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A few words from the Director of the NRS

Use of high technology is the *leitmotif* that unites the stories in this *Transect*. The studies described here utilize diverse sensors: some so small they have been called "motes," others so large they can "eavesdrop on the earth," and some designed to track elephant seals for thousands of miles, communicating with satellites. State-of-the-art genomic techniques have also come into wide use in the NRS, as illustrated here by experiments that examine the role of genetic variability and gene flow on the ability of plants to adapt to new conditions.

The opening article in this issue describes a landmark event for the NRS: the James San Jacinto Mountains Reserve has become a partner in a newly created NSF-funded Center for Embedded Networked Sensing (CENS)

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In This Issue

If a tree falls in the forest and no one is around to hear, does it still make a sound? Yes — if that forest is outfitted with sensors, some of them tiny as this "Smart dust" from CITRIS: <http://www.citris.berkeley.edu/SmartEnergy/brainy.html>. Courtesy of Kris Pister, CITRIS

James Reserve places nature virtually at our fingertips

Mike Hamilton, director of the James San Jacinto Mountains Reserve in Riverside County, refers to himself as a "wirehead." Others have called him the first "digital naturalist." However he is classified, this son of an electrical engineer is equally comfortable studying a rare plant species or troubleshooting a balky computer. And now, thanks to a 10-year, $40-million grant from the National Science Foundation, he and a host of colleagues will have the opportunity to explore new areas where technology and field research overlap.

Their NSF-funded project is called CENS — the Center for Embedded Networked Sensing — and will involve scientists and engineers from UCLA, UC

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Riverside, University of Southern California (USC), California Institute of Technology (Caltech), and California State University, Los Angeles. It will focus on designing networks of embedded sensors for use in a range of different environments. Embedded sensors are ubiquitous and have transformed our lives. They're the inexpensive, miniaturized microprocessors that control everything from the antilock braking system in your car (along with dozens of other systems), to the beeper in your waffle iron that lets you know when breakfast is ready.

The CENS Project will seek to extend the use of embedded sensors into four very different scientific endeavors. One CENS team will design sensors to monitor plankton in the ocean. Another will use them to create smart buildings that detect and respond to the first tremors of an earthquake. A third CENS group will look at integrating sensors into buildings or wells to detect and prevent groundwater contamination. And at the James Reserve, the sensors will be used to provide an unprecedented look at the forest ecosystem. As Hamilton noted in announcing the grant: "These devices are so small and cheap we can put hundreds of them throughout a study area. Some will be small mobile robots, while others will have fixed locations, and all will communicate directly to the Internet via wireless Ethernet. The applications for these devices are extremely wide, and the potential benefits are enormous."

Those who know Hamilton shouldn't be too surprised at this latest venture. Throughout his 20-year career with the NRS he has always been at the forefront in exploring how new technologies might be used to advance research. Back in the eighties, he was using an Apple II and a laserdisc to create one of the first virtual tours (his subject, of course, was the James Reserve). Over the last decade, his innovative work with GIS technology has helped local firefighters reduce the destruction caused by periodic wildfires by focusing their mitigation efforts and improving their containment strategies. The reserve itself is powered by a solar energy system he designed, installed, and maintains.

"The science paradigm is completely affected by technology," Hamilton says. "Nobody will deny that. There aren't any Luddite scientists anymore. When I started using GIS in the early eighties, people said, GI what? But by the early nineties, half of our field biology students were taking a GIS course to learn how to use it. Today it's used by anybody who deals with anything that relates to the landscape.

A bit about the NSF's STCs

The new Center for Embedded Networked Sensing (CENS) — in which Mike Hamilton and the James Reserve will be playing an important role — is one of six projects recently selected from 143 applications by the National Science Foundation (NSF) to join its new group of Science and Technology Centers (STCs). These six new STCs (along with their principal investigators and lead institutions) are:

• Center for Embedded Networked Sensing (Deborah Estrin, UCLA)
• Center for Integrated Space Weather Modeling (Jeffrey Hughes, Boston University)
• Center for Biophotonics Science and Technology (Dennis Matthews, UC Davis)
• Center for Advanced Materials for Water Purification (James Economy, University of Illinois, Urbana-Champaign)
• National Center for Earth Surface Dynamics (Gary Parker, University of Minnesota, Twin Cities)
• Materials and Devices for Information Technology Research (Larry Dalton, University of Washington, Seattle)

The STC program was started in 1987 in an attempt to encourage large, collaborative research and to move beyond the NSF's traditional emphasis on small grants to individual investigators. At first, many scientists feared the STC program would focus on applied research and drain support for basic research. However, as Nathaniel Pitts, head of the NSF's Office of Integrative Activities (which runs the STC program), points out: "It's a chance for PIs to do something that their department or discipline can't do on its own." All the new centers will have multiple institutional partners — UC Berkeley, for example, is involved with four of the six new STCs. Additionally, STCs are expected to find innovative ways of training young scientists, improving diversity in the scientific workforce, and fostering public understanding of science.

The NSF's first class of 11 STCs completed its 11-year run in 2000, while a second group of 12 STCs will be finishing up this year. This year's six new centers, including CENS, will join five centers created in 2000. Another competition is scheduled to begin next year. — *SGR*

The same will be true with these new technologies. They're going to change the way we work."

To see an early prototype of what Hamilton envisions, log on to the James Reserve's website: <http://www.jamesreserve.edu/>. In addition to the usual text and photos, the site incorporates a "Wildlife Observatory" that consists of feeds from a number of other unique sources. Strategically placed video cameras provide close-ups of nest boxes, meal worm feeders, hummingbird feeders, and a "bat apartment." A remote weather station provides real-time feeds on the current temperature, precipitation, and wind patterns at the reserve. There's even a robotic camera that web surfers can control — panning, tilting, and zooming in on objects they want to observe more closely.

Originally installed as part of an NSF education grant, these cameras were designed to help elementary students study field biology from their classrooms. Over time, however, they've served a much larger process: introducing a whole new audience to the reserve system. During the last year, the James website recorded more than a million visits, compared with the 1,500 students, teachers, and scientists who were actually able to visit the reserve during the same period. And though these virtual visitors don't get to smell the fresh mountain air or hike through the woods, in many ways their experiences can be just as rewarding. For example, a researcher interested in the nesting behavior of western bluebirds can learn more about their behavior by reviewing a season of archived "nest-cam" images than from a month of on-site observation.

Michael "Wirehead" Hamilton working in his lab at the James Reserve.

Hamilton believes a network of embedded sensors will make virtual visits to the reserve even more important. "I see this as really enhancing the time-scale side of doing science," he explains. "In typical field biology, you try to capture significant observations in those periods of time when you have live humans out there, and you have no data in between, except maybe a few expensive satellite images. We tend to ignore some questions because they can't be done in a cost-effective manner. This technology opens up the possibilities for potential new discoveries. If you had the right sensors, you could listen to all the birds singing in the James Reserve every hour for the entire breeding season. That data set is extremely different from anything we've ever collected because it's continuous and it doesn't involve a human, so there isn't the disturbance factor."

