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Title
Transect

Permalink
https://escholarship.org/uc/item/49k7d48b

Journal
Transect, 28(1)

Author
UC Natural Reserve System

Publication Date
2010-07-01

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The NRS
Transect

University of California Natural Reserve System
Office of Research and Graduate Studies —
Division of Academic Affairs

Summer 2010 • Vol. 28, No. 1

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Salamander art (above) by Margaret L. (Peg) Herring

View from Sentinel Dome in Yosemite National Park. Photo by Eric L. Berlow

Yosemite hosts new NRS field station — guided by a far-sighted vision

The first NRS reserve to be administered by the University of California's tenth and newest campus — UC Merced — holds major significance for this Central Valley institution of higher education. Officially known as the Sierra Nevada Research Institute's (SNRI) Yosemite Field Station, the site, with its location within one of this country's most spectacular national parks, has enhanced public perception of the young campus, helping to attract high-quality faculty and students.

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Eric Berlow, the Yosemite Field Station's first manager, explains: "Student tours [of UC Merced] always mention the Yosemite Field Station because they realize it's a big selling point. Faculty members do the same thing with grad students. Even Chancellor Kang is very aware, and proud, of what we have going on here. The partnership with Yosemite National Park is intrinsic to the campus's evolving image."

A site's symbolic value and its role as a functioning field station are two very different things, however. Berlow and SNRI Director/UC Merced Professor of Engineering Roger Bales have been working hard since the field station was established in 2006 to make sure the reality matches the vision. Bales, a noted hydrologist, already has a major research presence in the southern Sierra Nevada that focuses on processes across the rain-snow transition in the area's mixed-conifer forests. From his perspective, the Yosemite Field Station is important because it is near one of the five ground-based instrument clusters he and his colleagues have installed to study mountain water flow (see <https://snri.ucmerced.edu/CZO>).

Berlow has focused on expanding the programs and facilities at the field station itself, which is located within the historic village of Wawona (<http://www.yosemitepark.com/Accommodations_WawonaHotel_History.aspx>), just inside the park's south entrance. As a long-time field researcher with experience working at stations such as the University of Washington's Friday Harbor Laboratories (<http://depts.washington.edu/fhl/>), UC's White Mountain Research Station (<http://www.wmrs.edu/>), and the Rocky Mountain Biological Laboratory in Colorado (<http://rmbl.org/rockymountainbiolab/>), Berlow came to his current position with a specific vision of what made these sites special.

"My PhD was in marine biology, and I did a lot of work at Friday Harbor," Berlow recalls. "I remember that, within ten minutes of arriving at the lab, I would be having really great discussions with people about their research, getting new ideas, bumping into professors and having conversations you wouldn't normally have on a campus because everyone was too busy. In my mind, field stations are places where you go for an extended period and change your pace of life. You get a lot done, but you also have time to interact more with colleagues and students, and that's critical."

Upon reaching Wawona in 2006, however, Berlow realized that the available facilities wouldn't be sufficient to support a vibrant research community. The station was fine as a base for field research that involved collecting samples or making measurements, but it lacked sufficient housing. The original facilities provided by the park included a manager's residence; an historic house and stable that had been refurbished to serve as an office, meeting room, and work space; and a third house for a single visiting group.

Berlow realized that lack of adequate housing would prevent him from hosting the critical mass of scientists required to foster informal conversations, long-term research projects, and interdisciplinary collaborations. Working together with park personnel and park partners, they were able to add and restore five more homes near the station. Today he can offer housing for groups of up to 40 in comfortable guesthouses that are much more than the rustic dorms found at many reserves. UC Merced's Facilities Maintenance staff has remodeled the dated houses to provide a comfortable environment for a wide range of users: from student groups on a weekend field trip, to researchers accompanied by their families who are there for an extended research stay, to faculty groups working on proposals or holding a multiday retreat.

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Field station office at Yosemite. Photo by Eric L. Berlow

Tenth campus UC Merced stewards its first NRS site

Last year, the UC Regents approved the addition of the Sierra Nevada Research Stations: Yosemite Field Station to the UC Natural Reserve System. This action gave UC Merced its first NRS reserve — and brought the NRS's total number of sites statewide to 36.

