BIOLOGY AND MEDICINE

A researcher hauls in a *Dissostichus mawsoni* from the icy waters of McMurdo Sound. Scientists are studying how the fish keep their blood from freezing in the 28ºF water.
(NSF photo by Aaron Spitzer)

Antarctica is a place like no other - as an intriguing habitat, a scientist's dream. A land where water is scarce - truly a desert - despite containing more than two-thirds of the world's freshwater supply trapped in the ice. Though it borders the world's major oceans, the Southern Ocean system is unique in the world, a sea where average temperatures don't reach 2°C in summer, where even the water itself is so unique that it can be identified thousands of kilometers away in currents that originated here. As the Earth makes its elliptical journey around the Sun each year, tilted on its rotational axis, the Sun "sets" in April, not to be seen again until September. And the ice - unimaginable, incomparable vastness of ice - in a dozen different varieties, at times and in places several thousand meters thick, two major ice sheets (the East larger than most countries), changing dynamically all the time.

Adaptations and behavior developed in response to these extreme conditions provide insight into the intricacies, as well as the fundamental processes, of evolution. These extremes have also driven the development of ecosystems simple enough to reveal wonderfully clear pieces of the web of life on Earth.

The Biology and Medicine program funds research to improve understanding of antarctic ecosystems and life forms - their physiology, genetics, behavior, adaptations, and relationships. Projects range across all organizational levels - from the molecule, gene, cell and organism to relationships within communities and ecosystems, to the level of global processes and the biosphere. This is another area of inquiry where scientific goals and benefits extend far beyond learning (in this field, about flora and fauna) in the high latitudes. Support is focused on the following areas:

• **Marine ecosystem dynamics:** Among the research topics are understanding the natural variability of marine ecosystems; correlating the structure and function of the marginal ice-zone ecosystem with oceanic and atmospheric processes; exploring the sources of nutrition and their influence on prey and on primary production; and the role of marine phytoplankton in carbon-dioxide cycling.

• **Terrestrial and limnetic ecosystems:** Organisms in ice-free areas and in perennially ice-covered lakes show remarkable adaptations to extreme environments. Relatively few species thrive here, which facilitates the study of ecosystem dynamics and the interpretation of experiments, although much more remains to be learned about adaptive mechanisms and evolutionary processes.

• **Population biology and physiological ecology:** At the next level, looking at relationships among organisms, studies have focused on the variability and dynamics of populations of krill and other zooplankton. Ecological relationships among and between fish species, marine mammals, and birds have also been the object of much research, with many issues still to be further explored. Advances in genetic testing now permit scientists to establish relationships between individuals and species in the wild that were previously unverifiable. As organized programs of antarctic science enter their fifth decade (some even longer), data sets and ongoing observations are elucidating manmade as well as natural changes.

• **Adaptation:** Antarctic extremes present a fundamental research opportunity; topics include low-temperature photosynthesis and respiration; enzymatic adaptations and adaptive physiology, such as the development in fish of antifreeze compounds and modifications to the circulatory system in seals; also continuing interest in the response of (and impacts upon) organisms to increased UV-B radiation from the ozone hole. Here too, new molecular DNA advances have had a profound impact on the types of studies that can be mounted.

• **Human behavior and medical research:** Antarctica's extreme climate and terrain impose a quite spartan and unconventional existence upon scientists and others who live and work there. As people are subjected to social, psychological, and physiological

stresses (exacerbated during the winter isolation) research opportunities arise. Studies focus on epidemiology, thermal regulation, immune system function, individual behavior, and group dynamics.

Function and chemical nature of ice-active substances associated with sea-ice diatoms.
James Raymond, University of Nevada at Las Vegas.

Sea-ice diatoms (a particular class of algae) are plentiful in McMurdo Sound, Antarctica, in the ice platelet layer and congelation ice. Previous work suggests these particular diatoms produce certain extracellular ice-active substances (IASs), molecules with large molecular weights that appear to be glycoproteins. They are widely distributed in the Southern Ocean, occur in both summer and winter sea ice, are associated with many, if not all, of the diatoms found in sea ice, and are apparent as darkly stained areas in the sea ice. Because similar molecules have not been found in temperate water diatoms, they apparently have a function related to cold or icy environments.

The IASs represent a novel type of ice-binding molecule that is distinct from the antifreeze proteins and glycoproteins found in some fish species. Since they are ubiquitous in the antarctic sea-ice communities but absent in warmer regions, they would appear to have an important role in polar communities. But what is that role? Our studies focus on that question and others about the nature of these molecules.

While different in structure, however, the IASs do share some properties with fish antifreezes, and so understanding their ice-binding properties and chemical structure will make it possible to better understand how this family of molecules interacts with ice. Finally, unlike the fish antifreezes, the IASs are produced in large quantities in nature - perhaps they could be used in other applications.

We will examine additional questions about the function and chemical nature of these unusual substances:

• Preliminary evidence suggests the IASs have cryoprotective properties. To explore this possibility, we will try to assess the IASs' ability to prevent freeze-thaw damage in a test enzyme (LDH) as well as in whole cells and also their ability to inhibit the recrystallization of ice, which is a common measure of antifreeze activity in plant studies.

• The IASs are known to bind to ice crystals. To better understand the binding mechanism we will conduct additional studies to determine the specific crystal faces to which they bind.

• We will try to better characterize the chemical nature of the carbohydrate and protein components found in the IASs, using mass spectrometry, amino-acid sequencing, and other techniques.