To illustrate the potential impact of doing remote fieldwork, Hamilton takes reserve visitors outside and shows them a wooden box nailed to a tree. Though the box is empty right now, he's already working on the equipment that will be installed there. "We call it the MossCam," he says, opening the door to the box and indicating where a camera and processor will be mounted. "It's designed for the remote sensing of external physiological change in this patch of *Tortula princeps*."

Hamilton points out a smudge of dried moss on a granite rock a few feet from the camera box. "[UC Berkeley professor] Brent Mishler and his students are studying the physiology of this arid moss species. This station will give them the ability to continuously monitor the moss from their lab. They can watch it through all seasons to see how it responds to changes in the environment — primarily precipitation and temperature. Our camera system will be a multispectral camera that will capture visible light and infrared, and it will be a web cam so the data will be collected every thirtieth of a second and uploaded to a server where it can be sent via FTP or viewed as a web page via the Internet." [*Editor's note: MossCam is now a reality at — <http://www.jamesreserve.edu/mosscam>.*]

He goes on to explain that the remote-sensing characteristics will be directly comparable to weather station data that will be available right next to it. The students will be able to correlate visible infrared light changes in the plant as the moss dries up and rehydrates after being dry. How rapidly that change occurs and how often will be visible to the camera.

The MossCam will serve its purpose well, allowing a team of scientists hundreds of miles away to track the subject. But it's still just a first step in realizing Hamilton's vision. "If this was software," he says with a laugh, "I'd call it Version 0.0. The next step is to cut the line, at least the data line to make the unit wireless … and it's not a smart sensor yet because it's just going to stream data constantly to a server. A human will still have to make decisions about what data

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we collect, when we store it and when we don't. There isn't any intelligent processing going on at the sensor itself. That will be the next step."

Hamilton's goal is to have 100 nodes at James within a few years. Some will have specialized uses; others will be general-purpose nodes collecting a wide range of parameters. "One of our collaborators is John Rotenberry [director of the UC Riverside-administered NRS reserves]," he notes. "He's an ornithologist interested in the acoustical data that could be processed for bird identification, location, and interaction. We might have special nodes programmed to identify unique individual songs. By triangulating this reading with other nodes hearing the same sound, we can pinpoint the location of that singing bird, all in real time. Over time we can track the locations of those singing territories as a 'cloud' of presence and absence activities. We can use this data to create a cloud that indicates where the singing male bird spends most of its time. The cloud could be darker towards areas of higher frequency and lighter where frequency is lower. Then we can have these adjacent clouds of other birds so we can see whether individuals are spending a lot of time at the boundaries interacting and defending the edges, or whether they're spending more time in the center defending the higher quality habitat where the female is."

Embedded sensors will also change the scale at which researchers can conduct their studies. GIS resolution is fine for doing landscape-level analysis, but the new systems will let scientists visualize phenomena on a much smaller scale. "The frontier is the ever-shrinking scale of observation, both in time and space. We're taking our scale of observation down from communities of vegetation to what's happening in a single tree or what's happening within a square meter surrounding that vegetation. You need very different tools to do that. And on a time scale, we're going from seasonality — four times a year — to once every minute or once every second."

Hamilton acknowledges that the visualization of such data "is a real challenge because you're dealing with orders of magnitude more data than you were in the past." But he isn't too concerned about being overwhelmed by so much data: "We're developing a small microcomputer that will have the ability to look at the data that comes from the sensors, process it, and then decide whether to store it, send it, or notify a human. That's called 'intelligent processing.' Once we figure out how to classify and determine what it is we're looking for, a lot of these processes can be automated to where the software will tell us when something important is happening."

Hamilton foresees a day when thousands of tiny, inexpensive sensors scattered throughout the forest are constantly monitoring the movement of animals and changes in the environment. Given current technology trends, he thinks it's realistic that soon some of these devices will be the size of beetles. "Each sensor should actually be designed so it is part of the niche we are trying to monitor," he explains. "And sometimes the niche will change over time, so the node really ought to be able to track that as well. I could see the devices going up a tree and coming back down, or going underground, or going under water and coming out again like an amphibian. Ideally, our designs should almost mimic the life forms they're designed to monitor."

Just as the website's Wildlife Observatory has opened up the James Reserve to a global audience much larger than it can hold physically, Hamilton foresees a day in the near future when embedded technology will do the same thing for the entire Natural Reserve System: "We serve a fundamental need in terms of preserving and protecting these areas and making them open to scientists, but these are not undisturbed ecosystems. People are a constant element here, and the success of a reserve is largely judged upon how much it is used. We need to have the ability for science to go on here, but there is a finite carrying capacity at any site before [use of the reserve] begins to change the ecosystem and impact the experiments of other scientists. We're hitting our heads against that already at many of our sites. How can you allow new people to study in areas that are already at capacity? I think the virtual reserve is one way to do that. Developing a passive remote-sensing network that allows researchers to have virtual access is going to be crucial."

Personally, Hamilton sees this latest focus as one he will maintain for the rest of his career. "This will be my last decade, my swan song. I'm planning to see the system used at all of our field stations and to facilitate its implementation at other field stations around the world. After the first three years of the CENS Project, I see the rest of the reserves becoming part of the experiment, and I certainly will see the NRS fully wired in less than ten years. We're at the point where I think we all better fasten our seat belts, 'cause this is going to happen fast." — *JB*

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Some say Mike Hamilton is playing with fire — and they're right (and they're glad he does)

Recent devastating wildfires in Los Alamos, New Mexico, and Sydney, Australia, highlight how the increasing encroachment of cities into wildlands is dramatically raising the stakes involved in out-of-control burns. Mike Hamilton and his colleagues at the James San Jacinto Mountains Reserve have been involved in fire-related studies for 15 years, working closely with firefighters from the nearby town of Idyllwild. "We're interested in fire hazards," Hamilton explains, "fire risks, the propensity of vegetation to burn, and, ecologically, why it needs to burn."

Fire-suppression campaigns have been very effective in the western United States over the last 50 years (remember Smokey the Bear?). Perhaps too effective. The buildup of brush and deadwood in our forests — referred to as "fuel load" — has prompted scientists and forest managers to look at what happens when fire is removed from a natural ecosystem. How does breaking the natural cycle of regular small fires influence the risk and spread of catastrophic blazes?

As part of "The Mountain Communities Firesafe Project," Hamilton is using remote-sensing analysis to build typical vegetation models for the area and GIS to produce data sets that model fire-spread behavior on a computer. He and his co-workers have used this technique to simulate historic fires, and Hamilton also worked with the software during actual fires to see if he could predict a fire's spread. Unfortunately, so many factors are involved that a 24-hour, fire-behavior simulation takes about three days to run. "You can't make decisions during a fire based on what the computer tells you," he explains, "because you don't have the time. Those capabilities are still a few years down the road."

