NRS
Natural Reserve System
University of California

Transect

Autumn/Winter 1999 • Volume 17, No. 2

A message from the director of the NRS

The University of California Natural Reserve System was formally established in 1965 largely through the efforts of a few visionary and altruistic professors. Their legacy is now a system of thirty-three sites that encompass much of the state's ecological diversity. No other university in the world can boast of such a resource for research and education in the field sciences.

The world has changed in many ways in the short time since 1965. In many areas, these changes have contributed dramatically to the health, technological capabilities, and wealth of humanity. With respect to the environment, however, the anthropogenic changes have been negative and have taken

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In This Issue

Researcher Roland Knapp on the job. Photo by Eric Knapp

From drudgery to discovery: The real life of field researchers

"Being a researcher is wanting to have a eureka moment, even when you know it's not happening," says Susan Harrison, a UC Davis associate professor and faculty manager of several UCD-administered NRS sites. The prospect of making new discoveries about nature can be invigorating, even romantic. But field research can also be a dirty business, with countless hours working on the ground, getting your fingers grimy and your feet wet.

The life of a field researcher has its drawbacks — yet most such scientists would never trade working in the wild for a desk job. Dan Costa, a UC Santa Cruz professor and faculty manager of the NRS's Año Nuevo Island Reserve, expresses the sentiment with these words: "When I'm out with my students on Año Nuevo Island, and we're wrestling a giant elephant seal in the mud, I just take a deep breath and say to them, 'You know, some people get to do this for a living!'"

From mountaintops to ocean floors, the highs and lows of field research range as dramatically as the possible topics of study. All researchers have their own stories

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The real life of field researchers

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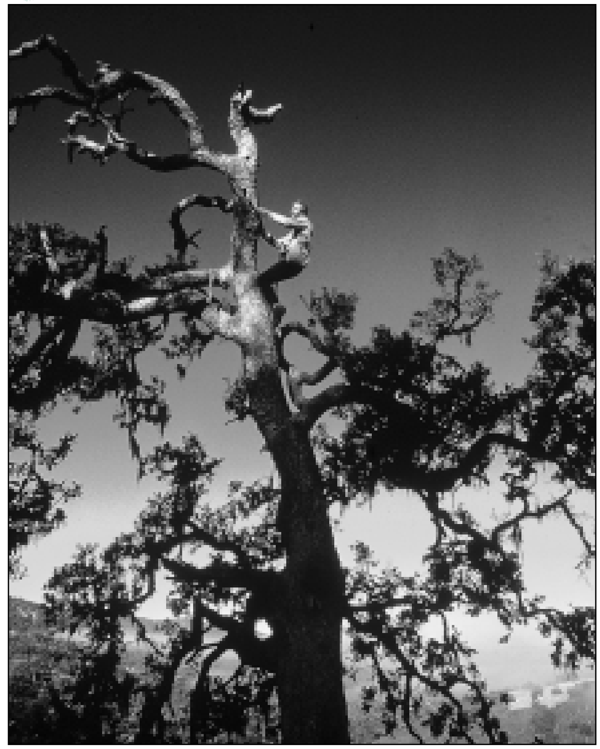
to tell about why they chose their particular paths and what they like and dislike most about their work. But whether field research was a lifelong ambition or a lifestyle they fell into after completing their undergraduate degrees, most of these researchers say they are driven by three passions: unrelenting curiosity, love of the natural world, and commitment to the scientific method.

"Curiosity may have killed the cat, but rarely the field ecologist," says Peter Bowler, a UC Irvine professor and member of the NRS's Universitywide Advisory Committee. "We're lucky to be paid to have so much fun getting the answers — or trying to — to the things that puzzle us." This nagging curiosity jumpstarts field researchers, enticing them to venture out into nature and begin the process of discovery.



Scientist Walt Koenig, after a quarter of a century of studying acorn woodpeckers at Hastings Natural History Reservation, still gets high on his research. Photo by Galen Rowell

Applying scientific method to the madness

In a sense, the roots of environmental field science reach back to the beginning of humanity. As long as people have walked the earth, they have been taking in information about their environment and forging a relationship with it. Although this environmental "science" is very old, environmental field study as a formal academic discipline is relatively new, gaining popularity and depth with the increasing prevalence of environmental awareness and concern.

Researchers explain that the difference between simple nature appreciation and actual research is application of the scientific method of observing, asking questions, collecting and analyzing data, and drawing conclusions. One former NRS reserve manager, Claudia Luke, calls the method "a tool for biting off a small piece of an infinitely vast problem which gives us a glimpse into a mysterious world."

The science method does help researchers grasp some of nature's mysteries, but it also demands weeks, even years of fieldwork. And the process of data collection is rarely glamorous. More often, it is tedious and repetitive — a test of one's patience, stamina, and nerves. It may require staying up all night radio-tracking coyotes or painstakingly sifting through huge mounds of dirt in hopes of finding a few archaeological fragments.

Some researchers resort to guerilla tactics to collect data. Roland Knapp, a researcher at the NRS's Sierra Nevada Aquatic Research Laboratory (SNARL), plunged into his data-quest by snorkeling in half-frozen lakes — which gave him a mammoth ice-cream headache with his whole head as the epicenter. Over two summers he also hiked 800 miles in the thin air of the far back country of the high Sierra Nevada (9,500 to 12,000 feet) to survey declining native frogs and other fauna in a whopping 2,200 lakes and ponds. What he sacrificed in oxygen, he made up for in baggage, oftentimes lugging up to 80 pounds of field equipment. "We have little choice but to push the limits to do the research that needs to be done," says Knapp. "I like the adventure; it keeps us on our toes." (See article page 9: "Native frogs are 'sitting ducks' for introduced predators.")

Despite the challenges, Lisa Levin, a UC San Diego professor, whose research takes her by submarine onto the ocean floor, says her thrills run deep. "I love having the chance to see environments and animals for the first time," she says. "Often it is the first time *anyone* has seen them." For instance, in the Arabian Sea, she discovered large numbers of never-seen-before protozoans the size of golf balls. New to science, these single-cell animals, which she nicknamed "jellyballs," turned out to be an unusual group of gromid.

Discoveries, no matter how small, excite researchers and make them feel their efforts were worth the toil and patience. Says Luke: "There's usually a moment as you work with your data when all the numbers have been run and — wha-bam! You suddenly know something no one else has ever known before, an infinitely small piece of the huge complex puzzle. It's small, but it's new and shiny and wondrous."

Joining science to see the world

For itchy-footed thinkers, fieldwork offers an opportunity (we might even say an excuse) to study elements of nature virtually anywhere in the world. Some scientists, for example, may investigate exotic species that live exclusively in the paradisiacal environment of lush tropical islands — a tough break! On the other hand, fieldwork can present certain hazards unimaginable to those who hold down office jobs: from mountain lions and great white sharks to more pesky nuisances, like poison oak, stinging nettle, and angry bees, and even such anthropogenic hazards as zealous customs agents and travel in politically dangerous countries. Field equipment failures also pose certain risks. Levin recalls the time her research submarine lost power on the ocean floor and slid down a seamount (underwater volcano) in the dark.