• Finally, we will also attempt to raise antibodies against the IASs, as these will have several uses in determining the origin, seasonality, relatedness, and possibly the function of these molecules. (BO-001-M)

Antifreeze protein antarctic fishes: Ecological and organismal physiology, structure-function, genetics, and evolution.
Arthur DeVries, University of Illinois.

Despite temperatures that can dip below 0°C, antarctic waters provide a life sustaining environment for a number of fish species. How are they able to take the most frigid waters on earth through their gills without themselves freezing? A primary reason are the so-called antifreeze proteins, an adaptation found in a number of polar and subpolar species. These biological molecules have a similar effect to antifreeze in a mechanical engine. The Southern Ocean provides the ideal laboratory and molecular biology the ideal probe to study this phenomenon. As the world's coldest marine environment, the near-shore waters of Antarctica, replete with ice crystals, hover just above seawater's freezing point.

We are studying the physiology of fish and larvae from these waters to see how ice grows in biological tissues - a crystallization process called nucleation - and how antifreeze glycoproteins (AFGP) inhibit it. Evolving the antifreeze function has enabled the antarctic notothenioids to colonize their frigid habitats very successfully. We are mounting comprehensive multidisciplinary analyses of this adaptation at the level of the gene as well as the protein.

Specifically, we will

• examine the structure of antifreeze proteins;

• refine the molecular model of how these proteins adsorb ice and inhibit ice crystal growth;

• study the physiological parameters governing the natural growth of ice crystals;

• pinpoint the chromosomal locus of the gene family and its protease progenitor gene;

• sketch its evolutionary history by calibrating the rate of notothenioid nuclear protein coding sequences; and

• focus on when these AFGPs develop during embryogenesis and early larval stages. (BO-005-M)

Use of a long-term database and molecular genetic techniques to examine the behavioral ecology and dynamics of a Weddell seal *(Leptonychotes weddellii)* population.
Donald B. Siniff, University of Minnesota-Twin Cities.

The Weddell seal *(Leptonychotes weddellii)* is found in regions of pack ice or fast ice close to the antarctic continent. These seals are relatively long-lived, and the waters of McMurdo Sound have provided a continuous environment in which to study their survival and aquatic reproductive patterns. A series of long-term population studies, ongoing since the mid-1960s, have generated a rare and valuable set of data.

Recently developed molecular biology techniques now enable scientists to examine the DNA of groups of seals, as well as individuals. This new lens provides insight into the seals' genetic histories, breeding systems and reproductive fitness. We know that breeding males behave characteristically; looking at this behavioral ecology and their mating systems through the lens of their DNA permits scientists to project backwards in time and correlate the seals' reproductive success with the effective size of their populations.

We are testing hypotheses, estimating parameters, and producing models and studies of population demographics by using and building on the long-term data set. We will also explore population dynamics by tracking immigration and emigration into and out of the group.

We are continuing with several collaborative efforts:

• In one, blood, scat and diet samples will be collected for researchers studying Weddell seal blood chemistry, health parameters, blood parasites, and diet.

• In another, small video cameras mounted on some of the seals will produce data for Japanese scientists studying diving and other underwater behaviors of free-ranging seals.

• And a remote camera surveillance will be set up to observe the spacing patterns of adult females, both on the ice and underwater.

As the southernmost breeding mammal in the world, the Weddell seal exemplifies the ability to adapt to environmental extremes. Understanding the mating strategies these seals employ should contribute to a deeper understanding of the evolution and population dynamics of the Pinnipedia (a suborder of aquatic, carnivorous mammals, including all the seals and walruses) in particular, as well as how marine mammals more generally, compete. (BO-009-O)

Hunting behavior and energetics of free-ranging Weddell seals.
Randall Davis and Markus Horning, Texas A&M.

Weddell seals *(Leptonychotes weddellii)* are the apex predators in the antarctic marine ecosystem, in large part because of behavioral and energetic adaptations that enable them to forage in the cold, dark antarctic fast-ice environment. Earlier work pioneered the use of an animal-borne video system/data logger to record the behavior, physiology, and locomotor performance of marine mammals at depth. For the first time, we witnessed seal hunting strategies, predator-prey interactions, and were able to make corresponding estimates of diving metabolism. Here we follow up on those results, and hope to provide insight into marine mammal foraging tactics and contribute to the fields of physiology (diving and energetics) and ecology (foraging theory and behavioral ecology).

By using isolated-ice-holes, we formerly preserved the seals' ability to choose the depth and duration of a dive, but left them no alternative but to return to a single place to breathe, thus limiting their range. We didn't permit them to haul out of the water or interact with other seals on the ice, and thus they may have been exposed to fewer prey than when foraging naturally. Now we want to remove those constraints and focus on the behavior and energetics of completely free-ranging seals. Although the "constrained" study demonstrated important new principles in Weddell seal foraging and has increased understanding of diving behavior and swimming performance, we believe that it is now essential to determine whether those principles apply to unconstrained animals.

To answer this question, we will test hypotheses related to general foraging strategy, foraging location, searching mode, prey detection, locomotor performance, the cost of diving, and foraging efficiency of free-ranging Weddell seals. In addition, we will examine locomotor performance and behavior during diving to estimate the costs associated with hunting, and the benefits gained from hunting (type and frequency of prey captures).

The study will continue to employ a multidisciplinary team of scientists with highly skilled technical support. The results will advance the understanding of the foraging ecology of Weddell seals and create a basis for similar research on other species of marine mammals that are more difficult to study in the open ocean. (BO-017-O)

The chemical ecology of shallow-water marine macroalgae and invertebrates on the Antarctic Peninsula.
James B. McClintock and Charles D. Amsler, U. of Alabama, Birmingham.