Hamilton's work has been most effective as a preventative measure. He has completed a standard risk assessment survey for the local mountain area by overlaying his GIS models on property ownership maps. Fire agencies use the data to target properties they should inspect for safety compliance. Homeowners will eventually have access to the system to assess their own properties and determine their own fire-prevention priorities.

Big Creek fire of 1985. Photo by Larry Ford

"In the near future, our website will allow users to determine the relative risk factors for each property and how those risks fluctuate on a daily basis," Hamilton explains. "People who live on a steep, south-facing slope with 50-year-old chaparral are always at risk, of course. If you're on a stream with a conifer forest around you but you're only a mile away from that chaparral, then your risk factor is lower — but it increases as the season progresses, so you have to be careful."

The new CENS grant from the NSF will have two effects on Hamilton's wildfire work. First, it will bring powerful new technology to the reserve. "We'll be able to accomplish far more computer simulation of fire behavior," he notes enthusiastically, "because I'll have a whole bank of very fast UNIX computers that can run the software. And it's all designed to run on parallel systems, so you can have the same model running on five computers simultaneously, and it will run five times faster."

Second, the grant will allow Hamilton to model appropriate construction for a fire-prone area. "Our newly proposed research lab will have a metal roof and cinderblock walls filled with concrete," he observes. "The bottom floor will be built down into the ground — basically making it a fireproof vault — and that's where we'll put our servers and other precious materials. That floor should survive even if the building above it burns. If you choose to live in a wildland setting, you really should be able to live with fire." — *JB*

To view the Mountain Communities Firesafe Project, visit: <http://www.firesafeidyllwild.org>.

McLaughlin Reserve gets mined for DNA data

Major changes are underway at the McLaughlin Natural Reserve, located in Napa, Lake, and Yolo Counties, two hours' drive northwest of UC Davis. As the on-site Homestake gold mine processes the last of its stockpiled ore, UC Davis scientists are picking up the pace of scientific discovery under complementary grants from the Andrew W. Mellon and David and Lucile Packard Foundations for a collaborative research program called "Ecological and Evolutionary Responses of Plants to Habitat Mosaics at the University of California's McLaughlin Reserve."

The same tumultuous geology that once attracted gold miners to the rugged coast range north of San Francisco is now attracting a growing group of landscape ecologists, population biologists, and molecular geneticists. And, just as it took advances in mining technology to release the microscopic specks of gold found in the coast range deposits, researchers are relying on new technologies to reveal the genetic secrets underlying plant adaptation and evolution.

For scientists, this reserve is filled with intriguing puzzles and research opportunities. The steep flanks of the hillsides burst with colorful wildflowers and grasses, as exotic and native species vie for territory. The crests of the hills host stands of blue oak, pine, and serpentine chaparral scrub. Old mineral hot springs ooze down many of the hills, hinting at the volcanic activity that stirred the area two million years ago. In addition to Homestake's open-pit gold mine, 130-year-old mercury mines tunnel beneath several of the hills. The Stony Creek fault, part of the larger San Andreas fault, slices through the reserve, separating ancient ocean crust from valley sedimentary formations.

The scientists are using McLaughlin as a model ecosystem, much as geneticists use simple animals for their studies. Maureen Stanton, a professor in the Section of Evolution and Ecology at UC Davis and one of the project's principal investigators, explains their strategy: "Molecular genetics has made incredible strides in the last twenty years by focusing on a few model systems that they get to know well enough to ask the really tough questions. [The fruitfly] *Drosophila* is the model system for animal genetics. *Mouse* is the model system for mammals. *Arabidopsis** is the model system for simple plants. It's not that these species are representative of all other species, but you have to start

McLaughlin Reserve was special from the start

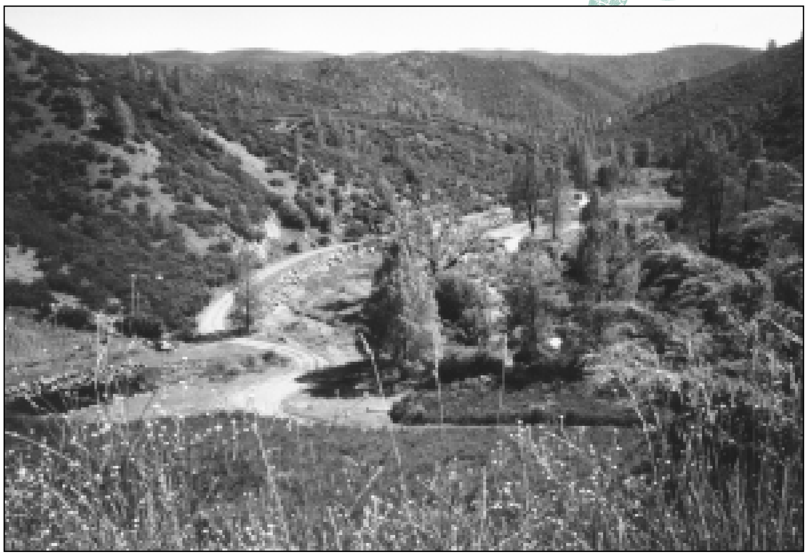
The Donald and Sylvia McLaughlin Reserve is unique among NRS reserves: both for having a working gold mine on site and for joining the reserve system in stages over a period of 20 years.

Back in the early 1980s, the Homestake Mining Company decided that, once it finished mining, the property would become an environmental research station instead of vacant land. In 1985, Ray Krauss, then Homestake's environmental manager, approached UC about the project. In 1992, the UC Regents approved the first stage: a reserve of approximately 300 acres owned by Homestake, but available for research and teaching through a use agreement. Since then, the McLaughlin Reserve has grown to 7,050 acres.

The McLaughlin gold mine has been recognized by the Sierra Club, the Soil Conservation Society of America, and other organizations for its rigorous environmental monitoring and innovative reclamation. While securing mining permits, Homestake spent millions of dollars collecting baseline data on the area's geology and soils, hydrology, air and water quality, terrestrial and aquatic ecology, and archaeology — and the company continues its environmental monitoring. From the start, Homestake welcomed educational use of its long-term data sets.

The McLaughlin Reserve was named for the late Donald McLaughlin — Homestake geologist, former dean of UC Berkeley's School of Mining, and a UC regent — and his widow, Sylvia McLaughlin, a founder of the Save the Bay Foundation. She continues to be an active environmentalist in the San Francisco area. It was often said that their marriage combined the interests of resource use and preservation.

Nowadays the McLaughlin Reserve (along with two other NRS reserves, Quail Ridge and Stebbins Cold Canyon) is also part of the 500,000-acre Blue Ridge Berryessa Natural Area (BRBNA), which incorporates portions of Solano, Napa, Yolo, Lake, and Colusa Counties. The BRBNA conservation partnership, with members from over 130 agencies, works for positive open space planning and to reduce piecemeal development (whether residential, industrial, or recreational), directing new development toward other areas already fragmented. — *SGR*



In this characteristic McLaughlin Reserve landscape, gray (or foothill) pines (*Pinus sabiniana*) on the hillside suggest the underlying presence of serpentine. Photo by Ray Krauss

somewhere. … If you don't have this kind of data on the environment, you can't hope to tackle the important questions."