Getting grounded in fieldwork

Simply establishing and maintaining a secure field research site can present an enormous challenge, especially in a developed area. Private lands pose a problem. Harrison says: "Every so often I am nervously knocking on someone's door, ready to put on my most harmless and winning smile and ask permission to work on their land." But public lands are a problem, too. Many are grazed, and, in some areas, researchers have returned to their field sites, only to find them newly paved over. Such frustrations originally led UC faculty to press for the formation of the NRS in 1965.

Researcher Bill Thomas (left) digs deep in his study of snow algae. Photo by Topper Thomas

Holding down the 24-hour-a-day job

For some researchers, *where* they choose to work becomes the greatest influence upon their lifestyle. This is especially true if they reside in remote settings and/or extreme environments. For example, some NRS reserve managers (and their families, too) who reside on site — conducting research and the business of running a research site — live off the power grid, rely on solar power and well water, and endure extreme temperatures and high elevations. Most field researchers have put in their time sleeping on the ground and eating out of ice chests. Many eventually feel the need to balance their fieldwork with other aspects of their lives.

Field researchers are generally free from punching a time clock or submitting to the supervisory scrutiny of The Boss. Their schedules tend more to be governed by personal motivation and (predictably) the demands of nature. Costa gave this example: "One time our house visitors were surprised when I went out to Año Nuevo Island on Christmas. But the elephant seals didn't know it was a holiday!" He emphasized that a researcher really needs to be self-motivated. The good news is: a field scientist gets to do a lot of the work on his or her own, without constant supervision or prodding. The bad news (for the unmotivated) is … the same. And Knapp adds this insight: "It can be beautiful or miserable. Sometimes you'll wake up to a beautiful clear sunny day. And some days, you'll wake up in the rain, eat breakfast in the rain, hike in the rain, take samples in the rain, and sleep out in the rain."

Tracking on paper trails

Although field research is based outdoors, it nevertheless involves more deskwork than might be expected: data analysis, write-ups and reports, lab work, library work, substantiating and checking results. Levin explains that in just a few hours or days in a submarine, she can collect enough samples to generate months or even years of processing in the laboratory.

The endless grant proposal writing, another dirty desk job, is a major complaint of researchers. Bill Thomas, a retired scientist who still conducts investigations based at the NRS's

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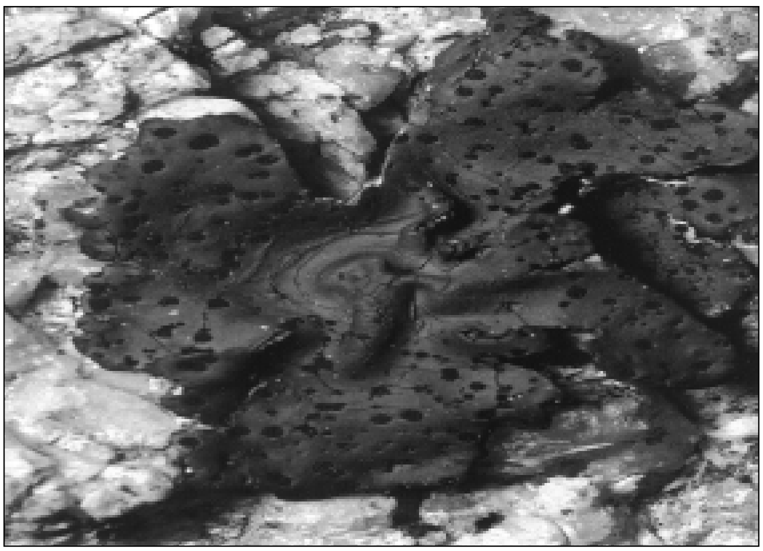
Granite Mountains lichens no longer overlooked

No one knows how many lichens grow in California. Also, no one knows how many lichens *no longer* grow here. To compensate for the scarcity of detailed studies on lichens found in the California desert, members of the California Lichen Society (CALS) visited the NRS's Sweeney Granite Mountains Desert Research Center in the East Mojave to survey that site's species.*

"The reserve has never had an inventory of its lichens," says Claudia Luke, former co-manager of this reserve. "CALS collected and identified lichens and plans to establish a long-term monitoring plot. Because lichens are sensitive to changes in air quality, the plot may reflect those changes over decades."

Lichens come in a variety of colors and grow on soil, rocks, tree bark, and other plants. They are described in three categories: *foliose* (leaflike), *fruticose* (hairlike or shrubby), and *crustose* (crustlike). About 1,000 species have been identified in the state, with 20,000 species estimated worldwide. Although several researchers have conducted extensive studies, no comprehensive catalog of California lichen flora has been published since 1978. (A comprehensive *Catalog of Californian Lichens* was published in 1978. Shirley Tucker, its first author and a co-principal investigator of the Granite Mountains study, is working on a revision with co-author Bruce Ryan.)

This oversight troubles lichen lovers, because it appears that vast numbers of lichen species are disappearing. Their dramatic decline since the early part of this century has been attributed to urban sprawl, agriculture, and pollution. Lichens are not true plants; rather, they are one part fungus, one part alga. The fungal partner (mycobiont) is most often a member of the class Ascomycetes. It is the dominant as well as larger of the two partners, protecting and hydrating the other in a symbiotic relationship that nevertheless tends to favor the fungus. The single-celled algal partner (photobiont), usually of the genus *Trebouxia* or *Pseudotrebouxia*, synthesizes carbohydrates through photosynthesis, which feeds the mycobiont. (Some lichens actually partner not with an alga, but with a cyanobacterium. These lichens are capable of fixing atmospheric nitrogen, just as legumes do.)



Umbilicaria phaea Tuck, a small (about a centimeter in diameter), dark brown, foliose lichen, shown here growing on granite. This common lichen found at the Granite Mountains in Southern California is used for dyes. Photo by Richard Doell

This symbiotic relationship endures some of the harshest environmental extremes on our planet, from frigid high latitudes to heat-parched deserts. Lichens can withstand nearly total desiccation — then spring to life when rehydrated. Ironically, their remarkable hardiness contributes to their undoing: they readily absorb toxic substances (including pesticides and such heavy metals as lead), but have no way to excrete them. Lichens, therefore, turn out to be sensitive indicators of pollution. Founder and past president of the Lichen Society Janet Doell explains: "They are very long-lived, so we can watch them over time and see whether changes in the environment have impacted them."

Lichens also retain radioactive cesium. "Lichens of the genus *Cladonia* are the main winter food of caribou and reindeer," Doell says. "During and following atmospheric nuclear testing, people of the far north who ate reindeer meat were often exposed to excessive amounts of radioactivity. This was also true following the Chernobyl accident." Yet Doell emphasizes that the reappearance of lichens in older cities, such as Paris, and in some cities on the U.S. East Coast is a heartening indication that atmospheric pollutants, such as sulphur dioxide, are being reduced.