In a number of plant species, evolution has adapted the basic strategy of developing chemical substances designed to defend the organism. One general group of these substances are classified as defensive secondary metabolites. We plan to explore three "cost/benefit" ideas that are often woven into viable theories on the evolution of chemical defenses.

• The Resource Availability Model of chemical defense. The proposed research will examine whether macroalgae (grown under reduced light to limit carbon) will produce greater amounts of defensive compounds than will those grown in an optimal light environment. A related question is whether antarctic macroalgae found in the nutrient-rich peninsula region are likely to develop chemical defenses that include nitrogen compounds.

• The Optimal Defense Theory in macroalgae and invertebrates. The proposed research will determine how much chemical defenses are more abundant in tissues with a high energy content, such as reproductive tissue and offspring (larvae). A related question is whether larvae that rely on lecithin (for nutrition) use chemical defenses more than do larvae relying on plankton.

• What about habitat? How do chemical defenses vary across different areas? Using previous work in the Ross Sea as a starting point, we will seek out possible evolutionary factors that might subserve any variations we find.

The program should also advance our general understanding of the evolution of chemical defenses. We hope to elucidate the nature and role of bioactive agents in the specific ecology of antarctic marine benthos (that is, organisms living at the bottom of, or in very deep, marine environments). (BO-022-O)

Dynamics of predator-prey behavior in the Southern Ocean.
Richard Viet, City University of New York; College of Staten Island.

Seabirds foraging in the Antarctic necessarily respond to the abundance and locations of their prey, which is primarily krill (Euphausia superba). These planktonic, shrimp-like crustaceans are found in swarms in sea ice and elsewhere, provide the primary diet for whales and other species, and themselves dine on phytoplankton and algae. In Antarctica, the seabirds and krill collaborate on a spectacular and economically important ecosystem, especially in the Elephant Island region.

This project brings two groups of undergraduate students to the Antarctic to help with the collection of data on the abundance of seabirds and their foraging behavior. They will be tutored in mathematical modeling, to begin the process of making scientific sense of their observations, and will also acquire a broad collection of skills by collecting data on physical and biological oceanography.

We will study bird behavior near krill swarms and then compare it to behavior in areas with no krill. From such comparisons, we hope to build foraging models that predict the dispersion of birds under differing levels of krill abundance. The goal is to quantify the link between prey abundance and bird behavior - long-term, we hope to be able to predict the impact of future changes in krill stocks on seabirds.

The heuristic element of this project is twofold. First, the project will expose inner city college students, through their work on an oceanographic research vessel, to diverse research topics and methods, ranging from behavioral ecology to physical oceanography. Then, back at the College of Staten Island, they will apply basic mathematical reasoning and computer modeling to a real world problem of which they have hands-on experience - determining how foraging choices made by seabirds can ultimately impact their reproductive success. (BO-023-O)

Studies on the impact of sewage-associated microorganisms on indigenous seal and bacterial populations and drinking water quality at McMurdo Station.
John Lisle, Montana State University.

Human impacts on the environment are typically complex and often reverberate through a wide ecological spectrum. While a comparatively pristine environment, Antarctica is still a populated continent, with all of the inherent issues and challenges of environmental protection. For years, human sewage has been released into the seawater at McMurdo Station, untreated except for the process of maceration (which dilutes or softens a material by steeping it in liquid). What are the impacts on the marine ecosystem?

This project focuses on bacteria known to thrive in the sewage deposits, tracing their progress into the drinking-water intake at Intake Jetty, and also into other organisms and indigenous species, such as Weddell seals. One of the bacteria previously associated with this problem is Clostridium perfringens, which researchers have suspected were colonizing Weddell seals in the area of the sewage. These and other deposit-feeding invertebrates appear to assimilate the nutrients associated with the sewage and to increase body mass and organ sizes.

These earlier results are driving this work, which will use more advanced genetic molecular biology and more sensitive culture-based techniques to determine a number of issues:

• Are the sewage-associated bacteria and viruses the specific ones that are colonizing Weddell seals?

• Are these microorganisms exchanging their DNA with indigenous species, thus potentially altering the procaryotic gene pool of this ecosystem?

• Are they entering the drinking water system at McMurdo Station?

• The microbiological quality of marine and drinking waters at McMurdo Station is currently monitored, but are we underestimating the risks to the marine environment and to human health?

The results from this study should help in the evaluation of current monitoring systems and the design of remediation efforts. A sewage treatment plant is currently planned for McMurdo Station, and these data will provide a baseline for efforts and studies of ecosystem recovery. The data will shed light not only on the coastal waters off of McMurdo Station but also on other coastal waters around Antarctica that may be similarly affected by the discharge of untreated human sewage. (BO-024-O)

Temperature compensation in antarctic pteropods: An integrative approach.
Robert Dudley, University of Texas at Austin.

Life in frigid polar waters reveals many adaptations; creatures have developed physiologic specializations so as to function and react more effectively in the cold. The long-standing hypothesis holds that animal taxa indigenous to these climates evolved the ability to regulate basal and active metabolic rates better than their temperate-zone counterparts; but this theory remains contentious and - in any event - has been applied only to fish and benthic invertebrates.

Polar pteropods, small gastropod molluscs commonly found in antarctic zooplankton, are abundant, metabolically active, and provide a different species (another taxon) in which to probe thermal compensation mechanisms that may subserve the physiological processes underlying locomotion.