(**Editor's note:* Arabidopsis *is a member of the mustard (Brassicaceae) family (which includes such cultivated species as cabbage, broccoli, and radish). It is considered a "model" organism because it is easy to grow in the lab, has a short life cycle, makes lots of seeds, has a small genome compared to other higher plants, and can be "transformed" — that is, genes can be introduced into a plant.*)

The team includes professors, postdoctoral researchers, and graduate students — with areas of expertise that range from molecular genetics to landscape ecology. Each team member brings along a specific research specialty, but all are eager to expand their perspectives. "I'm excited to work on a more holistic level," says Susan Harrison, another principal investigator on the project, professor in the UC Davis Department of Environmental Science and Policy, and campus director for the NRS sites administered through UC Davis.

Kevin Rice is a perfect example of the group's interdisciplinary approach. A UC Davis professor in the Department of Agronomy and Range Science, his primary research focus has been on patterns of species distribution, especially invasive plants. "In some ways, I was pulled kicking and screaming into looking at genetic issues in terms of plant distribution," he says with a laugh. "But it's become pretty obvious that genetics can make a difference in terms of the capacity of a plant to live where it does."

McLaughlin's extensive serpentine outcrops are a key attraction for many of the researchers. For plants, serpentine is a tough neighborhood: high in minerals like nickel, zinc, chromium, and magnesium, and low in nutrients, such as calcium and nitrogen. Serpentine deposits have become botanical ghettos inhabited primarily by native California plants that have adapted to them. Harrison explains why plant evolutionists tend to gravitate towards serpentine: "[There] you can find the real rarities and interesting systems to study speciation. In California, we have this young, rapidly evolving flora, and serpentine has been a hotbed for that kind of recent burst of speciation … there's probably a few dozen genera of plants that have gone wild with serpentine endemism."

On serpentine, native California plants are relatively free from competition with the invasive species that now dominate most nonserpentine environments. "Many times exotics can't tolerate the serpentine," Harrison says, "but that's not absolute. Serpentine grasslands are actually fairly invaded, they're just not *as* invaded as nonserpentine grasslands."

Plants have an amazing ability to adapt to new conditions, sometimes within a few generations. New technologies are giving scientists a deeper understanding of how this adaptation happens at the limits of their range. "Using molecular techniques to understand the balance between selection and gene flow is crucial," Rice explains. "I'm trying to understand how rapidly exotic species change evolutionarily. If they have enough genetic variation and the selection is strong enough, they can change pretty quickly. But the one thing that often reduces the capacity for change is gene flow. Plants come up to a gradient and begin to adapt, but if there's gene flow coming in from someplace else where the selection pressure isn't as strong, that really slows down the capacity of the plant to change. Measuring gene flow has always been difficult, but with the new molecular markers we have, it's relatively a snap. You can go in and do paternity analysis and *see* who begat whom."

The effects of the technology aren't just limited to looking at invasive species. "We've done work with blue oaks," Rice says, "and just from doing traditional fieldwork, you can see that oaks are becoming more and more fragmented in the landscape. They've become pollen-limited. You think, my god, there's got to be enough pollen to go around, but it's not necessarily true. One really interesting question is the oak's breeding structure: Where is the

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pollen coming from? Is it local? If one tree is the big daddy to lots of the other trees, if it's fathering lots of acorns, why is that? Is there something about the time of pollination? That type of paternity analysis, which was unheard of five to ten years ago, has become routine."

Grad student Marina Alverez (L) and postdoc Jessica Wilcox Wright (R) conducting a plant survey at McLaughlin. Photo by Jerry Booth

Map it and they will come

Other technologies that have greatly facilitated the work at McLaughlin are GIS (Geographic Information Systems) mapping and GPS (Global Positioning Systems). In fact, one of the group's first steps in developing their project was to overlay a portion of the reserve with a huge grid. Postdoc researcher Brian Inouye, who led the effort to design and map the grid, was also the team's original "cat herder" — a job that entailed organizing meetings and seminars among faculty, grad students, and postdocs. (Kendi Davies is the team's new cat herder.)

Inouye's first challenge was to get everyone to agree on where the grid would be. The team selected a hilly site that incorporated three ridges of serpentine, separated by varying degrees of nonserpentine soils, grasslands, and chaparral environments, a major section of the fault, and two fossil mineral springs. Over this mixed environment, they laid a 550- by 600-meter (27.5-hectare) grid. Most of the grid is marked at 50-meter intervals, but some areas of particular interest are divided into 10-meter or even 1-meter squares. There are about 500 sampling sites over the grid, and at each one, Inouye collected soil for analysis, so he and his fellow researchers would have a fairly detailed map of the area's soil chemistry.

Once the soil had been characterized, Inouye began the laborious task of cataloging the plants at the same sites. "Collecting the vegetation data required two rounds of sampling," Inouye recalls. "In the early spring, we found all the small annual flowers — most of the natives are annuals that flower quite early. Then we went back again in June for a second round of sampling to identify all the grasses."

The Mellon and Packard grants have been a boon to the researchers, both graduates and undergraduates. A dozen projects are already underway at McLaughlin and more are in the planning stage. GPS technology is critical for coordinating and accessing the huge amount of data being generated. "We use GPS receivers to document the locations of all our sampling points," Inouye explains. "All the graduate students funded for this project have a stipulation that they take accurate GPS readings of all their study sites so we have an accurate record of who has been working where, and so all the data we collect over time will be spatially referenced in the literature."

"Back in the lab, we can then sort all this information by whatever factor we want. Say you want all exotic species that are perennials growing on a certain soil type. The computer will produce that for you, so when you go back into the field, you know exactly where to look."

Harrison, long accustomed to doing her work with pencils and topo maps, has been very impressed with the team's new technology: "You go out, walk around a patch of your plant, and hit the button on your GPS to record data points. Then you go back and dump that file into your computer (which already has a map of the study site with all the other attributes we've measured), throw your map on top of those other features, and from there you can very easily calculate how many patches you have, what their total area is, and how many of those patches are on which kind of slope or which kind of vegetation community. The technology makes the process a lot slicker and the data a lot more accurate. And it really facilitates people sharing and exchanging data on the grid, so it's helped foster connections between the different projects."

For Rice, the accuracy of GIS technology has led him to rethink the idea of a gradient as a transition from one environment to another: "We're looking at larger spatial scales in the environment, and rather than taking a simplistic view of a serpentine gradient, I want to think about how important the patchiness of that gradient is."