* *The report on this survey of the lichens of the Sweeney Granite Mountains Desert Research Center was published in the* Bulletin of the California Lichen Society *(Volume 6, No. 1) in the summer of 1999. Reprints are available.*

In addition to functioning as pollution monitors, lichens are used in fields as diverse as medicine and glaciology. Birds and small mammals harvest lichens for nest building; and the surface of lichens offers habitat to microscopic animals that are capable of surviving desiccation. The ecological significance of lichens in the soil crust community in colonizing rocks, binding soil particles, and decomposing rock faces is just beginning to be better understood. — *PP*

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Lichen Sources

CALS publishes the biannual *Bulletin of the California Lichen Society*. It is also developing a database of lichen density and distribution throughout the state. CALS offers workshops at San Francisco State University and conducts local field trips.

A valuable reference book on lichens is *Lichens of California*, by Mason E. Hale, Jr., and Mariette Cole (University of California Press, 1988).

A useful website on lichens (with references to many other internet sources) has been created by the American Bryological and Lichenological Society (ABLS) at the University of Nebraska: <http://www.unomaha.edu/~abls>.

Red blooms of snow algae ring in the spring high above SNARL

If you have ever been hiking during spring or summer high in the back country of the Sierra Nevada and encountered a patch of pinkish-red snow, then you have probably seen snow algae. What you might not know is that red snow, or "watermelon snow," serves an important role in a microscopic ecosystem in the snowbank.

"Think of it like your lawn," says Bill Thomas, retired staff researcher from the Scripps Institution of Oceanography. "Snow algae make up the meadow of the snow fields." He has been using the NRS's high-elevation Sierra Nevada Aquatic Research Laboratory (SNARL) near Mammoth Lakes as a base for study since 1978. However, his investigations into red snow began several years earlier, in 1969, when he was joined by 200 enthusiastic hikers, skiers, and rangers to survey red snow in the Sierras.

Although Thomas has worked for 44 years at an oceanographic institution and has a long history of research on algae in oceans, he feels most at home on mountaintops. He takes samples from 10,000-foot elevations at Tioga Pass, the eastern entry to Yosemite National Park, and analyzes them at SNARL.

Most of his work focuses on the species *Chlamydomonas nivalis*, the most common of more than 350 species of snow algae. Each *C. nivalis* plant (or "alga") is just a tiny single cell (as opposed to one of its cousins, kelp, a macroalga), and 2.5 million of them can live in just one teaspoon of snowmelt. Snow algae can be found on every continent, including Antarctica, where snow persists until summer. (In fact, Thomas has trekked as far as New Zealand in search of it.) And, although *C. nivalis* turns red when it "blooms" above timberline, it is still considered a *green* algal species. In forested, shady locations, other snow algal species color the snow green, golden, even colorless.

Adept at surviving in both extreme cold and high ultraviolet light, *C. nivalis* has a two-color annual cycle. As snow melts, the red spores from a patch of watermelon snow wash down into the soil, where they rest all winter. Eventually, they are covered by new dry winter snow and subjected to subfreezing temperatures.

The red spores wait until spring and summer, when the snow becomes waterlogged and light penetrable. In response to sunlight, red spores germinate and send out green gametes (male or female sex cells containing one-half the genetic material of a somatic cell). Each green gamete cell has a tail-like flagellum, half as long as the cell, which enables it to "swim" through the watery snow to near the surface. (They only swim 95 percent of the way up, since too much solar radiation at the surface bleaches and kills the green cells.) The green cells reproduce sexually by fusing in pairs to form zygote spores (or "zygospores"). In response to high sunlight and nutrient deficiency, the spores turn red, or "bloom," and the cycle starts all over again.

Thomas and others have discovered that red cells of snow algae have protective "accessory" pigments, like a natural sunscreen, which he compares to autumn leaves. He found these pigment molecules, called mycosporin-amino acids and astaxanthin esters, in solvent extracts from red spores. This protection is important for the survival of red spores, because high-elevation snow fields receive 30 percent more ultraviolet radiation than that at sea level.

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Snow algae

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Found in very high concentrations, these red accessory pigments absorb blue and ultraviolet light and transfer this energy to chlorophyll, which can increase the photosynthetic rate of snow algae by up to 25 percent. The more red spores present in snow, the greater the absorption of both visible and ultraviolet radiation. In general, fresh snow is very reflective and only absorbs approximately 15 to 20 percent of incoming solar radiation (as opposed to a meadow, which absorbs 75 to 80 percent, or an ocean, which absorbs 60 to 95 percent.) However, red snow can absorb considerably more radiation than white snow.

Red snow also contains higher concentrations of bacteria than does white snow. When *C. nivalis* photosynthesize, they excrete 25 percent of the carbohydrates they create. This feeds numerous bacteria. So, although red snow really does look and smell (and reportedly tastes) like watermelon, it should not be eaten.

Bacteria are just the beginning of a food chain based on snow algae. In some parts of the world, red snow also supports insects, spiders, and nematodes, including seething colonies of slim black snowworms one inch long. Even birds can be seen pecking at particles in the snow. Continually fascinated by the ability of tiny plants and animals to survive, even flourish, in such a harsh environment, Thomas says, “I cannot imagine stopping my work on snow algae. It’s what I do for fun.“ — *EMB*

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This bee is a female of a species of the genus *Panurginus* (family Andrenidae). The females of this species of solitary bee specialize in collecting pollen from flowers of *Downingia* (family Campanulaceae), as shown here. Photo by D. L. Briggs

Field of dreams fails? Native bees find no home sweet home at manmade vernal pools

If you build it, will they come? If you bulldoze vernal pools for development, highway construction, and agriculture, then mitigate elsewhere with humanmade vernal pools, will all the species return? Probably not, according to Robbin Thorp, professor emeritus of entomology at UC Davis.

Thorp emphasizes that the vernal pool habitat is both a community and an ecosystem. But, all over California, 90 percent of vernal pool habitats have already been sacrificed, and mitigation attempts have often replaced once-thriving ecosystems with relatively incomplete ones.

“We’re trying to point out to developers that the (vernal) pools are more than just the pools themselves,” says Thorp, who has studied the habitat for thirty years, recently with a former doctoral student, Joan Leong. A vernal pool is characterized by a clay hardpan with a perched water table forming pools in depressions in the topsoil during winter rains. Specialized seeds are adapted to inundation. As the pools evaporate in the spring, the seeds germinate and form a bathtub-ring effect of showy blooming flowers. Some of the plants’ common names — meadowfoam, goldfields, and yellow carpets — reflect their vibrancy.

The plants are dependent for pollination on native bees from upland areas. This fact is often overlooked by developers, Thorp says. In his studies of ground-nesting solitary bees, Thorp found that some specialize exclusively on the pollen of the showy vernal pool flowers. “Their whole lifecycle is tuned and keyed to these plants,” he explains. As solitary bees, the females have no contact with their developing young, and they produce only one generation per year. This makes them very vulnerable to habitat loss and also dooms the plants that depend on them for pollination. Thorp believes this close association of the flowering plants and their host bees has had a long evolutionary history. And while some plants have received protection as listed species, the specialist solitary bees, which keep the plants reproducing year after year, tend to be overlooked by conservation efforts.