Sentinel Dome at Yosemite National Park. Photo by Eric L. Berlow

Located in the historic Wawona Village just inside the south entrance to Yosemite National Park, the Yosemite Field Station is well situated to serve researchers and instructors in Yosemite National Park and the Sierra National Forest, providing access to more than 1.2 million acres of federally protected land. The site's location on the western slopes of the central Sierra Nevada range also fills in a major gap in the NRS's coverage of critical habitats throughout California.

Roger Bales, a professor at UC Merced and the director of the Sierra Nevada Research Institute (SNRI) — a suite of field stations, one of which is the Yosemite Field Station — views the inclusion of one of his sites in the NRS as a major development both for UC Merced and for the entire UC system of ten campuses. "The addition of the Yosemite Field Station to the UC NRS signifies our strong commitment as a campus — and as part of the UC system — to develop a sustainable presence in the central Sierra Nevada," he said. "Being a part of the NRS will strengthen UC research in this critically important region."

Opened in 2006, the Yosemite Field Station features offices, a laboratory, and a classroom/meeting room, all located in a refurbished historic house and stable, as well as overnight lodging for up to 40 visitors in six nearby (former) vacation homes. The field station already supports a wide range of research projects focusing on climate change, mountain and snow hydrology, invertebrate biodiversity, alpine meadow ecology, wildlife conservation ecology, and fire ecology.

A number of programs and funding sources are also available to support student participation at the field station. SNRI fellowships, for example, are available annually for artists interested in "scientific visualization," whether their focus is painting, photography, dance, or music (see <https://snri.ucmerced.edu/snri/wawona/programs.html>). The Yosemite Leadership Program is "committed to developing environmental leaders for today and for the future" (see <http://ylp.ucmerced.edu/>) and offers summer internships that give UC Merced undergraduates an opportunity to participate in research programs. The NSF-funded program entitled Research Experiences for Undergraduates (REU) (see <http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5517&from=fund>) provides independent research opportunities for undergraduates nationwide and has already awarded grants to a number of students working at the Yosemite Field Station.

Programs for younger students are also beginning to emerge at Yosemite. Adventure Risk Challenge (ARC), a leadership and literacy program originally developed at the NRS's Sagehen Creek Field Station, has already adapted its curriculum to the new site. ARC provides unique outdoor leadership and English literacy training for high school-age English Language Learners who have demonstrated leadership potential (see <http://www.arcprogram.org/home.html>).

For more information on the Yosemite Field Station, visit the NRS systemwide website page on this site: <http://nrs.ucop.edu/Yosemite-Field-Station.htm>. Or go to the SNRI-Yosemite Field Station page at: <https://snri.ucmerced.edu/snri/wawona/index.html>. — *JB*

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The power of interns

With the facilities coming together, Berlow next turned his attention to attracting users, both researchers and educators. Though many people in the park were excited about the opportunity to collaborate with University of California faculty, others were taking a wait-and-see attitude. Wanting to produce some tangible results quickly, he decided to focus on education.

When he visited the Merced campus, Berlow had been impressed by the diversity of its student body. He also knew the National Park Service was facing a real challenge throughout the country in recruiting ethnically diverse rangers and staff who would reflect the shifting demographics of park visitors. The two situations were a perfect match. "Together with the park education branch chief, the chief ranger, and the Yosemite Conservancy," he says, "we set up an internship program that gave UC Merced students the opportunity to work throughout the park, including visitor interpretation and education. Because the campus is so diverse, those student interns who speak Spanish, Hmong, and other languages proved especially valuable as bilingual interpreters for presentations at the Mariposa Grove. When park officials realized they had a resource in these interns, they began hiring them into summer jobs as seasonal rangers."

"The parks are really concerned about the lack of diversity in their ranks," Berlow continues. "It's not for lack of trying. They struggled with how to tap into these communities.

Giant sequoias in the Mariposa Grove — five miles from the Yosemite Field Station. Photo by Tobias Luthe

So these students — many of whom grew up less than two hours away from Yosemite, but had never visited — are now excited about the park. They go home and tell their families how beautiful it is, and they bring their families for a visit. This has really helped to solidify our relationship with the park staff. Where once we had to push interns on them, now they're fighting for them."