To explore these phenomena, we will use two different sister pteropod species, one from the polar and one from a temperate zone. Experiments will focus on basal and metabolic rates and mitochondrial energetics; also on biomechanical and on neural responses to different water temperatures and viscosities - all in the context of locomotor performance. The neurons that underlie the swim-system will be evaluated at different temperatures, with particular reference to resting potentials, firing thresholds, action potential durations and ion-channel kinetics. A central question is the extent to which all three aspects (metabolic, biomechanical and neural) may provide polar pteropods a coordinated ability to compensate for thermal conditions and extremes.

Not only should this investigation provide fundamental physiological and behavioral information for this taxon, but we hope to systematically evaluate the hypothesis of cold adaptation across organizational levels in pteropods. We may also be able to shed light more generally on the nature of thermal and locomotor constraints for the many invertebrate taxa living and moving within polar waters. (BO-030-O)

Factors regulating population size and colony distribution of Adélie penguins in the Ross Sea.
David G. Ainley, H.T. Harvey and Associates, California.

Over the past few decades, the Adélie penguin *(Pygoscelis adeliae)* colonies in the Ross Sea region have grown dramatically in size. What demographic mechanisms might account for this change? This collaborative project will investigate one such possibility - previously-documented changes in the region's climate. We will look at the birds' nesting habitat as a function of access to food and hope to distinguish the relative importance of the key resources that constrain the growth of colonies. A number of behavioral and demographic mechanisms may influence a colony's growth, relative to its initial size and distribution pattern. One good candidate is a phenomenon known as philopatry - how breeding effort and success relates to the balance achieved by immigration/emigration.

As the first empirical study to consider the geographic structuring of a seabird population, we expect our results to increase understanding of how populations regulate themselves, and the patterns they follow when they disperse. We also hope to elucidate the effects of climate change (as indicated by changes in the extent of sea-ice cover) on penguin populations. The results should also provide a context in which to interpret conflicting data on penguin population trends from existing programs; in particular, fluctuations in Adélie penguins have been analyzed as an indicator of such anthropogenic impacts on antarctic resources as fishery catches and disturbances created by tourism. But without the regional perspective on penguin life history this project is undertaking to develop, researchers will have difficulty trying to distinguish changes due to man from those caused by nature.

During the 2000-01 summer season, the arrival of iceberg C16 provided a natural experiment, which suggested insights into the competitive effects of one colony on its neighboring colonies. The iceberg blocked the very numerous Cape Crozier penguins from foraging as far west as they normally do; this allowed the smaller numbers of Cape Bird and Beaufort Island penguins to forage much farther east than normal.

C16 has remained through the winter, and we will continue to pursue this de facto experiment in competition for spatially limited food resources. Moreover, the very large iceberg B15A has since grounded in a way that may block the return of penguins to Cape Bird and Cape Royds in the 2001-2002 season. This may provide a second de facto natural experiment with insight into the processes that affect the tendency of young penguins to return to their birth place, and of adults to return to the colony where they formerly bred.

Landcare Research New Zealand (LCRNZ, independently funded) has collected data and tested new equipment during two preliminary field seasons. This project will build on their results, and they will collaborate with us throughout the lifetime of the project. (BO-031-O)

Investigations of abandoned penguin colonies in Antarctica.
Steven Emslie, University of North Carolina.

Climate change is assumed to be a pivotal factor in the success of many species. This project will investigate the history of Adélie penguins in late Holocene Antarctica. By locating and examining the fossil remains of former colonies, scientists hope to develop a model of when they thrived and when colonies were abandoned - and thus their success - relative to climate change. This model could inform current science on the relationship between climate and population dynamics.

Our study will integrate data from the ecological, geological and paleobiological records with satellite-imagery analyses. The climate factor will be inferred by data contemporaneous with the fossil evidence, in particular the extent of the sea ice and marine productivity. The population factor will be developed through field and laboratory investigations of abandoned colonies along coastal Antarctica.

Researchers will first collect surface and subsurface bones, feathers, and eggshell fragments preserved at these sites; later, in the lab, scientists can reconstruct the occupation history of each abandoned colony, through standard and radiocarbon analyses. Sediments from each site will be sifted to recover organic remains (such as squid beaks and fish otoliths) believed to be staples of the penguin diet. Statistical analysis of such indicators can trace the changing size of the colony at specific prehistoric times, and thus prey consumption becomes a proxy for population success. This timeline can then be matched to past episodes of climate change, which are well documented for the late Pleistocene and Holocene in ice-core and marine sediment records.

We expect these ancient responses by penguins to climate change (as indicated by the paleoecological record) to parallel those observed in Antarctica today, where regional warming has been documented over the past 20 to 50 years. Ultimately we will be able to test the hypothesis that Adélie penguins - for decades and centuries - have been responding to climate change in a predictable manner and that those responses can be anticipated, relative to fluctuations in sea-ice extent and marine productivity. (BO-034-O)

Investigations on deterioration in the historic huts of the Ross Sea region of Antarctica.
Robert A. Blanchette, University of Minnesota.

During the first two decades of the 20th century - Antarctica's "Heroic Era" - Europeans mounted a handful of expeditions in hopes of reaching (and claiming) the geographical South Pole. Base camps established in the McMurdo Sound region - by Scott at Cape Evans and by Shackleton at Cape Royds - were abandoned once the expeditions were over, leaving behind thousands of artifacts, as well as the huts they built for shelter and storage. Over the intervening 90 years, the extremes of the polar environment have actually protected some of the artifacts from rapid decay, but conservators have recently become concerned about serious degradation of what is an important historical, archaeological site.