Developers who mitigate usually do so by constructing a new pool in another location. Attempting to recreate natural hydrological conditions usually consists of building the hardpan, covering it with soil, and inoculating the new environment with topsoil taken from the original pool and containing shrimp eggs and cysts, and plant seeds. The new pool fills with water from winter rains. “An instant vernal pool,” comments Thorp. But he concludes, “It’s not satisfactory.”

Thorp describes one mitigation located at the interchange of I-80 and Highway 113 at Davis, CA: “A series of pools is full of water in the spring. When the water recedes, you see mostly grasses and some goldfields blooming. But we’ve never found any specialist bees there.” Thorp says that in order for the bees to recolonize, natural vernal pools must be close by. He points out that the nearest viable habitat is 20 miles away at the NRS’s Jepson Prairie Reserve. This is too far for the specialist bees to travel in order to colonize the new site.

“Developers are obliged to monitor the new pools for five years before they are written off as successful or not,” explains Thorp. “But five years is too short, considering vacillations in the environment.” He estimates that at least fifteen years of observation are needed to determine whether essential ecological processes, including pollination, are occurring.

Another mitigation method involves adding pools to an existing vernal pool ecosystem in exchange for destroying them elsewhere. “This way, flora and fauna can easily move into the expanded area from a short distance away,” explains Thorp. But he warns that this method is not ideal, either. “For every vernal pool you create, you’re removing upland area — the habitat for the bees and other organisms, like salamanders, that move out of the pools during the dry season.”

Thorp and Leong urge preservation of the entire physical and biological vernal pool ecosystem and its associated upland areas, rather than simply those few plants that are legally protected.

Their work on vernal pools has been funded by the Department of Entomology, the Institute of Ecology, and the Public Service Research Program at UC Davis; by an NRS Mildred E. Mathias Graduate Student Research Grant; and by the California Department of Transportation. — *PP*

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Beesites

For more buzz on bees, check out the following websites:

• *The world viewed through a honeybee's eyes* — <http://cvs.anu.edu.au/andy/beye/beyehome.html>

• *The Apitherapy Society, including bee-sting therapies* — <http://www.apitherapy.org/aas>

• *“The Wonderful World of Bugs” (consult site index for files containing bee information)* — <http://www.insect-world.com/main/six.html>

• *USDA Carl Hayden Bee Research Center at Tucson, AZ (with information on bee diversity, bee gardens, Africanized honey bees, and online access to the classic USDA publication,* Pollination Handbook*)* — <http://gears.tucson.ars.ag.gov>

• *USDA Bee Biology and Systematics Laboratory* — <http://www.loganbeelab.usu.edu/>

• *The University of Florida's Cooperative Extension apiculture newsletter,* APIS — <http://www.ifas.ufl.edu/~mts/apishtm/apis.htm>

• *Beekeeping (English only)* — <http://www.beekeeping.com/index_us.htm>

• *Beekeeping (English, French, Spanish, and German)* — <http://www.apiservices.com>

One ecologist sheds some light on worldwide decline of frogs by investigating the UVB connection

When scientists speculate upon the ongoing, widespread disappearance of amphibians, they seem to agree there is probably more than one reason for the decline. Blame has been assigned to pollution, habitat loss, nonnative species that eat or compete with amphibians, disease, culinary uses, global climate change, and increasing ultraviolet (UVB) radiation through the thinning ozone layer. It is this last possibility that interests UC Davis-trained ecologist Lara Hansen.

Hansen investigated how UVB radiation affects the embryos and immune systems of *Hyla regilla*, the Pacific tree frog. "All amphibians have vascularized skin through which they have varying amounts of gas exchange," she explains. "Theoretically, this makes them more vulnerable to toxins in the environment." Hansen chose *H. regilla* because of its broad ecological range: it can be found as far south as the southern tip of Baja California and as far north as British Columbia, at elevations that range from sea level to more than 3,000 feet.

Hansen conducted field work at three NRS reserves — Younger Lagoon, Quail Ridge, and the Hastings Natural History Reservation — and at high-altitude sites in the Sierra Nevada. Then, shifting from field to lab, she took *H. regilla* eggs, of both high-elevation and low-elevation populations, to a solar simulator to measure the effects of radiation on the embryonic development. She replicated five levels of UVB: no UVB, subambient UVB, two ambient UVB levels that bracketed the UVB range existing during a noon-time high, and an extremely high UVB level, which Hansen believed would quickly kill the eggs, thus providing her with a positive control.

To her surprise, she "discovered that even with the really high level of UVB, twice what you'd get at ambient, I couldn't kill the embryos." She did find that if she continued the experiment with that same high-level UVB, the tadpoles would die within the next five to ten days following hatching. "But," she said, "I never got significant mortality with the ambient doses."

Pacific tree frog (*Hyla regilla*).
Photo by Lara Hansen

She did, however, uncover sublethal effects of UVB exposure, including disturbed growth rate and relative size. Her decision to compare low- and high-elevation populations had been based on the theory that high-elevation populations are going extinct because of enhanced UVB due to stratospheric ozone depletion. What she found was only the *low*-altitude tadpoles were negatively affected by UVB exposure (in both stage and weight); high-altitude embryos remained unaffected. It may be that high-altitude amphibians are already adapted to high UVB levels.

Next, Hansen examined the egg-mass jellies of *H. regilla* and *Bufo canorus* (the Yosemite toad). She has read previous studies regarding other frog species in which the jelly itself offered photoprotection against UVB radiation. But the jelly absorbed no UVB. "At different levels of UVB exposure, the eggs still hatched, indicating there's something else going on." She suggests they may have adaptive mechanisms like protective pigmentation, a photoprotective compound, or DNA repair mechanisms. Hansen realized that for both *H. regilla* and *B. canorus*, UVB does not seem to be playing a role in the populations' decline — unless, perhaps, it is interacting with contaminants in the environment.

So Hansen returned to the sites where she had captured the frogs to see if she could characterize toxins — for example, as metals or pesticides — in the field. "We know that most petroleum by-products, such as polycyclic aromatic hydrocarbons, are photoactive: they become activated and more toxic when exposed to UV light. But there's still a bunch of other environmental pollutants we haven't tested. When people do run tests in the lab, they find that more and more compounds are activated by UV radiation." But she warns: "If you do just single-contaminant testing, you may never find out what's causing amphibian decline. It probably isn't just one thing. The landscape, locally and globally, is so full of contaminants that it could be a combination of them and have nothing to do with UVB."

Hansen has joined the U.S. Environmental Protection Agency in Gulf Breeze, Florida, where she is studying the effects of UVB on coral. However, she plans to eventually resume her research on the adverse effects of UVB on amphibians. Her amphibian work was funded by the UC Toxic Substances Research and Teaching Program, the World Conservation Union's Declining Amphibian Populations Task Force (DAPTF), the Switzer Foundation (which awarded Hansen its environmental fellowship), the Center for Ecological Health Research at UC Davis, and the Association of Women in Science. — *PP*

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"And why … should anyone care about the plight of the lowly frog? Because frogs are sentinel species that serve as a window on biodiversity and ecosystems. When frogs show signs of distress there is an implicit warning that what is stressing them may well have bearing on humans."

