by Knut Fladmark of Simoń Fraser University in Vancouver. Fladmark's coastal-migration hypothesis offers an alternative to the traditional route into the Americas: an ice-free corridor geologists think opened up between 12,000 and 15,000 years ago just east of the Canadian Rockies. Fladmark argued instead that at least some of the first Americans came down the coast in boats after crossing the Bering land bridge from Asia. The idea isn't outlandish, says Dennis Stanford, chairman of archeology at the Smithsonian Institution. "We know people were capable of [building] boats at least 40,000 years ago—you had to have a boat to get to Australia—so why couldn't they have used them to come along the coast of Alaska?" And Stanford, who isn't a partisan of the coastal migration idea, says the findings from the caves "sound real exciting."

Still, most archeologists think the odds are against the coastal migration route. Even if there were isolated coastal "refugia," the glaciers jutting out into the ocean elsewhere would have posed formidable barriers, says University of Alaska anthropologist William Workman. The absence of coastal Indian cultures in California before 11,000 years ago also argues against the theory, says Workman. "Why would humans perfect coastal living and then give it up when they hit Washington State—jump ashore and head for the grasslands? I just can't go for that."

But Dixon and Baichtal hope that further exploration of the caves will bolster the theory. They were quick to follow up the initial finding by recruiting amateur cavers to map the cave system and search for artifacts. Baichtal has organized a cadre of marine geologists, botanists, archeologists, and glaciologists to map other coastal refugia on Prince of Wales Island by tracing glacial moraines and changes in sea level. The survey, they hope, will focus the cave exploration by revealing which ice-free areas lay close to the water in the last ice age. Explains Owen Mason, a research associate at the Alaska Quaternary Center at the University of Alaska, who is taking part in the survey, "Studying sea level will tell us where people would have been able to travel."

There's a special urgency to the search, say Baichtal, Dixon, and their colleagues. Carpeting the cave-riddled bedrock on Prince of Wales Island is the Tongass National Forest, scene of Alaska's largest logging operations. Debris from the logging has already clogged some of the caves. And while the logging has recently slowed in sensitive areas, the researchers aren't confident the reprieve will last. Evidence of ice-age mariners that might have escaped the glaciers could still disappear before the chain saw.

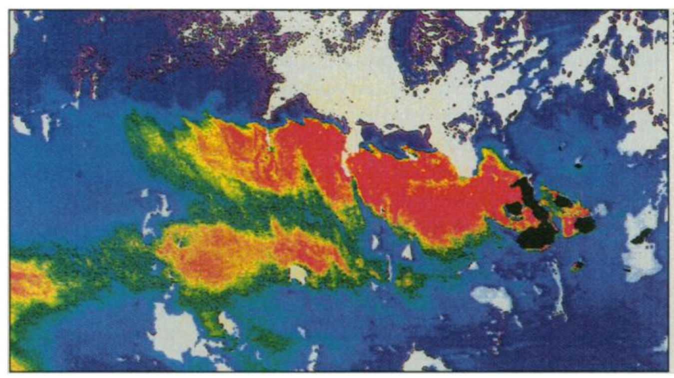
–Lisa Busch

Lisa Busch is a freelance writer in Alaska.

OCEAN CHEMISTRY

Iron Fertilization: A Tonic, but No Cure for the Greenhouse

It's been called the Geritol solution to greenhouse warming: Dose millions of square kilometers of ocean with the tiniest bit of iron, a scarce trace nutrient, and the surface waters would bloom. The burgeoning microscopic plants would absorb carbon dioxide to build their tissues. Then, when they die and sink into the deep sea, they would store away the carbon where it could do no more climatic mischief (*Science*, 27 September 1991, p. 1490). Most oceanographers are deeply troubled by the notion of planetary engineering, but the idea that trace amounts of iron could be vital to the ocean's ecology was so appealing scientifically that they couldn't resist at least a test of it in the real ocean.



Oceanic oasis. This false-color satellite image shows the fertilizing effect *(red denotes abundant plant life)* of iron from the Galápagos.