Some of the most exigent threats:

• Wood in contact with the ground is being destroyed by a specific wood-destroying fungus. Various molds and cellulose-degrading fungi are attacking artifacts made of leather, textiles, and other organic materials.

• Exterior wood is being degraded by non-biological deterioration processes as well, including salt, ultraviolet radiation, and wind erosion.

• Chemical damage within the huts is apparent, and the soils on site are contaminated with aromatic hydrocarbons from petroleum products.

We plan to identify the biological and non-biological agents responsible for causing the deterioration, study the mechanisms and progressive sequence of events taking place during decay processes, test methods to be used to control future deterioration, determine the extent of environmental pollutants in soils at the historic sites, and evaluate chemical spills within the huts. The goal is to provide the scientific data required by conservators to help protect these important historic sites for future generations. But the project should also shed scientific light on these unique deterioration processes, as well as augment scientific understanding of the biology of antarctic microorganisms and the biodiversity of microbes present in this unusual environment. (BO-038-O)

Penguin-krill-ice interactions: The impact of environmental variability on penguin demography.
Wayne Trivelpiece, NOAA Southwest Fisheries Science Center.

How well organisms thrive in their environment is often revealed by basic ecological relationships. For two decades at Admiralty Bay on King George Island in the Antarctic Peninsula region, data have been collected on several species of penguins, including the Adélie, gentoo and chinstrap. Looking at some of the basic aspects of the lives of these predators - such as survival and recruitment, population size and breeding success, and diets and foraging ecology - scientists have been able to develop and test key hypotheses about variability in the antarctic marine ecosystem.

This project focuses on one of these relationships. As the extent of sea-ice cover changes with the season and year-by-year, krill (a key food web species in the Southern Ocean that accounts for nearly 100 percent of the prey eaten by dominant predators such as baleen whales, seals, and penguins) are more or less abundant, which directly affects the population biology of the penguins. Years with heavy winter and extensive sea ice paradoxically favor krill recruitment, because larval krill find refuge and food in the sea-ice habitat. The long-term seabird research indicates that in those same, heavy sea-ice years, Adélie but not chinstrap penguins are also favored.

To explore these relationships, we will capture adult and juvenile penguins periodically to band, measure, and weigh them, and to collect blood and diet samples for genetic and physiologic studies. During the breeding season, the penguins and the sea ice will be observed by satellite. Another aspect of the population biology of penguins relates to the possible impact of commercial fishing, so this study will provide useful information to the Convention for the Conservation of Antarctic Marine Living Resources, which is the part of the Antarctic Treaty System that focuses on fisheries management. (BO-040-O)

Seasonal dynamics of giant agglutinated foraminifera.
Samuel Bowser, New York State Department of Health.

Found in all marine environments, foraminifera ("forams") are single-celled, shelled (agglutinated) creatures with a key role in the ocean food web. They may be planktonic - floating in the water - or benthic, living on shells, rock, seaweed, or in sand or mud at the bottom of the ocean. Their characteristic habitats, and the chemistry of their shells (which reflects qualities of the local water they live in) make them very useful to scientists as an indicator of when and under what conditions they lived. Antarctica and the Southern Ocean ecology is no exception.

Previous studies have shown that the forams assemblage in Explorers Cove in McMurdo Sound consume a wide variety of prey, ranging from bacteria through a taxonomically diverse group of metazoans, including juvenile invertebrates. These studies have been restricted to specimens collected from October through early December, immediately following the austral winter.

But in the succeeding months, the austral summer shows a burst of biological productivity, both under the ice and in the benthos. Lacking studies during this period, we do not know how the forams might be responding to this summer food pulse. We plan to document changes in relevant abiotic and biotic factors in the Explorers Cove benthos from austral spring to late summer and to characterize how the agglutinated foram community structure responds; looking at such indices as species composition, densities, size distribution, and others. To accomplish these analyses we will use sediment cores, underwater microscopy, molecular tools, isotope analysis of lipids, and some other newly refined methods.

We expect these combined approaches to elucidate the roles played by larger agglutinated forams in the Explorers Cove benthic food web, especially how these roles may change consequent to the summer food pulse. Further, the results of these studies should have wider significance in the ocean sciences because Explorers Cove and its agglutinated foram assemblage are comparable to many bathyal and abyssal deep-sea localities.

To enhance insight into marine processes associated with global climate change, we are also collaborating with investigators from Russia, to

• test the universality of meltwater turbidity impacts documented in the Arctic,

• assess changes (by adapting modern biochemical and molecular assays) in the living foraminiferal assemblage in response to glacial meltwater, and

• explore ways of revealing the imprint of glacial proximity in the antarctic fossil record. (BO-043-O)

Inter-annual variability in the antarctic-Ross Sea (IVARS): Nutrients and season production.
Walker Smith, Virginia Institute of Marine Sciences.

Oceanographers and other scientists - during the past few decades - have found significant variations in Southern Ocean biogeochemical processes from year to year. Some of the more significant of these inter-annual variations are ice extent and concentration, the composition of herbivore communities, and the distributions and reproductive success of bird and marine mammals.

Surprisingly - because it is so central to the food web - little is known about how phytoplankton production varies from year to year, or what role these variations may play. The production system in the Ross Sea consists predominantly of two major functional groups - diatoms and Phaeocystis antarctica, a colonial haptophyte. In this project, we will collect time-series data and assess the inter-annual variations of the production of phytoplankton in the southern Ross Sea, Antarctica.