— David B. Wake
Professor of Integrative Biology / Curator at Museum of Vertebrate Zoology, UC Berkeley, and Chair of the Universitywide NRS Advisory Committee
— Andrew R. Blaustein
Professor of Zoology
Oregon State University

Native frogs are "sitting ducks" for introduced predators

A nonnative threat is swimming in high Sierra lakes. "No one ever spent the time or money to study the effects of introduced trout prior to stocking," says Roland Knapp, research scientist from UC Santa Barbara's Marine Science Institute. "So, in effect, fish were put into a 'black hole.'" Unfortunately, the "black hole" turned out to be an aquatic hunting ground rich with the mountain yellow-legged frog (*Rana muscosa*), a California endemic species particularly vulnerable to the predatory trout.

Since 1996, Knapp has used the NRS's Sierra Nevada Aquatic Research Laboratory (SNARL) as a nearby base for studying declining populations of the mountain yellow-legged frog. He teamed up with U.S. Forest Service biologist Kathleen Matthews to complete the most extensive survey of frog habitat: fully 2,200(!) lakes and ponds at elevations of 9,500 to 12,000 feet. The air was thin, but not their data. For each and every body of water, they collected detailed information on frogs, fish, invertebrates, and physical lake characteristics.

The Knapp and Matthews study area comprised one-tenth of the entire high-elevation portion of the Sierra Nevada and overlapped two backcountry areas: the John Muir Wilderness (U.S. Forest Service) and King's Canyon National Park (National Park Service). They found that in King's Canyon, where fish stocking was phased out during the 1970s, frogs still remained in 35 percent of lakes. However, in the John Muir Wilderness, where fish stocking had always been more intensive and continues regularly today, frogs remained in only 5 percent of lakes.

"Many researchers are looking at pollution, UV radiation, and other factors in causing the disappearance of amphibians around the world," says Knapp. "But in this study area, we found that the pattern of decline shown by the mountain yellow-legged frog points strongly to introduced fish as a primary cause."

More evidence that fish stocking has turned into frog stalking is that frogs generally survive only in trout-free lakes. Says Knapp, "When trout enter a lake, they mow through all the easy-to-eat stuff first, namely the frogs." And because so many lakes have been stocked, few safe frog habitats remain. The researchers found that 80 percent of the total water surface area, from large lakes to small ponds — primary frog habitat — has been stocked with brook, brown, rainbow, and California golden trout (*not* the federally threatened Little Kern golden trout).

"If ever a species were vulnerable to trout, it would be the mountain yellow-legged frog," says Knapp. As an adaptation to the cold, the frog spends two to four years as a tadpole before metamorphosing into an adult. When shallow waters freeze during winter, tadpoles are forced into deeper water, where hungry trout lie in waiting. By contrast, another native amphibian, the Pacific tree frog (*Hyla regilla*), has managed to survive the introduction of trout. Tree frog tadpoles stay in the fishless shallows and become adults in one summer. In addition, adult tree frogs spend most of their lives away from water. Mountain yellow-legged frogs, on the other hand, are rarely found more than a few hops from a

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Sitting ducks

Continued from previous page

lake — behavior that makes even adult frogs easy targets for trout and hinders their ability to colonize other lakes, even at relatively short distances. In a study where Knapp eradicated trout from four frogless lakes, frogs reappeared in only the one lake that had a healthy population nearby.

Frogs evolved in the high Sierras in the absence of any fish, so it is not surprising they appear defenseless against the introduced trout. Fish were unable to colonize most lakes higher than about 4,000 feet, the same elevation as Yosemite Valley, because they were unable to swim up the waterfalls taller than 6.5 feet typically found at higher elevations.

Fish stocking in the Sierra Nevada began in the middle 1800s, when settlers transported the fish to easily accessible lakes using milk cans and mules. Stocking intensified and was expanded to the remote backcountry (inaccessible to mules) in the 1950s, when the California Department of Fish and Game started dropping hatchery-raised fingerlings 200 feet out of airplanes. (Fingerlings are small enough to survive the fall.) Even now, each year one million trout are jettisoned into Sierran lakes to support the recreational fishing industry. According to Knapp, trout are reproducing well on their own, and regular stocking of these nutrient-poor lakes frequently results in an overpopulation of trout that are stunted in their growth.

It is not known exactly how many mountain yellow-legged frogs lived in the Sierras prior to stocking. However, in a 1915 study, Joseph Grinnell, renowned co-founder of the UC Berkeley Museum of Vertebrate Zoology, determined that the mountain yellow-legged frog was the most common of all amphibians in the Sierra range. Now, in 1999, the species is likely to be petitioned for listing as federally endangered.

Knapp believes the mountain yellow-legged frog can be saved. He does not advocate the end of all stocking, but rather the establishment of a series of frog refuges by eradicating trout and translocating frogs. He contends that setting aside just 10 percent of lakes, particularly in the backcountry where fishing use is low, could allow the frogs to stage a significant comeback. “It’s not just fish versus frogs,” says Knapp. “For the first time, we have detailed information on the interactions between frog and fish populations, and this information suggests we can make the habitat much better for mountain yellow-legged frogs by removing fish from some lakes while improving the fishery in other lakes.”

Funding for Knapp’s work has been provided by the U.S. Forest Service and the National Science Foundation. — EMB

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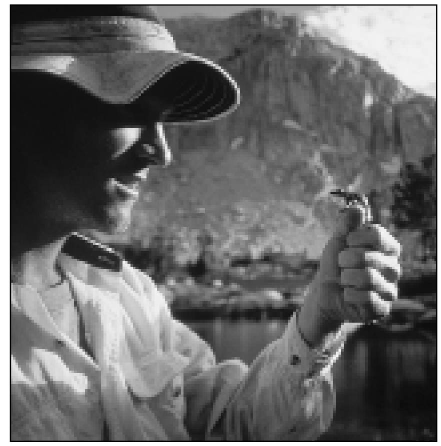

Researcher Vance Vredenburg confronts the subject of his study. Photo by Mary Power

Can frogs smell trouble coming?

Investigating whether the imperiled mountain yellow-legged frog (*Rana muscosa*) can defend itself against hungry trout, UC Berkeley doctoral student Vance Vredenburg used the controlled artificial environment available at the NRS’s Sierra Nevada Aquatic Research Laboratory (SNARL) to monitor tadpole behavior. He was hoping to determine if they are able to use their sense of smell to detect the presence of introduced fish predators.

No one can forget the smell of dead fish. But many do not realize that live fish also leave scent in the water. Odors are released when fish breathe, flushing water in and out of their gills. In addition, they constantly produce a slimy, odoriferous coating on their skin, which continually washes away into the water. Excretions of urine and feces as well leave behind a scent.