The test was carried out last fall in the equatorial Pacific, and "the results were spectacular," says marine biologist Richard Barber of Duke University's Marine Laboratory, chief scientist for the Transient Iron Addition Experiment (IronEx). "Adding iron did in fact stimulate the [phytoplankton]," says chemist Kenneth Johnson of the Moss Landing Marine Laboratory, a colleague of the late John Martin, who first raised the possibility of the Geritol solution several years ago. That's enough to confirm the underlying "iron hypothesis": that the limit on marine life in places like the relatively unproductive northeast Pacific, where essential nutrients such as nitrogen and phosphorus are abundant, is lack of iron.

In spite of the "spectacular" stimulation of plankton growth, the results don't bode well for the possibility of cooling the climate with a dose of iron, as Barber reported last week at the annual meeting of the American Association for the Advancement of Science (AAAS, publisher of *Science*) and the Ocean Sciences Meeting in San Diego. (For additional coverage of the AAAS meeting, see page 1084.) Although many samples remain to be analyzed, it seems that in the ocean, the medicine goes down a little too well. The iron supplement "just didn't stick around very long," says Johnson. Dissolved iron, the kind phytoplankton can use, quickly formed particles that sequestered the iron and eventually sank. The same thing seems to happen to iron from natural sources, say the researchers, which would explain the shortage of iron in the ocean's surface waters in the first place.

Although the researchers expected some iron loss, the experiments that inspired IronEx gave no inkling of its extent. In those experiments, Martin and others took bottled samples of plankton-laden seawater and added iron. In response, the plankton population doubled and doubled again, but those results were suspect because a 1-liter sample bottle is no ocean. For one thing, a liter of seawater may not include some of the larger (millimeter-scale) and therefore rarer animals—such as copepods—that feed on phytoplankton and help keep their numbers down. What's more, bottles have walls, where bacteria can proliferate, perturbing the food web. And nothing can enter or leave the bottle.

To get around these limitations, Martin and, after Martin's death, Johnson and his Moss Landing colleague Kenneth Coale planned IronEx. To stage a realistic test of the iron hypothesis, the researchers decided to enrich iron in a patch of water so large—8 kilometers square—that the enrichment would persist long enough for oceanographers to monitor its effects. Five hundred kilometers south of the Galápagos Islands, where natural iron concentrations are a minuscule 0.03 nanomolar, the researchers dribbled 480 kilograms of iron in the form of iron sulfate solution into the prop wash of a research vessel as it steamed back and forth through the square. The researchers kept track of the patch by measuring levels of the inert and easily measured tracer sulfur hexafluoride, tiny quantities of which were released with the iron solution. As the iron concentration rose by a factor of 100, to 4 nanomolar, the researchers monitored plankton growth and dissolved carbon dioxide.

"Most of us were wildly optimistic," says Johnson—optimism that seemed justified when the amount of phytoplankton in the patch and its rate of production more than doubled in the first 3 days. That observation left little doubt that iron is the limiting nutrient for plankton growth near the Galápagos, say Johnson and Barber, and probably in other low-productivity areas where iron is low and other nutrients high.

But after the initial surge, the phytoplankton stopped growing any faster, instead of reaching up to 10 times the starting population, as they can in a bottle. Even though other nutrients were still abundant, the enhanced but hardly extraordinary abundance held steady for the rest of the 9-day experiment. The abrupt stalling of the plankton's increase seems to have been due to the rapid loss of usable iron from the surface waters. By 4 days after the enrichment, dissolved iron concentrations had dropped from 4 nanomolar to below the detection level of shipboard analyses, 0.2 nanomolar. The iron was apparently precipitating out of solution as ultra-fine particles, coagulating, and sinking. Plant debris and animal wastes sinking out of the surface layers may also have been carrying off iron.

In fact, on the second leg of the cruise, IronEx researchers saw the same process at work in nature, says Barber. They found that westward currents washing around the Galápagos Islands pick up dissolved iron, apparently from the shallow-water sediments there. But the resulting plankton bloom fades downstream of the islands, where the iron-rich plume moves over deeper and deeper water. There, iron lost from surface waters doesn't return as it can in shallow waters, and its concentration drops. That's a process that an experiment in a closed bottle could never reproduce, says Johnson. "If you do this in a bottle, there's nowhere for the iron to go" and you get a dramatic greening of your "ocean."