The Ross Sea provides a unique setting for such an investigation, for a number of reasons. We can build upon a de facto time-series already ongoing in the Ross Sea because so many studies have been conducted there in the last decade. Also, it is established that there are fewer species there (relative to some other sites) and that seasonal production is as great as anywhere in the Antarctic. Most importantly, seasonal production of both the total phytoplankton community (as well as its two functional groups) can be estimated from late summer nutrient profiles.

Inter-annual variations in seasonal production (and of the two major taxa of producers) may be an important factor in the growth and survival of higher trophic levels within the Ross Sea food web. They also shed light on the natural variability of the suite of biogeochemical processes in the region. Having a scientific handle on that baseline of change is important, because of the scientific efforts to model how climate may change in the future. As climate changes, so certainly too will biology be profoundly affected, and to model and evaluate such change we need to place it in the context of "natural" inter-annual variability. (BO-047-O)

Facultative sex-ratio adjustment by female king penguins in response to mate quality.
Paul Nolan, Auburn University

Considerable evidence has accumulated suggesting that female birds may exert control over the sex ratio of their offspring. Under optimal conditions, more female chicks are produced; when poor environmental conditions prevail, more of the young are males. Several plausible explanations have been suggested for this:

• In some cases, young males disperse and so under stressful conditions do not compete with parents or siblings.

• In other instances where habitat conditions are favorable, mothers with new chicks are assisted by older female offspring, increasing reproductive success.

• In species that lay clutches with multiple eggs, there can be chicks of both sexes and self-assessment of parent condition may not be as crucial.

But what about other species, where only one or two eggs are laid during each breeding season, such as penguins? With a higher de facto investment in each egg, females who would apply this sex-ratio allocation strategy must be very capable of assessing the condition of both their habitat and that of their would-be mates. Penguins are dominant predators in their environment and shifts in a population parameter as fundamental as offspring sex ratio might reflect changes in climate or in distribution and abundance of food resources.

To determine if females are controlling the gender of chicks, we are focusing on the sex ratio of king penguin chicks in the context of the conditions of their parents. We plan to determine the sex of the chicks through DNA analyses of blood samples, a new method to be tested on king penguins in this project. Quantifying parental condition employs standard measures, such as body size, parasite load, and immunocompetence. We will also explore whether plumage coloration - as it is in other bird and fish species - might be an indicator of condition in penguins. Plumage color is from diet-derived carotenoids and may be a useful proxy for evaluating health and fitness.

The results of this work, which will be conducted in collaboration with scientists from the French Antarctic Program, should provide a better understanding of penguin population dynamics and the complex mechanisms of environmental biofeedback. (BO-068-O)

Phylogeny, reproductive mode, and parasitism in antarctic cidaroid sea urchins.
John Pearse, University of California, Santa Cruz.

Where did most antarctic biota originate? Forty million years ago, Antarctica separated from Australia and effectively isolated circumantarctic habitats. The isolation of antarctic biota from the rest of the world's oceans was nearly complete when Antarctica pulled away from South America 15 million years later; the Antarctic Circumpolar Current and the Polar Frontal zones developed to mitigate migration of most species.

The deep sea here does not follow the pattern, however, as it is continually replenished by cold, sinking antarctic bottomwater. Because many endemic antarctic species show apparent affinities to species in the deep sea, a sharp research question arises. Did deep-sea organisms invade and radiate into the antarctic benthos after it became isolated and cooled down, or did antarctic biota provide the source of deep-sea organisms?

To address this issue, we focus our research on cidaroid sea urchins, as part of an international antarctic deep-sea biodiversity program to be conducted on the German Antarctic program's research vessel *Polarstern.* The cruise will be conducted in the Scotia and Weddell Seas, and we hope to collect material from the antarctic shelf to the floor of the adjacent deep sea.

Phylogenetic analysis should help to resolve the origin of this group of organisms. We will also study larval development, which is unknown in some species. Finally, we will examine a fungus-like parasite that occurs on the spines of some species of antarctic cidaroids to place this parasite into a recognized higher taxonomic category and to set the context for understanding how it influences echinoid development. This project will provide new information on a understudied part of the world's ocean and should contribute to general work on the world's biodiversity. (BO-069-O)

Evolutionary loss of the heat-shock response in antarctic fishes.
Gretchen Hofmann, Arizona State University, Tempe.

Evolution has crafted a way for organisms to respond to the stress of abrupt environmental changes, in particular a sudden elevation of temperature. Commonly viewed as a "universal" characteristic of organisms, the heat-shock response (HSR) triggers previously inactive genes to synthesize one or more classes of molecular chaperones, known as heat-shock proteins (Hsps). But what about Antarctica, where such a sudden burst of heat is so unlikely? In previous studies on a cold-adapted, stenothermal antarctic teleost fish, *Trematomus bernacchii,* it was determined that this adaptational response has been lost over evolutionary time.

If evolution at subzero temperatures has indeed altered the gene expression patterns for molecular chaperones in antarctic fish, then the study of how cells respond to temperature at a molecular level may be a legitimate, new frontier in biology . At this stage, however,

though HSR - perhaps the quintessential example of the environmental regulation of gene expression - has been well-described at the cellular level, there is little information on how the response is actually regulated in ectothermic animals in a natural environment.