Frogs breathe through their skin and smell through their skin. By picking up the predator’s scent, the tadpoles of many frog species, including some close cousins of the mountain yellow-legged frog, employ defense mechanisms to increase their chances of survival. Some react by burrowing into the mud, swimming to a safe area, freezing in place, or even excreting toxins.

Studies in Oregon of the native red-legged frog (*Rana aurora*) revealed that tadpoles exposed to predatory bullfrogs (*Rana catesbeiana*), a nonnative species that invaded parts of the region just fifty years ago, quickly evolved an ability to detect their scent. Bullfrogs still manage to eat many native frogs, but the frogs' evolved olfactory abilities have improved their survival rates. Red-legged frogs that live separately from bullfrogs still seem to lack the ability to smell them.

To test whether the mountain yellow-legged frog has evolved similar olfactory abilities as its red-legged cousin, Vredenburg devised two sets of "flow-through" tanks at SNARL. Each set had a small upper tank that drained through a narrow hose to a large lower tank. Tadpoles, some previously exposed to trout, were placed in both large lower tanks. One small upper tank contained fish; the other did not. All day, every day, Vredenburg pursued the tedious task of monitoring the tadpoles' behaviors. He found that tadpoles in tanks receiving "fish water" (carrying the predator's scent) acted no differently than the tadpoles receiving "clean" water. In similar experiments where tadpoles were placed in the same tanks as trout, they still showed no signs of detecting the fish.

"It's unfortunate, but not surprising, that the mountain yellow-legged frog has not developed an olfactory sense for detecting predators as did the red-legged frog," says Vredenburg. "The main difference is that fish are much more aggressive aquatic predators than the bullfrogs, and bullfrogs have a more varied diet than the fish. The fish eat all the frogs until there are none left. There are no survivors to pass down this defensive trait."

To double-check his findings, Vredenburg repeated the experiments using the frog's primary *native* aquatic predator, the terrestrial garter snake (*Thamnophis elegans elegans*), instead of fish. Since trout had eaten all the frogs in nearby lakes, Vredenburg had to hike 25 miles from SNARL into the backcountry to find a large population of frogs coexisting with garter snakes for the experiment. Upon repeating the test, he found that tadpoles receiving "snake water" reacted by freezing in place. This behavior tricks the snakes, which are visual predators attracted to movement. Says Vredenburg, "A snake could actually swim right over a tadpole and not go for it until it moves around." Hence the frogs that stayed still are the ones that survived, passing along this defensive trait. Frogs and snakes have coexisted in the high Sierras for several thousand years (since the end of the Pleistocene glacial epoch).

(Tadpoles have also learned to avoid native terrestrial predators that stalk them from above, such as Clark's nutcracker. When these birds and other threatening species — including humans — hover over the water, the tadpoles swim away. Consequently, during his studies, Vredenburg had to be careful not to lean over the tanks.)

"The take-home message of my study was that the frogs had evolved mechanisms to deal with native predators, but not these introduced fish," says Vredenburg. "This provides more evidence that yes, indeed, frogs are very vulnerable." — EMB

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Frogsites

For more ribbiting info on frogs and other amphibians, check out the following "webbed" sites:

• *The homepages of the Declining Amphibian Populations Task Force (DAPTF), which operates under the umbrella of the World Conservation Union (IUCN), with links to many other amphibian sites, including current and back issues of FROGLOG, IUCN's Species Survival Commission —* <http://www.open.ac.uk/OU/Academic/Biology/J_Baker/JBtxt.htm>

• *The North American Amphibian Monitoring Program (NAAMP), encompassing the U.S., Canada, and Mexico —* <http://www.im.nbs.gov/amphibs.html>

• *Frogwatch USA, a program of the USGS's Patuxent Wildlife Research Center, "monitoring frogs for fun and science" —* <http://www.mp2-pwrc.usgs.gov/frogwatch/>

• *The Society for the Study of Amphibians and Reptiles —* <http://www.ukans.edu/~ssar/SSAR.html>

One less *Rana muscosa*. Photo by Vance Vredenburg

Millennium falcons: Peregrine recovery research takes wing at NRS sites

The American peregrine falcon swooped off the endangered list on August 20, 1999. Thirty years ago only two breeding pairs were known to nest in California. But by the year 2000, at least 200 breeding pairs will circle the skies above California, says Brian Walton, coordinator of the UC Santa Cruz Predatory Bird Research Group (SCPBRG) at Long Marine Laboratory.

Populations of the world's fastest bird nosedived throughout North America in the fifties and sixties due to widespread environmental contamination by the pesticide DDT. Peregrines absorb DDT from the air, water, and ingested prey and can accumulate high concentrations in their fatty tissues. The stored toxin causes females to lay thin-shelled eggs that dry out or crack beneath the incubating adults.

The Channel Islands, including the NRS's Santa Cruz Island Reserve, still have among the highest levels of the toxin, because a Long Beach DDT manufacturing plant dumped its waste offshore along the Southern California coast. Although the U.S. banned DDT in 1972, residues persist in the environment, so some egg mortality still occurs and the peregrines have not fully repopulated their historic range. Yet successful techniques developed by the SCPBRG for restoring peregrine populations have enabled the raptor to recover sufficiently to be removed from the endangered species list.

"Two NRS reserves — Big Creek and Santa Cruz Island — are both regional centers to the recovery," says Walton. "That's where we figured out about eggshell thinning and the ways populations expand and disperse. All the basic research techniques were developed there, which allowed us to manage the birds everywhere else."

Peregrine falcon. Art by Hans Peeters. Courtesy of SCPBRG

The SCPBRG has successfully bred peregrines in captivity and released them to the wild from "hackboxes" placed on high cliffs.* Open on one side, these protective wooden boxes are modeled after training wagons (or "hack carts") used by falconers in Elizabethan times. Researchers surreptitiously place food in them while six-week-old released falcons use them as bases for learning to fly and hunt.

The research group also performed hundreds of switcheroos by rescuing fragile eggs from wild nests, hatching them in incubators, and reintroducing them to wild foster parents — either peregrine pairs or more common prairie falcons — which raised the chicks as their own. Mountain climbing their way to eyries (cliff-ledge falcon nests), researchers temporarily replaced the real eggs with fake plasterlike eggs until chicks were slipped back in. The fake eggs looked, felt, weighed, and conducted heat the same as real eggs. "Otherwise," says Walton, "the peregrines would know."

Walton's interest in peregrines fledged when he was assigned to write a term paper on the raptors. He was then a ninth-grader attending L.A.'s (aptly named) Aviation High School, which had a falcon mascot. That was when he made his first-ever long-distance phone call: it was to a peregrine expert in Idaho.

"After that call, something clicked in me," he recalls. "I became obsessed." Hunting for even more information, he took his first falcon trip: a nerve-

**A wonderful book on SCPBRG — intended for children, enjoyable by all — is Carol Arnold's* Saving the Peregrine Falcon *(Minneapolis: Carolrhoda Books, 1985). Glorious photos by Richard R. Hewett. See also SCPBRG's award-winning website,* FalcoNet: <www2.ucsc.edu/~scpbrg>.