Susan Harrison, in her role as director of those NRS reserves administered by UC Davis, is delighted with the ongoing research, the impact it is having on the reserve, and the support it has received. "Research on evolution and diversity is a natural for McLaughlin," she says with a smile, "but the Mellon and Packard grants have really jump-started the process. Having money to get the word out to researchers, to offer mini-grants to grad students … it's made things happen in a year or two that might have taken five years. I think it will really put the reserve on the map for people who get excited about plant evolution and ecology." — *JB*

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What's in a niche? Gridwork is helping to define it

Principal investigator Maureen Stanton's research at the McLaughlin Reserve provides a good example of the kinds of projects being carried out on "the grid." Her team's goal is to address a basic, long-overlooked question of ecology: what factors determine a niche?

Stanton explains: "Ecology has been defined as the study of the abundance and distribution of species, but since the seventies we really haven't been asking why a species grows here and not there. And we realized that this grid provides a fabulous opportunity for trying to understand the concept of *ecological niche*, where a species lives and why."

Stanton's work focuses on a small annual native, *Gilia tricolor*, that has very clear distribution patterns and boundaries. "There are two reasons you get patches," she says. "Either the seeds don't get dispersed too far, or the seeds that are dispersing only succeed in certain areas. So the first question is: what are the immediate factors that keep the species from broadening its distribution through the whole environment? The second question is much trickier: why doesn't the population adapt for the conditions beyond its current boundaries and spread? In evolutionary terms, what keeps the niche constant?"

Her study involves a series of lilliputian research plots filled with toothpicks and collars marking each of the hundreds of tiny germinating plants. Stanton describes her method and her results thus far: "We've set up transects going from the core area in the patch where there's lots and lots of *Gilia*, to the edge where it's petering out, and then perhaps 10 meters beyond the edge, which we call the periphery. In each area, we've transplanted *Gilia* seeds collected last year from the center of the patch. They shouldn't be adapted to the edge in any way. Now we're monitoring the seedlings to answer several questions. First, can they succeed perfectly fine beyond the patch edge? If so, then that suggests it's just dispersal limitations, just a historical accident that the species grows where it does."

"That's not what we're finding. We're finding that the seeds are not doing that well outside of the native distribution, even if we help some of them by clearing away other seedlings and dead plant material. … In the center of the plot, you have just about equal numbers of seedlings emerging in the weeded and unweeded plots. As we move to the edges and beyond, we find that weeding has more of an impact. If we don't weed and clear away competitors, *Gilia* has very little success. So it's not just seed dispersal limitation; in this zone, some combination of competition and litter is impeding emergence and probably changing survival as well. That kind of experiment has been done elsewhere quite a lot, but not for serpentine populations."

Stanton's next step will be to look at the genetic part of the story. She plans to take a few seedlings that survive in the peripheral sites and analyze them to see if their genes have adapted to the new conditions. And if so, why doesn't the population produce successful seeds that will establish there again next year, thus extending the boundary of their niche? Her current hypothesis is that gene flow from the center of the patch dilutes the potentially adapted genes, but that remains to be seen. Stanton pokes at the ground, extracting a *Gilia* seedling. "Niche is something ecologists spend a lot of time worrying and talking about," she muses, "but we haven't done much to develop a picture of the niche that's really predictive. And with the grid in place, we have the template to do that here at McLaughlin. That's where we're going next." — *JB*

Año Nuevo Island scientists tag sharks and seals to determine how the great whites know dinner is ready

It happens each year like clockwork. The great white sharks arrive in the waters south of San Francisco near the NRS's Año Nuevo Island Reserve just in time to feast on young elephant seals as they return from foraging in the open ocean. Researchers have long wondered about the sharks' uncanny timing, but only recently — through the use of modern technology — have they been able to expand their understanding of the movements of both these creatures. The story they're uncovering is more amazing than they had imagined.

Like modern commuters whose new cars come equipped with GPS mapping systems, marine researchers are benefiting from the increasing sophistication and miniaturization of computers, as well as from the growing fleet of communications satellites in low earth orbit. More and more animals — such as sharks, elephant seals, bluefin tuna, even large seabirds — are heading into the open ocean equipped with miniature tags that record everything from their geographic positions and traveling speeds to their heart rates and diving depths.

Among the researchers whose work has benefited from the new technology are UC Santa Cruz professors Burney Le Boeuf and Dan Costa, two leading experts on the northern elephant seal (*Mirounga angustirostris*). They and their colleagues have been studying the seals at Año Nuevo since the late 1960s, when the population was just beginning to re-establish itself. Today, at the height of mating season, thousands of elephant seals crowd the 8-acre island and spill across the narrow channel to the coastside state park. (*Editor's note: The NRS's Año Nuevo Island Reserve is a 25-acre portion of the 4,000-acre Año Nuevo State Reserve, site of the world's largest mainland breeding colony for the northern elephant seal, owned and operated by California State Parks.*)

In many ways, elephant seals are ideal subjects for study. Though they spend much of their lives in the open ocean, they regularly return to Año Nuevo to molt, breed, and give birth. Their onshore behaviors are well documented and provide a perfect opportunity to attach and retrieve tags. Sharks are more difficult to study, but their habit of returning each year to the waters off Año Nuevo and the Farallon Islands makes it at least feasible to tag them, even if retrieving the tags is not quite so easy.

Offshore studies of the elephant seals began in the early 1980s when researchers outfitted elephant seals with the first time-depth recorders, developed by Gerry Kooyman of the Scripps Institution of Oceanography. (Though time-depth recorders had been used on other animals, this was the first time they were deployed on elephant seals.) Back then, the devices used film to record the elephant seals' diving behavior over a limited time period. "They could only record data for 14 days," recalls Costa, "but they provided the first glimpse of the animals' diving behavior. Until then, we didn't realize the animals were routinely diving to 1,800 feet and spending 90 percent of their time underwater."

Unfortunately, the early recorders could only provide data on the animals' behavior. What scientists still didn't know was where the elephant seals were performing their amazing feats. That capability — to determine *where* the seals did what they did — came in the early 1990s when Roger Hill, of Wildlife Computers, and Bob DeLong, of the National Marine Fisheries Service, developed electronic tags that could measure light level and temperature. The light-level data allowed scientists to track sunrises and sunsets to determine an animal's approximate longitude and latitude. The temperature data allowed them to refine their position estimates.

Tracking of white sharks at Año Nuevo improved markedly in 1997 when Le Boeuf and UC Davis colleague Peter Klimley, of Bodega Bay Marine Laboratory, installed three sonobuoys offshore, 550 yards apart. When a tagged shark approached the area, a computer on the island tracked its exact position in real time by triangulating the readings from the three buoys. This system provided new insights on the behavior of the great whites in the coastal waters, revealing that they hunt 24 hours a day and often use the camouflage of the rocky bottom to surprise their prey.

Today researchers have expanded their studies far into the ocean, using tags that can record an animal's behavior and travel patterns for months at a time and then archive that data for later retrieval. An elephant seal typically carries two of these tracking devices. A head-mounted platform transducer provides Argos satellite telemetry data to track the animal's daily movements, while a time-temperature-depth recorder (TTDR), attached to its back, records diving patterns. TTDRs are typically archival devices that scientists recover and download when a seal returns to the reserve.