We hope to build upon that evolutionarily significant observation by examining this profound change in the environmental regulation of gene expression on two levels. First, we will try to establish how widespread the loss of the HSR might be in the suborder Notothenioidei, including antarctic and non-antarctic members of the group. Second, we will try to determine the nature of the lesion in gene expression that accounts for the loss of the expression of stress-inducible genes in antarctic species. Both of these objectives will entail experiments on closely related, cold temperate species from New Zealand waters.

Ultimately, the lesions in the Hsp gene expression in antarctic notothenioids may serve to highlight aspects of the "cellular thermostat" and to provide key information about the actual molecular response mechanism triggered by environmental stress. The results should contribute to our knowledge of the environmental physiology and evolutionary biology of the antarctic notothenioid fishes, as well as enhance our understanding of the extreme stenothermality in these fish. (BO-134-O)

Diversity, vertical distribution, and metabolic activities of inorganic sulfur-cycling prokaryotes in Lake Fryxell, Antarctica.
Michael Madigan, Southern Illinois University.

Cold environments comprise more than 90 percent of Earth's biosphere. Our scientific knowledge is not proportional, however, for relatively little is known about the diversity, physiology, phylogeny, and metabolic activities of cold-loving (psychrophilic) microorganisms.

Focusing on bacteria involved in the process of cycling sulfur at 0ºC in the lakes of the McMurdo Dry Valleys, specifically Lake Fryxell, we hope to add to that store of knowledge. Though it contains significant levels of sulfide in the water column, Lake Fryxell is meromictic; that is, its waters do not fully circulate throughout the basin. The sulfide produced by sulfate-reducing bacteria works at distinct levels, fueling the autotrophic metabolisms of anoxygenic phototrophs and sulfur-oxidizing chemolithotrophs.

To dissect the microbiology and microbial ecology of sulfur cycling that occurs throughout the depths of Lake Fryxell, we will conduct in-situ biodiversity studies, isolation and laboratory cultures, and molecular analyses of metabolic activity. We are targeting three key metabolic genes in the process (pufM, csoS1 and dsr) and will focus the biodiversity studies on Proteobacteria.

We expect our results to

• reveal for the first time the biodiversity of sulfur-cycling prokaryotes active in an important nutrient cycle at permanently cold temperatures;

• make available new genetic resources (of psychrophilic phototrophs, sulfur chemolithotrophs, and sulfate-reducing bacteria) for basic research and for biotechnological exploitation; and

• reveal the most ecologically significant sulfur-cycling prokaryotes in Lake Fryxell and identify metabolically important organisms that remain to be cultured.

In addition to enhancing our understanding of the sulfur cycle in microbes - and the lowest temperature limits at which it can occur - this work also has implications for exobiology (the study of extraterrestrial life), suggesting how we might recognize and even cultivate microbial life beyond the planet. (BO-0174-O)

Gene expression in extreme environments: Extending mircoarray technology to understand life at its limits.
Alison Murray, Desert Research Institute.

One of the most difficult challenges facing scientists who study life in extreme environments is observing the organisms in situ, and then extrapolating those observations into descriptions that capture both the unique aspects of life and the adaptations required for survival. The antarctic marine psychrophiles (cold-loving organisms) provide an excellent model group of extreme microorganisms to study; very little is known about their biological and functional diversity or about the metabolic adaptations they have developed to live at -1.8ºC.

Such work may well have fairly direct practical benefits. DNA microarray technology can be applied to studies of life in extreme environments and may identify new genes for use in biotechnology. You begin by identifying specific adaptations to extreme environments and then try to detect genes that are uniquely expressed to subserve them. By discovering these genes in natural (though extreme) environments, we not only learn about their functions, but might obviate the need for having to cultivate them.

The details of this work entail

• sequencing six large bacterial genomic DNA fragments isolated directly from antarctic marine psychrophiles;

• constructing two different types of DNA microarrays designed to identify genes being actively expressed in uncultivated microorganisms living in the sub-zero marine waters of the Antarctic;

• optimizing specific aspects of microarray technology for use with environmental samples; and

• developing a transferable methodology that will be useful for other researchers in accessing gene expression information directly from the natural environment. (BO-179-O)

Diving biology of emperor penguins.
Paul J Ponganis, Scripps Institution of Oceanography.

Because the emperor penguin *(Aptenoidytes forsteri)* lives within the pack ice zone of the Antarctic, its advanced ability to dive has been a subject of interest for many years. Emperor penguins routinely hunt for food for between 2 and 10 minutes, at depths ranging from 50 to 500 meters. These birds have reached a measured depth of nearly 550 meters. The longest dives are not the deepest, however; the

recorded longest of 22 minutes was nowhere near that record depth. They provide an excellent model to investigate the physiology and behavior of diving birds and mammals - in this study specifically, thermoregulation, underwater behavior, and the homoeostatic regulation of myoglobin.

Working with emperors (captured from McMurdo Sound) in a man-made corral with dive holes, we hope to elucidate both the physiological and behavioral mechanisms underlying the breath-holding capacity of these diving birds. To probe how these physiological limits may affect the natural diving behavior and ecology of the penguins, we will focus on the role of decreased body temperature in extending the duration of aerobic metabolism during diving; also we will explore how organs and tissue tolerate oxygen deprivation. Mounting a small camera on some birds will permit us to examine their behavior during their dives. We are able to correlate changes in body temperature (in the body's core and in muscle) with which prey they ingest as well as with their wingstroke frequency.