This real-world demonstration of iron fertilization and its limits proves the value of large-scale experiments like IronEx, say oceanographers. "The big excitement is that you can do this sort of experiment in the ocean with the entire food web," says biological oceanographer Sallie W. Chisholm of the Massachusetts Institute of Technology. But she and most other oceanographers are, if anything, relieved that the experiment doesn't bode well for tampering with ocean ecology on an even larger scale, to cool the climate. Says Chisholm, "I've always believed that proposition is incredibly shortsighted." For now, Earth's Geritol stays on the shelf.

–Richard A. Kerr

ENVIRONMENTAL SCIENCE

Theoretical Ecology: Winning Its Spurs in the Real World

For most of its century-long history, ecology has been by and large a descriptive science. Researchers conducted field studies, aimed at describing, say, the interactions between predators and their prey or assessing the impact of the many pesticides that have come into use on nontarget species such as birds or helpful insects like bees. Studies like these have amassed a wealth of data. But they have usually been limited in scope and duration. And while some ecologists have long taken a broader, more theoretical approach, looking for principles that govern the dynamics and interactions of populations in whole ecosystems, these theorists were in a distinct minority.


PAT AND TOM LEESON/PHOTO RESEARCHERS

At risk. Models showed Northern Spotted Owls need bigger ranges than originally planned.

This relative scarcity of a theoretical approach was at least partly due to the difficulties in collecting and analyzing the large data sets needed to describe complex ecological systems—especially in precomputer days. But it made it difficult, if not impossible, to apply the results of the smaller studies to the many environmental problems that have cropped up in recent decades—problems such as how to control insect and other pests without also killing desirable species, reverse declines in ocean productivity, or save endangered species such as the Northern Spotted Owl. "We may know a whole lot about a square meter of earth or ocean, but we need to have adequate theories for expanding this [small-scale] information to help deal with real-world problems," says theoretical ecologist Edward Rykiel Jr. of Texas A&M University in College Station.

In the past 5 years or so, however, theoretical ecology has begun to mature and provide insights into some of these practical problems. "People in theoretical ecology are feeling particularly bullish," says ecologist Jonathan Roughgarden of Stanford University, who uses both theoretical and experimental approaches. "We're beginning to figure out how ecosystems work."

And that enthusiasm is not limited to the 100 or so researchers specializing in theoretical ecology. Their much more numerous experimental colleagues are taking notice, too. One indication of their interest came last summer at the annual meeting of the Ecological Society of America (ESA). Until recently, theoretical ecologists often kept largely to themselves, publishing in specialized journals. But at its annual meeting, the ESA created a subsection on theoretical ecology, putting it on a par with established subspecialties such as aquatic ecology, paleoecology, and soil ecology. The growing interest was also apparent at the meeting's theoretical sessions, which were packed, sometimes to overflowing.

Clues to AIDS spread. One example of how this budding theoretical approach to ecology has begun to affect practical problems comes from Roy Anderson and Robert May of Oxford University in England, who are among the small number of early theoretical ecology pioneers. About 20 years ago, they began modeling studies aimed at getting a better understanding of how, when, and where infectious parasites move in their nonhuman hosts. Then, shortly after the AIDS epidemic struck in the early 1980s, Anderson and May began looking to see what their models might reveal about the spread of the AIDS virus. The impetus for the work was their recognition that there are many parallels between the movement of successful parasites in nature and the epidemic spread of human pathogens. "We took some of our animal models off the shelf and made some adjustments," says May, adjustments for, among other things, the more complex social organization of human populations.

In those early days of the epidemic, it had become clear that gay males were particularly vulnerable to AIDS. But Anderson and May were among the first to go beyond descriptive work to predict the effect of behavioral patterns on the spread of the disease. Their models showed that the network of interactions by which the virus was transmitted could be as powerful a force in the spread of disease as the virulence of the pathogen itself. In particular, May says, they found that relatively small numbers of promiscuous individuals could be disproportionately responsible for the rapid spread of AIDS.

King Holmes, director of the Center for AIDS and Sexually Transmitted Diseases at