These tags have revealed that male and female elephant seals behave very differently in the open ocean. Males spend four months off the Aleutian Islands, feeding near the ocean bottom on benthic prey, and they tend to return to the same areas on subsequent migrations. Females, on the other hand, feed on pelagic prey, much nearer the Oregon and Washington coast, and they seem to vary their travel depending on the availability of food.

It took yet another major technology breakthrough to provide new insights into the great white sharks' movements. Instead of archival tags, Le Boeuf and UCSC graduate student Scott Davis deployed new satellite tags that automatically drop off the shark at a predetermined time and transmit data from the ocean surface to a passing satellite. These tags were developed by Barbara Block (Hopkins Marine Station), Roger Hill, and Paul Howie (Microwave Telemetry). Not only are the tags much smaller than the earlier ones, but they also hold much more data — 4 megabytes compared to 500 kilobytes — and record the shark's daily position and behavior over a four-month period.

This female elephant seal, fully outfitted with a head-mounted platform transducer and time-temperature-depth recorder (TTDR) attached to her back, is a participant in studies at Año Nuevo that aim to find out where she and her friends go, how they get there, and what they do. Photo by Dan Costa

In late 1999, researchers at Año Nuevo and the Farallones planted tags on four great whites. The results dramatically changed assumptions about their behavior. Researchers had long assumed that great whites stayed close to shore, patrolling up and down the coast in search of food. The tags revealed a very different story. All four sharks swam far out into the central Pacific — one male covered over 2,200 miles to Hawaii, traveling fast (an average of about 44 miles a day) and diving deep (as deep as 700 meters). And even when it reached Hawaii, it remained very deep in the water, at about 500 meters. The big question now is why. The scientists suspect breeding, but confirmation will require further research and more sophisticated technology. And there's still the mystery of how they can time their return to Año Nuevo so precisely.

Unique physiology

While advances in tagging technology have revealed a new world of oceanwide migrations, Costa and Le Boeuf have been using a very different technology to further their understanding of how the animals are designed to cope with this demanding lifestyle. Elephant seals, for example, dive much deeper than other seals and spend up to 90 percent of their time at sea underwater. When feeding, the males routinely undertake long dives of up to 1,500 meters that subject their bodies to tremendous water pressure and cause them to surpass the limits of their aerobic capabilities.

The challenge scientists faced was how to investigate how the elephant seal's internal body functions change underwater. "One obvious advantage of the Año Nuevo Reserve," Costa explains matter-of-factly, "is that just over the hill you have Stanford and its research hospital. Our location is unique because you have animals in a natural environment within close proximity to one of the state-of-the-art MRI research units in the country, if not the world. So we teamed up with Professor Peter Hochacka and graduate student Sheila Thornton, of the University of British Columbia, to take yearling elephant seals to Stanford to see what their blood flow is like under diving and nondiving conditions."

The scientists already had a good understanding of the seal's normal diving pattern, so their task was to simulate this pattern in the MRI facility. "To simulate a forced dive," Costa notes, "we put a mask on the animal's face and flooded it with water for 5 to 10 minutes. Then we evacuated the water very quickly to simulate diving. It's kind of like a terrestrial dive. In the ocean they dive for 20 or 30 minutes, so giving them a 3- to 4-minute dive here is nothing. You train them to get used to the idea that when the water level goes up, they should dive. And they just sit there and do it."

Costa was confident the animals would do well in the studies. "We trained them first, to get them used to the process ... and they're so calm, if we had one sitting in this room it would probably sleep ten minutes, holding its breath the whole time." He does admit to one problem, however. "We had to clear out their stomachs because they eat a lot of sand on the beach, and the sand at Año Nuevo has a lot of iron in it. It didn't hurt the animals, but it produced some very bizarre [MRI] images."

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Año Nuevo Island

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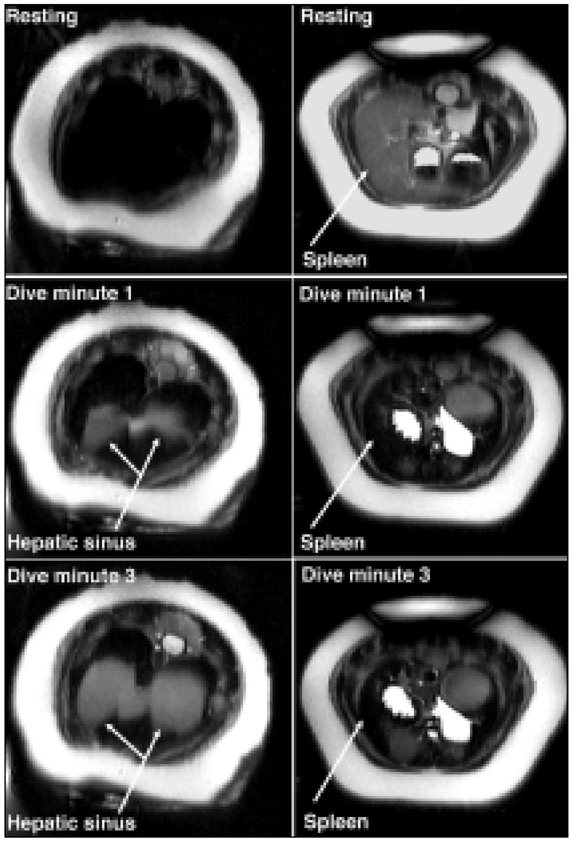
What the researchers discovered provided tremendous insight into how elephant seals have adapted to their diving lifestyle. In particular, the study focused on the animals' large spleens, which are full of oxygenated red blood cells. "As soon as the animal dives, the spleen squeezes down very quickly and the hepatic sinus enlarges," Le Boeuf explains. "The timing is such that this activity appears to modulate oxygenated blood cells to enter the vascular system throughout the course of diving."



MRI images taken at Stanford Hospital to determine how elephant seal internal body functions change underwater, keeping these creatures well oxygenated during deep dives. Photos courtesy of dan Costa

In open water, the seals only surface for short periods of time. This suggests the spleen remains contracted and the hepatic sinus modulates the oxygenated blood cells the whole time. So why is the spleen so big normally? "Sixty-five percent of a diving seal's blood is red blood cells," Le Boeuf notes, "and when you have that many red blood cells, the blood is very viscous, not the optimum way of transporting oxygen rapidly."

Cameras could provide a much clearer picture of what's actually happening. "For the males, we'd have to put a time delay on the camera," Le Boeuf explains, "because it takes them a month to 45 days to reach their feeding grounds. We may want to cue to depth as well, as they are benthic feeders. For females, you'd have to program the instruments a little differently because their feeding patterns are so different."