Beyond science

Seeking to attract a wide range of users to the field station, Berlow also established a Scientific Visualization Fellowship (<https://snri.ucmerced.edu/snri/wawona/programs.html>). Art has been a major influence in his life, and he loves to promote interaction between artists and scientists. "The neat thing about the Scientific Visualization program," he notes with a smile, "is that we created it out of nothing. We really had nothing to offer but the name *Yosemite* — a powerful lure — and a free place to live. At first, there was no stipend or anything. Someone at an NRS managers meeting had told me about the 'fake it 'til you make it' approach, so I designed an application for a 'highly competitive' internship. Now we've carved a bit out of our budget so we can offer the artists a stipend. That definitely makes it more attractive, and today it truly is a 'highly competitive' fellowship."

A major focus of the Scientific Visualization program is to get scientists — and ultimately the public — to think about their work in new ways. "One element that really interests me is bringing in an outside perspective

El Capitan in wintertime. Photo by Eric L. Berlow

by having an artist-in-residence who helps scientists communicate their results more creatively to the general public. So we specifically seek to recruit artists who are interested in working with scientists."

The concept for the fellowship was originally inspired by the Scientific Illustration Program at California State University, Monterey Bay (formerly at UC Santa Cruz). However, as the program has grown, it has expanded to include a wide range of artistic disciplines. "There's such a tradition of landscape art at Yosemite, it's hard to do something new," Berlow notes. "So we've branched out, hosting an avant-garde dance presentation and a number of musical performances. It's exciting to see how it's evolving."

Last summer's artist-in-residence was Patrick Cress, a San Francisco Bay Area musician, composer, and sound artist who accompanied Berlow on a number of research trips to alpine meadows. Berlow observes: "The Nature Sound Society in Emeryville provided some amazing high-quality recording equipment, and the results were really interesting. As a scientist, I'm trying to understand things rationally, looking for patterns, counting things, and so forth, and it was great to see what kinds of things piqued his interest. In the end, he took the sounds he had captured in the meadow, sampled them, looped them, layered them with saxophone and bass clarinet, and created pieces that were much more about the experience of being in this wilderness. It was a really nice complement to scientists who try to understand the wilderness so they can figure out the best ways to protect it. Patrick's completed piece, *Yosemite Soundscapes*, was more: 'Here's what it feels like to be out here, here's the mood it evokes."

Berlow is hoping Cress will return this summer to collaborate on a public presentation: "Our idea is that I will give a more scientific talk on meadows, climate change, and Yosemite toad decline, and he'll do a musical piece on sounds from the meadows. We'll use the two presentations to elicit discussion from the audience about how those approaches evoke different ideas, and the tension between the rational and the emotional approach to being in nature."

Another element in Berlow's vision is building a strong outreach program for primary and secondary schoolchildren. As part of his K-12 effort, he is helping to expand the ARC (Adventure Risk Challenge) program at the Yosemite Field Station. First established at the NRS's Sagehen Creek Field Station on the eastern slope of the northern Sierra Nevada near Truckee, ARC is an outdoor leadership and literacy program that targets high-potential secondary students whose families do not speak English as their first language (see "Summer at Sagehen Reserve Transforms Teens Through Program of Adventure • Risk • Challenge," in *Transect* 23:2 (2005), pp. 7-13; <http://nrs.ucop.edu/Transect/TR23.2%20PDF-full%20issue.pdf>).

"It has taken a lot of work to piece together funding from existing programs to get ARC going at Yosemite," Berlow notes, "but it's such a life-transforming experience for the students — 92 percent of ARC participants pass the English language arts portion of the high school exit exam (compared to 40 percent of English language learners statewide), and 77 percent are attending college — and the link with Yosemite is a natural. UC Merced, given its demographics and its interest in reaching students from the Central Valley, is totally excited about having a bigger presence in the area's

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Students in the Yosemite Field Station ARC Program (clockwise from upper left):