Surrogate parent and chicks. Photo courtesy of SCPBRG

wracking, six-hour bike ride to the UCLA library alongside the wind tunnel of speeding cars on Sepulveda Boulevard. Later peregrine trips included his honeymoon in 1974, when he and his wife surveyed the coast from San Francisco to the Oregon border. But they found not a single peregrine.

In fact, by the time Walton graduated from high school, only one pair of peregrines was known to nest in California. The nest was on Morro Rock. "So I moved there and enrolled in the local college," he recalls. "I guess that was an odd way for planning my future. But I practically lived at Morro Rock."

Years later, Walton and his family nested for 15 years in the lower quarry of UC Santa Cruz's campus where the SCPBRG built its original bird-breeding facility. This was the next-best thing to his childhood fantasy: "to sit in a high, cliffside eyrie and get the feeling for what a territory was as it lay stretching out beneath and in front of you."

Walton deeply appreciates the dedication of the hundreds of researchers and volunteers who helped raise over 800 chicks in 25 years. "I'm not exactly sure what united us in our passion for peregrines," he says. "You can admire their simple beauty and their dive speeds of 200 miles per hour. That is part of the lure of falcons." — *EMB*

Editor's note: The SCPBRG has also bred and released bald eagles, aplomado falcons, Harris hawks, and state-endangered elf owls. Walton is currently working on a plan to delist the bald eagle, another species that has suffered the effects of DDT. He's also starting a new oiled-bird facility at SCPBRG at Long Marine Lab.

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Peregrine chick. Photo by Brian C. Latta. courtesy of SCPBRG

Peregrine pair prefers to perch on panoramic print

Cities are peregrine habitat, too. The former headquarters of the NRS systemwide office in Oakland — the Kaiser Building — provides year-round digs for one breeding pair: they conduct their hunting forays from the giant blue lettering of the "Kaiser" logo twenty-eight stories up. This "Oakland Reserve" offers a bird's eye view of Lake Merritt, a tidal gathering place for prey of every feather — its five tiny "Duck Islands" being not only the first U.S. bird sanctuary, but in fact the nation's oldest wildlife refuge, established 1870.

Since the late 1980s, the Kaiser couple has nested inside a steel member under the eastern span of San Francisco's Bay Bridge. Another peregrine pair nests under the *western* span and dines in San Francisco. Each breeding season, the Santa Cruz Predatory Bird Research Group (SCPBRG) rescues chicks hatched on the bridge to prevent them from fledging into the bay waters. The SCPBRG also collects eggshells, which are gradually thickening, suggesting that the health of the mother birds is improving.

Every weekday for seven years, Beverly McIntosh, a CalTrans field biologist and long-time bird-bander at the NRS's James San Jacinto Mountains Reserve, has closely observed the Kaiser peregrines from her nearby office window on the fourteenth floor, compiling hundreds of pages of daily notes. Meanwhile, before he moved to UC's new Oakland headquarters on Franklin Street, John Smail, a data coordinator for UC and former director of the Point Reyes Bird Observatory, watched the pair from the *other* side of the Kaiser Building.

Awed by these once-endangered raptors swooping among skyscrapers, McIntosh named the 14-year-old female (now on her third mate): "Her Majesty Our Lady Queen of the Sky." — *EMB*

The real life of field researchers

Continued from page 3

Sierra Nevada Aquatic Research Lab, addressed this aspect of "field" research: "You more or less bounce around depending on funding opportunities. But since I retired in 1988, I've been on hard money for the first time — my pension. Now they call me 'Hard-Money Bill.'" (See article page 5: "Red blooms of snow algae ring in the spring high above SNARL.")

Knowing (and respecting) your limits

No wonder field research is not for everybody. In fact, the research life can really take its toll. One tired and disgruntled researcher, when asked for an interview for this story, replied that his answers would not be appropriate for a positive story on researchers. But he wished me luck in finding others who had a more upbeat view on what he called "the business."

Making friends while "playing the field"

Oftentimes, the social and intellectual context of the people themselves proves to be one of the greatest rewards of a career in field science. At NRS sites, for example, researchers from all disciplines have a chance to get together, share information, and socialize, gaining a broader, interdisciplinary understanding of the reserves and their own research. Levin appreciates the close friends she has made during long sea voyages in cozy submarines — especially when the airlines lose her luggage and her field companions loan her clothing for three weeks. Another researcher quipped that his friendship with his research partner has outlasted any of his marriages!

Living up to higher technological expectations

A variety of advanced technologies — used for DNA analysis, data recording, species tracking, computing, digital graphics, remote sensing, and more — have changed the landscape of environmental research in this century. Dataloggers, once the size of a steamer trunk, now fit in your hand. In many cases, the compass and spiral notebook have been replaced by GPS and GIS. But advanced technologies also create higher expectations. Field researchers can no longer rely exclusively on the knowledge they have acquired in such specialized fields as, say, geology or botany or entomology. In this computer age, researchers must also possess the skills of a mechanical and electrical technician, computer specialist, and data manager.

Asking the right questions

Like on the TV game show *Jeopardy*, the answers in nature are provided before the questions are asked. And when researchers ask the right questions, then understanding follows. Although researchers want their work to make a significant difference for science and the environment, they quickly learn they must maintain a realistic sense of scope, by narrowing down the possibilities and asking focused questions. Mark Stromberg, reserve manager of the NRS's Hastings Natural History Reservation, is working to restore native perennial grassland in Carmel Valley. When he first came to the area, he was dismayed by the patchwork of what he calls "barnyard weeds from Spain" supplanting the rolling hills of native California grassland. "It's like finding a jigsaw puzzle in pieces and no one else notices," he says. "I'd love to figure out how the pieces go together, but maybe I'll settle for just figuring out what the pieces *are*!"

"It can take years to gain an insight, even into a single species," adds UC Berkeley researcher Walter Koenig. For over 25 years, he has lived at the Hastings Reserve, studying the acorn woodpecker. More often found in the treetops than on the ground, Koenig believes that nature itself often picks research projects for you. "In many cases, you simply stumble upon things you didn't have time to see when you were busy focusing on the questions you thought you were interested in at the start," he says. "I often wonder how many people do their two- or three-year projects taking data on a particular aspect, thereby missing everything really interesting that their species is doing behind their backs!"

Some researchers seem to locate their topics by following pheromones, and later they simply cannot explain the almost chemical-like attraction that drew them to these research subjects. "I don't know exactly why my research turned out to be lizards and not, say, ungulates or some other type of animal," says Allan Muth, reserve manager of the NRS's Boyd Deep Canyon Desert Research Center. "I guess it's like you just somehow *know* when you've found the right one."