For his part, Costa thinks the seals might be extremely valuable as data-gatherers for monitoring the health of the ocean environment itself. He's now working with Barbara Block, George Boehlert (National Marine Fisheries Service), and Randy Kochevar (Monterey Bay Aquarium) on the early phases of a program known as "Tagging of Pacific Pelagics" or TOPP. The program's goal is to try to understand how large marine animals utilize the vast habitat of the north Pacific Ocean.

At sea, the seals are not high-activity animals. They hold a lot of oxygen, store it, and dive at a moderate-to-low rate. The fact that their blood is viscous isn't important because they're not doing things very fast. But all that changes when they come ashore. On land, where they need to fight or walk around, it's more advantageous to have a lower viscosity of blood, so they take the red cells and put them in their spleens.

Coming soon — SealCam?

Never content with the status quo, Costa and Le Boeuf are pondering how emerging technologies will shape future research. Already sharks are being tagged with more powerful devices that will be able to record their entire migrations. One idea is to put small "seal cams" on elephant seals that would provide time-lapse stills or footage of their activities. Today researchers must interpret printouts of diving and speed patterns to determine an animal's behavior.

In upcoming years, 4,000 animals — elephant seals, Pacific bluefin tuna, albatrosses, leatherback sea turtles, sharks, whales, and others — will be tagged in a coordinated effort that will follow all the species simultaneously. By overlaying these data with oceanographic profiles, researchers hope to gain a better understanding of what factors drive their migratory patterns. This information will become crucial as researchers try to protect these animals and the oceans from overfishing and increased human impact. — *JB*

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The return of El Niño suggests hard times ahead for the elephant seals at Año Nuevo Island Reserve

Scientists at the Año Nuevo Island Reserve have a perspective earned by only a few other long-term researchers. After roughly 35 years (since the late sixties) of working with a single, rapidly growing animal population, they have come to notice small variations in the animals that alert them to changes in the environment. The National Oceanic and Atmospheric Administration (NOAA) is currently tracking one set of environmental changes: evolving El Niño conditions in the tropical Pacific.

When an El Niño does develop, the team will already be tracking its impact on the elephant seals. After all, they've been weighing 100 to 200 pups at Año Nuevo every year since 1978. "We're in a good situation to detect a change caused by an aberration in the environment, like an El Niño," notes Burney Le Boeuf, UC Santa Cruz professor emeritus and long-time elephant seal researcher. "We're weighing pups right now, so we'll be poised to look for the effects on elephant seals, both direct and indirect. Bad weather at peak season is direct. Indirect would be if they have difficulty foraging as soon as they go to sea in the spring — then we would expect a much lower survival rate. Or if the mothers are affected when they're foraging, we would expect an impact on weaning weight. It depends on when the effect occurs and what kind of effect it is."

Le Boeuf goes on to explain that El Niño affects elephant seals differently than most animals:

You might think that elephant seals wouldn't be affected by El Niño because it's thought to be a surface phenomenon. They, on the other hand, range throughout the north Pacific and dive to depths of between 400 and 600 meters. But the data are very compelling. Elephant seals do respond very dramatically for an animal that one would think would be well buffered. [El Niño] hits seabirds or sea lions immediately because they're feeding when it comes. The female sea lion goes out, feeds, and returns to her pup, so her ability to feed is intimately connected with food availability. The elephant seal comes ashore in late December or early January, gives birth to a pup, and then stays with that pup, fasting for 26 to 28 days before she weans it. Her investment in that pup is determined by what happened over the previous nine months while she was feeding. So there could be an El Niño going on in the ocean, but what's happening on the beach doesn't reflect that yet. When the pup is weaned, it fasts for two to three months, so when it goes to sea, if the El Niño continues, it could face a shortage of food. That's when we'll see the impact."

During the last El Niño (1997-98), researchers saw a major impact on the seals. Le Boeuf says, "Dan Costa and I are working on a paper with [UCSC colleague] Dan Crocker on the effect of a previous El Niño on the foraging behavior of females. We weighed the females before we tagged them and when they returned. During an average year, the weight gain is 1 kilogram per day of feeding, but that year they gained only .33 kilograms per day. Some of the females didn't gain mass at all. And the seals weren't at sea as long as normal — the feeding was so poor. If another El Niño is coming our way, it might be good to have ten more animals out there this year." — *JB*

El Niño aside, the scientists have seen a disturbing trend over the last couple of decades that needs to be monitored: the weaning weight of elephant seal pups has been going down every year since 1980. Another UCSC scientist, Jim Estes, has noticed the same trend in sea otters. "You can jump to conclusions," Le Boeuf muses, "but it seems to suggest that there's something bigger going on out there. Elephant seals are a closed system. The mom feeds, she comes back, she gives birth, and everything she gives her pup is from body storage. How much she can give, what the pup weighs at weaning, is a function, in part, of how successful the mom was when she was feeding." Photo by Steve Davenport

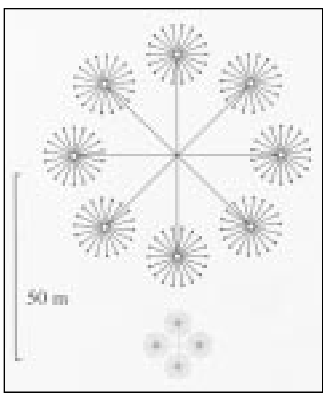
Boyd Deep Canyon Desert Research Center aids scientists in their effort to eavesdrop on the earth

A meteor explodes as it enters earth's atmosphere. But does it make a sound?

Instruments installed last summer at the NRS's Boyd Deep Canyon Desert Research Center at its Pinyon Flat site, south of the City of Palm Desert in Riverside County, will help scientists decipher this and other sounds we may never have heard.

This new installation is part of an array of instruments centered at UC's Piñon Flat Observatory in the mountains above Boyd Deep Canyon. The array is one of 60 similar listening posts that will be built around the world as a global "infrasound" listening network. Financed in part by the U.S. Defense Department's Threat Reduction Agency, the network was designed to help uncover nuclear weapons testing. But the scientific application of "infrasound" goes beyond detecting nuclear activity by rogue nations.

One of the first signals picked up by the Piñon Flat array was the sound of a ten-foot meteor exploding in the atmosphere more than 1,100 miles away.



Such large explosions create shock waves that displace massive amounts of air, generating sound waves through the atmosphere. The high-frequency waves dissipate rapidly, but the low-frequency infrasound waves, inaudible to human ears, can travel great distances. The sound wave dips and rises through the atmosphere, striking each listening post in a way that makes it possible to trace the path back to its source.

In addition to exploding meteors and nuclear blasts, the listening posts will be able to detect infrasound generated by volcanic eruptions, hurricanes, and earthquakes. These measurements, used in conjunction with, say, seismic data or weather satellite information, will give a more detailed description of activities that may be brewing above and below the surface of the earth.

Of the 60 planned listening posts, 13 have been installed. The Piñon Flat array is managed by UC San Diego's Scripps Institution of Oceanography, which has a second array under construction near Newport, Washington, and hopes to build two others.