At the molecular biology level, we will examine transcriptional control of the myoglobin gene to probe the high myoglobin concentration of emperors, as well as the large increases in myoglobin concentration during chick development. At the end of the study, all animals will be released at the ice's edge. (BO-197-O)

Antarctic killer whales.
Robert Pitman, National Oceanic and Atmospheric Administration.

Twenty years ago a new species of killer whale was described from Antarctica - smaller than the typical species found worldwide and with a different color pattern. During the course of previous work all around Antarctica, we have collected a couple dozen tissue samples from the typical form of killer whale but have yet to encounter the diminutive form, believed to be resident in the Ross Sea and around McMurdo. In this project, we plan to gather as many as 50 biopsy specimens from live, free-swimming killer whales and use molecular genetics to study killer whale systematics. The goal is to verify whether there are in fact two species of killer whales.

Working from a U.S. Coast Guard icebreaker in the Ross Sea area and enroute to McMurdo from Christchurch, we will use either a crossbow, or a specially modified .38 caliber rifle. With these we shoot darts that collect the tissue without harm to the animal and then float on the surface where they may be readily collected. (BO-289-O)

Planktonic invertebrate larvae and biogeography of Antarctica.
Rudolf Scheltema, Woods Hole Oceanographic Institution.

Because continental drift has isolated antarctic ecosystems since the Early Oligocene (about 40 million years ago), most invertebrate fauna commonly found there are native only to that region. Despite this extensive isolation, however, some benthic groups are comprised significantly (from 20 to more than 50 percent) of non-native species. To account for such species, scientists have proposed that intermittent reciprocal exchange must occur between populations resident on South America and Antarctica.

One hypothesis is that geographical distribution could be maintained and genetic exchange accomplished through the passive dispersal of planktonic larvae. We intend to target this hypothesis and hope to show that this dispersal actually occurs. To do so, we must demonstrate two facts:

• Larvae of sublittoral species actually can be found across the Drake Passage; further, that these do belong to species that can be found in South American and antarctic faunas.

• A hydrographic mechanism exists that can be used to explain how passive transport of larvae occurs between the two continents.

To address these two requirements, we will make transects of plankton samples across the Drake Passage and examine the possibility of cross-frontal exchange of larvae at the subantarctic and polar fronts of the Antarctic Circumpolar Current; we will also explore the possible transport of larvae in mesoscale rings. Our results should demonstrate that other species may be profitably examined using molecular techniques that compare individuals from bottom populations of both South America and Antarctica. (BO-281-O)

Origin and evolution of antarctic and deep-sea macroinfauna: Systematics and reproductive patterns of polychaetes.
James Blake, University of Massachusetts.

The International Antarctic Benthic Deep-Sea Biodiversity Program (ANDEEP) begins field work on the German research icebreaker Polarstern during the 2001-2002 austral summer. This larger project will conduct the first baseline survey of the deep-water (benthic) fauna found in the Weddell and South Scotia Seas, deeper than 1,000 meters. This relatively unexplored terrain is vital because it may contrast dramatically with what is known about the benthos of the Antarctic Shelf. The latter is fairly isolated, geographically and hydrologically, and has a richly described and interesting fauna; the former is a region scientists know much less about, though it is certain that its plate tectonic history has provided it with a rich and changing variety of habitats and environmental conditions over time and that it continues to maintain many connections with the surrounding Atlantic, Pacific, and Indian Oceans.

Our component of ANDEEP addresses the following themes:

• the origins of the deep-sea benthic fauna in relation to the antarctic shelf and links to the deep-sea faunas of the Atlantic and Pacific Oceans;

• development of hypotheses to explain high biodiversity in the deep sea;

• deep-sea benthic community structure in the Southern Ocean; and

• biological process, including reproduction and larval development of benthic invertebrates.

Our initial data will focus on seven polychaete families; we hope to enhance understanding of the origins and evolution of these families in the Southern Ocean. During two cruises, we will collect materials to map the spatial and bathymetric distributions of polychaete families while incorporating GIS mapping software. We will also examine the systematics of the selected polychaete families, and

observe larval and post-larval stages to understand the mode of larval dispersal for antarctic and deep-sea polychaetes. (BO-292-O)

Development of a classification scheme for species/habitat associations and biodiversity in antarctic benthic communities: Antarctic international collaboration.
Rikk Kvitek, California State University, Monterey Bay.

This project is a collaboration with investigators from the Italian Antarctic program's ENEA project, who hope to develop a species/habitat classification scheme for antarctic benthic communities near the shores of Terra Nova Bay. High-resolution acoustic remote sensing is a major tool for mapping seafloor communities just offshore of continental margins. It can produce a detailed and spatially accurate Geographic Information System (GIS) map of physical habitat diversity, and develop an appropriate scheme for classifying this diversity.

Italian biologists have developed video of Terra Nova Bay biotic communities with their georeferenced Remotely Operated Vehicle (ROV). The GIS map effort will attempt to relate spatial patterning of epifaunal biodiversity with variation in habitat types from 20-200 meters deep.

If successful, the approach and associated geophysical classification scheme would provide a cost-effective tool for the screening and initial assessment of marine areas proposed as Antarctic Specially Protected Areas (ASPAs). A byproduct of this work will be establishing a physical baseline map of the proposed ASPA at Terra Nova Bay - a crucial set of data in the ongoing effort to assess or monitor habitat change due to natural or anthropogenic disturbance. With such a framework in place, follow-up surveys could be done on an as-needed basis after specific episodes of concern or as part of a regular, acoustic mapping program to assess rates and changes characteristic to the area. (BO-320-O)

 previous section | Table of Contents | next section