- *"Bears on Fire" stop for a water break at Eleanor Lake in Yosemite National Park;*
- *Bebe San, from the San Francisco Bay Area, is slowly lowered down after a long rock climb on the east side of the Sierra Nevada;*
- *ARC's innovative curriculum links wilderness to academics, adventure to leadership, identity to literacy, and confidence to activism;*
- *Ernie Rubio, from Santa Barbara County, cooks dinner for the group during an expedition;*
- *ARC participants learn essential team-building and conflict-resolution skills during a one-day ropes course activity.*

All photos courtesy of ARC, reproduced with permission (<www.arcprogram.org>)

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high schools. ARC Director Jennifer Gurecki has done an amazing job of building relationships with new schools, establishing trust, and detailing curriculum standards. We're now building on the Sagehen program by having UC Merced students mentor participants while they're in the park. Combined with field trips to campus, these efforts make the ARC students realize that college is a real option."

Building the research program

All of this effort to promote educational use of the Yosemite Field Station doesn't mean that Berlow is less interested in building the

research focus that is at the heart of all strong field stations. Rather, he well understands that fostering research is a longer term process.

While the opportunity to work at an iconic national park might seem an attractive proposition to a layperson, many researchers see potential problems. From past experience, some are leery of the permit and approval processes required by the park service. Also, historically, major cultural issues have arisen between agency researchers, who face a multitude of pressing management issues, and academic researchers, who pursue less applied work. Many UC faculty already have full research schedules at existing sites, so the idea of expanding their research programs to a new site is not that attractive, despite the beautiful scenery and opportunities for investigation.

Berlow is addressing these issues in a number of different ways. First, he is continually contacting potential researchers and has visited college and university campuses throughout the state to talk to groups about the Yosemite Field Station. And once he finds interested researchers, he helps them understand and navigate the park's permitting process. As new graduate students who are able to take advantage of the historical data and ongoing measurement programs near Yosemite come to UC, more UC faculty will become involved.

Second, Berlow has maintained his own role as an active researcher working in mountain meadows. He explains: "I have a joint appointment as a research scientist with the USGS (U.S. Geological Survey), so I have collaborators through those projects. As I'm actively doing research in the park, I'm also building a relationship on the science side, so agency scientists realize that UC Merced is a resource, that we have things to offer them, and that we're looking to engage with them to find solutions to management problems. If we're not doing something that's really hitting their needs, it's not because we don't want to — it's because we don't know about it. And we're willing to work with them."

A great first step to attracting faculty researchers is to target their students. "We've been targeting undergraduates, as well as graduate students and postdocs, rather than professors, because they're open to looking for new projects," says Berlow. "The National Science Foundation's program, Research Experiences for Undergraduates (REU), has been a huge draw to get faculty interested in working at Yosemite, because these are small grants that get the faculty on board. Once they get some preliminary data, the professors realize, 'Hey, this could actually go somewhere.' And they've already gone through the process of writing a permit, so they realize it's not such a big deal. And now that I've built a relationship with USGS in the park, other sources of funding are available that are not usually available to professors. So now we can say, if you partner with a USGS scientist or a park scientist, there are these other pots of money that you could get to support your graduate students. Then they're all excited to collaborate."

The Yosemite Field Station is currently experiencing an influx of graduate students interested in working on environmental issues in the park. This summer four new graduate students and a postdoc are at the station to advise REU students on their projects with the goal of using this work as a seed for their own future research and PhD projects.

A new kind of field station

Since it opened in 2006 as an SNRI UC Merced facility, the Yosemite Field Station has gained momentum with each succeeding year. From those first days when even ordering office supplies was a chore because the young campus had not yet established any business procedures, Berlow now finds himself ever closer to realizing the vision that he and Roger Bales have for the station.

Berlow explains: "We have the advantage of starting a new reserve with a contemporary approach that's larger scale to help researchers collect a mix of both field data and virtual data to support today's multiscale

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Gaylor Lakes in Yosemite National Park. Photo by Eric L. Berlow

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Yosemite Valley in summertime. Photo by Eric L. Berlow

initiatives. People like Roger and the students in his research group have less need for a really nice facility to hang out at. What they want most is access to a lot of places, storage space for their equipment, and Internet access for themselves and for distributed sensors that remotely stream data to a central node. Their interest in a field station is much more virtual than a traditional field ecologist. So SNRI is trying to straddle the two worlds by having some traditional field station hubs with resident scientists and some more virtual field stations offering a network of points with a combination of instrumentation and access."