Installation of the instruments at Boyd Deep Canyon followed stricter-than-usual requirements to protect plants and soil. As it turned out, this approach to installation improved the array, making it cheaper and quicker to build, as well as more efficient to operate. According to Al Muth, director of Boyd Deep Canyon, leaving vegetation in place around the instruments reduced wind speeds, which in turn reduced background noise that would otherwise have interfered with infrasound reception. — *MLH*

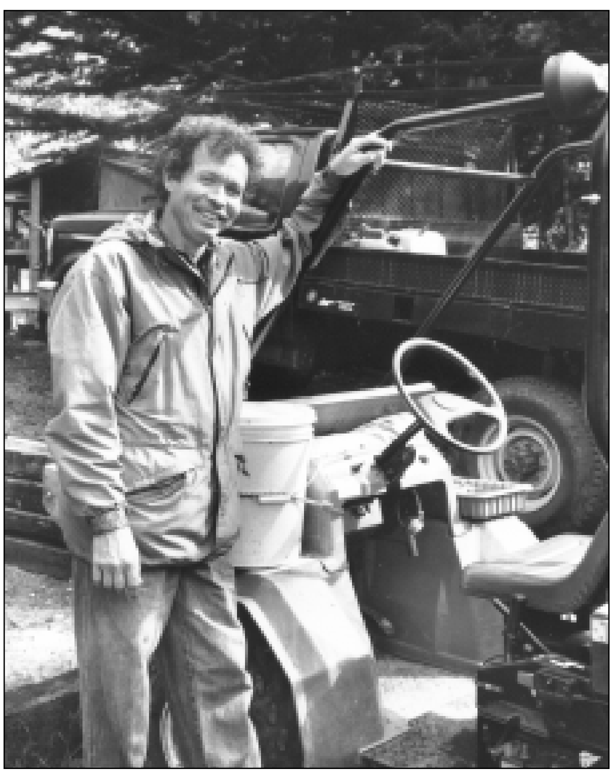
(Left top) Design diagram for a single listening-post array (one of 60 planned) in the global "infrasound" network.
(Left bottom) Array at L3, located on UC land at Boyd Deep Canyon's Pinyon Flat site.
(Right above) Infrasound detector (sensor) in a vault. Photos courtesy of Michael A. H. Hedlin, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, UCSD

Intrepid steward at Big Creek named Firefighter of the Year

A strong sense of community is crucial in remote areas of California. With hospitals and fire stations hours away — or sometimes not available at all — rural residents must rely on each other in emergencies. Staff members at the Landels-Hill Big Creek Reserve on the Big Sur coast play a crucial role in that isolated community. Their dedication was highlighted recently when reserve steward Feynner Arias-Godenez was honored as the 2001 Firefighter of the Year by the Big Sur Fire Brigade.

In presenting the award, Fire Chief Frank Pinney was lavish in his praise: "Feynner demonstrates an exceptional willingness to help his peers, and is dependable and cheerful, supporting his teammates in drills and incidents with a positive attitude and a can-do spirit. He has been seen many times to take a load of equipment straight up a hill while the rest of us are still catching our breath."

Engine Captain Montgomery London echoes Pinney's praise: "It's not that Feynner did one heroic action," she notes. "It's that he's always there … willing, confident, and smiling. During one fire, he and I were assigned to protect a house on the ridge. As we sat in the truck waiting, I admitted to him how scared I was. He just smiled at me and said, 'Don't worry. You'll do everything right.' And we did."



Feynner Arias-Godenez and his trusty "mule."
Photo by Susan Gee Rumsey

Feynner joined the volunteer fire department in July 1998 and has been one of its most committed members. John Smiley, director of the Big Creek Reserve, observes that Feynner responds to emergency calls at all hours and is often the first to arrive at an accident scene, sometimes clambering down cliffs to rescue stranded motorists and provide first aid.

Chief Pinney has been very impressed with Feynner's day-to-day contributions and his unfailing attendance at training and drills. He commented, "Feynner represents the spirit of volunteerism and serves as an example for his peers and the entire community."

Congratulations, Feynner! — *JB*

Big Creek Symposium Papers Available

During his lifetime, former state senator Fred Farr was known for bringing people together to share perspectives and concerns. After his death in 1997, it was clear the best way to honor the memory of one of the founders of the Landels-Hill Big Creek Reserve would be to convene a symposium of researchers and friends to discuss all that has been learned there since the reserve was established in 1977.

The results of this unique day-long event are now available in an attractive new book, *Fred Farr Research Symposium / Views of a Coastal Wilderness: 20 Years of Research at Big Creek Reserve*. The 82-page book features presentations by experts on the reserve's archaeology (Terry L. Jones), marine environment (Caroline Pomeroy, Mary Yoklavich), vegetation patterns (Paul Rich), entomology (John Smiley, Jerry A. Powell), and geology (Clarence A. Hall, Jr.), as well as color photographs and a presentation on one artist's research by UC Santa Cruz art professor Norman Locks.

The cost of the book is $25 (plus $4.00 shipping/copy). California residents should add 7 percent sales tax ($1.75/copy) to their order. Checks should be made payable to "UC Regents" and sent to:

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A few words

Continued from page 1

and a test bed for a habitat-sensing array of devices for biocomplexity mapping.

Current research on wireless sensor networks promises many benefits. For example, UC Berkeley's Center for Information Technology Research in the Interest of Society (CITRIS) is exploring the development of a wireless network of tiny, inexpensive sensors to monitor and help control energy use in a building to save electricity. This application has the potential of saving billions of dollars a year in energy costs. Similar sensor networks embedded in roads, bridges, and buildings could provide information in real-time on the condition of these structures after an earthquake. A fascinating look at the extraordinary future possibilities of embedded sensor networks is provided at <http://www.intel.com/pressroom/archive/speeches/tennenhouse20010827.htm>.

CENS will develop and field-test such new technologies "to explore the use of embedded networked sensing to monitor the interactions of terrestrial organisms in their habitats, at multiple coordinated temporal and spatial scales." At the technology's heart will be computers running in real time, connected to the physical world through wireless communication with new types of miniature sensors that detect things around them and with actuators that enable the computers to manipulate the world. It will be possible at the James Reserve to implement, over the project's initial ten-year life, advances being made in production of self-assembling networks of nodes, in machine learning, and in creating new types of information storage technology. The new "sensory networks" will revolutionize our understanding of the functioning of the natural world and offer unprecedented opportunities for research and learning at a distance.

Synergy between the NRS and advanced technologies takes many forms. NRS sites provide opportunities to ask fundamental questions about the functioning of the biosphere. They enable these questions to be asked by providing secure settings for long-term studies involving complex instrumentation. Finally, and most important, the NRS reserves are home to the research of many gifted scientists with unique areas of expertise, who eagerly adopt powerful new approaches in innovative ways.

— Alexander N. Glazer
Director, Natural Reserve System

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