1994 Veit counted seabirds from the deck of a research ship. "Over that period the total abundance of birds has gone down by 40%," Veit says. "The species that's declined most dramatically is called the sooty shearwater," by far the most common seabird in the California Current. Its population, he says, has fallen 90%.

These birds nest on islands in the Southern Hemisphere, and Veit at first suspected a disaster in the nesting grounds. But when he wrote to colleagues in New Zealand, they were surprised to hear about a possible problem, and Veit now thinks the cause is more likely to lie in the shearwater's feeding ground off California. "The bird and zooplankton declines match each other so closely," he says, that "it sure looks like there's a strong connection."

Birds seem to be declining elsewhere in the California Current as well. David Ainley of the Point Reyes Bird Observatory has documented decreases in several seabird populations around the Farallon Islands, offshore from San Francisco. He says one zooplankton-eating bird, the Cassin's auklet, has suffered a 60% population decline since the late 1970s—a period when, like McGowan and Roemmich to the south, Ainley and his colleagues noted increased temperatures and shifts in the zooplankton community.

All these researchers caution, however, that their data sets are too short to distinguish between a long-term climate change and shorter term environmental fluctuations. And other data suggest that this region may be prone to at least one strong natural cycle. Clues from an underwater basin off Santa Barbara indicate that the California Current ecosystem has a boom-and-bust history, possibly driven by cycles of ocean warming and cooling.

Oxygen is depleted in this closed basin, so there are no mud-dwelling animals to disturb the annual layers of the sediment. By counting the layers and examining the fish scales they preserve, says Tim Baumgartner of Scripps and CICESE, a research institute in Ensenada, Mexico, he and his colleagues have developed a nearly 2000-year-long record of anchovy and sardine populations. The record shows the two species rising and falling seesawlike, in alternating cycles lasting about 30 years. Because sardines prefer warmer water and anchovies prefer cooler, Baumgartner suspects cyclical warming and cooling is to blame for the population swings: "There's evidence that the anchovy and sardine variability is driven by an ocean climate oscillator."

"If it's part of a natural cycle, then it'll reverse itself."

—John McGowan

If so, it's happening again, now. The sardine population last crashed in the 1940s, destroying the California sardine fishery—an event documented by John Steinbeck in the novel *Cannery Row*. Now, after decades of negligibly small populations, sardines are returning to the California Current, while anchovies are declining. And that suggests that the present warming along the California coast could be the latest swing in a natural oscillation—one that Nicholas Graham of Scripps' Climate Research Division thinks may operate on a larger scale. Graham speculates that the ocean/atmosphere system of the whole North Pacific region periodically flip-flops between different modes, warming or chilling the California Current.

But even if the warming of the California Current is part of a natural cycle rather than a greenhouse warming, it offers researchers a chance to study how longer term climate change might affect ocean ecosystems. To take advantage of the opportunity, Berkeley's Powell and other oceanographers in a program called U.S. GLOBEC (GLOBal ocean ECosystems dynamics) hope to treat the California Current as an ongoing natural experiment. They are laying plans to trace its ecosystem cycles and how they respond to climate forcing.

Like surfers watching for early signs of a perfect set of waves, these researchers are waiting for the Pacific Ocean to offer up clues to its future. As Powell puts it, "I can't think of a better place to study how human pressures could modify the ocean's long-term natural cycles."

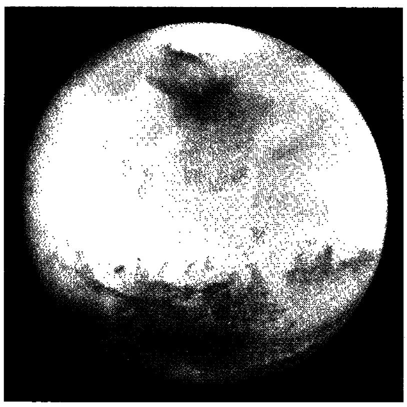
–David K. Hill

David K. Hill is a science writer in San Francisco.

PLANETARY SCIENCE

Hubble Glimpses a Hazy Day on Mars

Talk about global change! Since the late 1970s, when the Viking spacecraft visited Mars, ground-based radio telescopes monitoring its atmosphere have recorded a drastic, 20°C cooling. And last month, when Earth passed close to its neighbor, the Hubble Space Telescope photographed one legacy of this increasing chill: a near-global veil of high cirrus clouds, formed when water vapor froze out of the thin atmosphere. A 25-kilometer-tall volcano pokes through especially heavy clouds in the west (left), where the planet is emerging from the cold martian night.



PHILIP JAMES (UNIV. OF TOLEDO)/STEVEN LEE (UNIV. OF COLORADO)/NASA

The immediate cause of the colder, cloudier weather compared to Viking days is dust—or more precisely a lack of it. Globe-girdling dust storms can churn micrometer-size, red-orange dust particles high into the atmosphere, where they absorb solar energy, notes Steven Lee of the University of Colorado, a member of the team that took the Hubble images. Two such storms roiled the planet just after the Vikings arrived 19 years ago, warming the atmosphere. But lately martian dust storms have not struck with the same frequency or fury as in the late 1970s.

Why the storms should have abated, allowing the atmosphere to cool, no one can say. Clues might have come from the Mars Observer spacecraft, but it was lost in 1993 as it prepared to enter orbit around the planet. Until it is replaced, planetary scientists will have to rely on more long-distance views from Hubble, which will periodically turn a weather eye on Mars.

–Richard A. Kerr