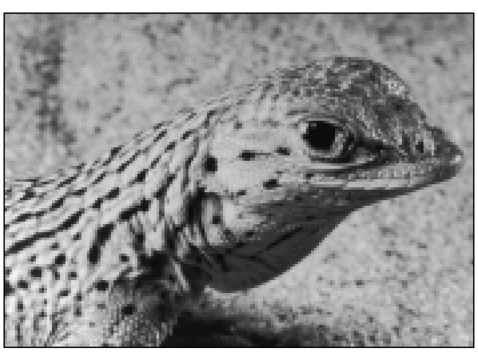
With the limitless complexities in environmental fieldwork, the researcher's job is never done. Bowler explains: "One could spend many lifetimes studying natural habitats, because the more we think we know, the more we realize that there is much more to be learned." And Knapp adds: "For some, realizing that we can never learn everything is part of the attraction. It reminds us there are forces greater than ourselves. Nature puts us in our place."

Answering the call of the wild — and making a life of it

Some scientists seem to have been born with a research gene — or, at least, were called to their work at a very early age. Thomas, who would eventually spend over 40 years as a research scientist at UC's Scripps Institution of Oceanography, began his career on his own while he was still in his early teens. Some people his age had their own garage bands — with his father's permission, young Bill had his own garage *laboratory*. And on the garage roof, he grew experimental bean plants, adding different nutrient solutions to see what would happen. Now in his seventies, Thomas continues to plow through snow algae studies at SNARL.

Other researchers seem to have heard their calling almost by accident. While passing time working a summer job before medical school, Harrison discovered her passion for *field* research while crawling on her belly on the grassy bluff of the NRS's Bodega Marine Reserve. She was assisting former reserve steward John Maron by counting invertebrates and identifying exotic weeds. "Suddenly I had a big revelation," she says. "The two halves of my brain came together — the half that loves nature, thinks it's wonderful, and wants to protect it, and the half that likes to learn, analyze, and discover. That's when I discovered: *this is me*."

Ultimately, most field researchers do what they do simply because they enjoy the life it brings them. Some are motivated by the discoveries they make; others draw their greatest pleasure from the process. "We're just boys who never grew up," says Muth. "There's the occasional eureka, but, you know, we just love lizards. My field research partner, Mark Fisher, and I will be out there in the desert, and it will be a really hot day, and we just look at each other and say, 'You know, we could be in an office right now.' But someone has to do this work, and we love it." — *EMB*



Coachella Valley fringe-toed lizard (*Uma inornata*), looking smug after receiving a couple of decades of research attention from field scientist Allan Muth. Photo by Jim Cornett. Courtesy of The Nature Conservancy (TNC)

Who's where in the NRS?

In a change in NRS administrative structure at UC Santa Barbara, David Coon, director of UCSB's Environmental Health and Safety Office, will serve as administrative advisor for the UCSB NRS. He will also serve as an ex-officio member of the UCSB NRS Advisory Committee, advising that group on environmental health and safety, administrative services, and community outreach. To contact Coon, phone: 805-893-4127; e-mail: dave.coon@ehs.ucsb.edu.

Cristina Sandoval and Kevin Lafferty, long-time stewards of Coal Oil Point Reserve, were recently designated resident reserve directors for that site. To contact them, phone: 805-893-8249 (Sandoval), 805-893-8778 (Lafferty); e-mail: sandoval@lifesci.ucsb.edu, lafferty@lifesci.ucsb.edu.

Virginia ("Shorty") Boucher was selected this summer to become NRS reserve manager at UC Davis. Formerly co-manager of UC Berkeley's Sagehen Creek Field Station near Truckee (1989-1994) and the NRS's Sedgwick Reserve in the Santa Ynez Valley (1994-1999), Boucher is now working with reserve steward Dan Tolson to oversee and develop four UC Davis-administered NRS sites: Jepson Prairie, McLaughlin, Quail Ridge, and Stebbins Cold Canyon. To contact Boucher, phone: 530-752-6949; e-mail: vlboucher@ucdavis.edu.

New to the NRS is Michael Williams, who this September took up the position of resident reserve manager for the NRS's Sedgwick Reserve, a UC Santa Barbara-administered site. Williams has been district botanist for the U.S. Bureau of Land Management in Nevada (1979-1981), manager of UC's Sagehen Creek Field Station (1981-1985), and head of Michael P. Williams Consulting, an environmental consulting firm formed in 1988. To contact Williams, phone: 805-686-1941; e-mail: wyethia@earthlink.net.

Finally, this past spring, two men dedicated to the NRS at UC Santa Barbara were commended for outstanding contributions to both the NRS and UC: Dan Dawson, resident director, Valentine Eastern Sierra Reserve (comprised of the Sierra Nevada Aquatic Research Laboratory and Valentine Camp), for 20 years of extensive service in every conceivable aspect of site management and development; and Wayne Ferren, director of Carpinteria Salt Marsh Reserve and associate director of the UCSB NRS, for managerial excellence, including creation of an award-winning management plan for his site. To contact them, phone: 760-935-4334 (Dawson), 805-893-2506 (Ferren); e-mail: dawson@icess.ucsb.edu, ferren@lifesci.lscf.ucsb.edu.

Message from the NRS director

Continued from page 1

place on an alarmingly large scale — most notably, climate change, ozone depletion, widespread irreversible losses in biodiversity, and fragmentation of ecosystems. These changes pose dangers to the health, the economic welfare, and, indeed, the long-term survival of human civilization.

Approaches to solving environmental problems encounter a tangle of poorly understood scientific, sociological, and economic issues. Concern is growing both within the scientific community and among the general public. The Sustainable Biosphere Initiative (SBI) of the Ecological Society of America (ESA)* states that "among the most critical challenges facing humanity are the conservation, restoration, and wise management of the Earth." There is consensus that we understand far too little of the functioning of the biosphere, but, paradoxically, that the successful management of the biosphere must be science-based.

In this context, the NRS is a treasure. Its diverse reserves offer researchers unique opportunities for manipulative research, with secure sites for long-term monitoring of environmental change. The reserves are also the field laboratories for the training of many graduate and undergraduate students — the future stewards of the biosphere.

Yet this treasure — the NRS — remains poorly equipped for the challenges of its increasingly important, multiple missions. Its physical facilities, staffing, and graduate-student support are bareboned. The vision for the immediate future of the system is constrained by these realities. The NRS must rapidly garner support for the construction of adequate research and instructional facilities at a number of sites, increase the budget for staff and resident researchers, and significantly increase fellowship support for field studies by graduate students.

The investment required is modest relative to that currently contributed by society to other research and educational endeavors. The rewards are likely to be appreciably greater.

— *Alexander N. Glazer*
Director, Natural Reserve System

* *The ESA was founded in 1915; the SBI office was established in 1992.*

Transect

Autumn / Winter 1999 • 17:2

Transect is published biannually by the Natural Reserve System (NRS), part of the Division of Agriculture and Natural Resources (DANR), in the University of California Office of the President (UCOP).

Subscriptions are free, available upon request. Contact: *Transect* Editor, Natural Reserve System, University of California, 1111 Franklin Street, 6th Floor, Oakland, CA 94607-5200; phone: 510-987-0150; fax: 510-763-2971; e-mail: jennifer.bello@ucop.edu.

Recent *Transect* issues are also available for viewing on the World Wide Web at: <http://nrs.ucop.edu>

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