In pursuit of this goal, Berlow and Bales just received more than $400,000 from NSF to renovate the historic stable next to the Yosemite Field Station office and turn it into networked office space. "Part of the idea is that we really need to push contemporary research," Berlow explains. "We don't need more areas to sort samples and put them in drying ovens. We need cyber-infrastructure so that people working in the field can download data and work with remotely sensed imagery to visualize it, so they can plan their next trip. They want to be able to pull data off the sensor network and make decisions based on that information. So this is part of being a different kind of field station that embraces the eco-informatics side of things. But then we also have a place that is quiet during the off-season, and we want to build it so it can be like an NCEAS at UC Santa Barbara, a center for synthesis and collaboration and data analysis. Just because a field station is in a beautiful place doesn't mean it should only be used for collecting field samples. It can also be an inspiration for more conceptual activities. Instead of having a workshop on campus, you could have it at Yosemite. We're trying to build the station so it will be a place you'd like to go in winter to do more collaborative retreats."

Great gray owl. Photo by Eric L. Berlow

Berlow extends an open invitation to the entire UC community to help him build a vibrant intellectual center at the Yosemite Field Station, whether their interest is in life sciences, physical sciences, social sciences, or the humanities. He says: "I really want to get across the idea to the University community that this place is here for them. They don't have to be collecting invertebrates in the streams. They could be working on a collaborative grant proposal. It's a legitimate use of the facility if their work is enhanced by walking through the mariposa grove as they work out their problems. That's a very legitimate use of the place." — *JB*

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A few words from the director of the NRS

The United Nations declared 2010 as the *International Year of Biodiversity*, initiating a year-long effort to celebrate life on Earth and promote worldwide awareness of the importance of biodiversity in our own lives. Central to this program is the UN's invitation to become involved in efforts to protect, restore, and revere life on Earth. As newly designated director of the UC Natural Reserve System, I am delighted to lead the NRS as a collaborator in the International Year of Biodiversity.

Countdown 2010 is the consortium of organizations throughout the world that support the UN's 2010 biodiversity initiative (<http://www.countdown2010.net/>). As signatories, these partner organizations must commit to specific efforts to tackle the causes of biodiversity loss. The NRS has therefore promised:

1. To provide 36 protected natural areas, encompassing more than 135,000 acres, where scientists can assess and monitor biodiversity in California's key ecosystems.

2. To support university-level instruction in the field sciences by providing protected study sites and on-site facilities for faculty and students from around the world.

3. To promote awareness of biodiversity issues through NRS-hosted education programs that reach thousands of California K-12 students. (These efforts include programs designed specifically to introduce low-income and inner-city children to the natural world.)

4. To fund and support undergraduate and graduate students using NRS sites to research questions related to ecosystem biodiversity.

5. To initiate the development of a centralized California Seed Bank facility at an NRS reserve in consultation with experts from the Royal Botanic Gardens, Kew Millennium Seed Bank, West Sussex, United Kingdom. (The purpose of this initiative is to collect and preserve the seeds of native California flora for use in restorating California's floral biodiversity.)

6. To host public events at NRS reserves and UC campuses in order to increase general awareness of the biodiversity crisis and the fact that California is identified as one of the world's "biodiversity hotspots."

7. To highlight biodiversity issues and the UN's International Year of Biodiversity in NRS publications and web content.

8. To foster the wise stewardship of natural lands by enhancing communication between University research scientists and public/private managers of natural areas throughout the world.

Celebrating biodiversity is not a frivolous enterprise. Recent statistics (2009) from *The IUCN* (International Union for Conservation of Nature) *Red List of Threatened Species* indicate that at least 16,928 species of fauna are facing possible extinction (<http://www.iucnredlist.org>). Globally, this represents 21 percent of mammals, 12 percent of birds, 31 percent of reptiles, 30 percent of amphibians, and 37 percent of fish. And a new IUCN report, *Global Biodiversity Outlook 3*, suggests there are:

> *several key reasons as to why the challenge of conserving and indeed enhancing biodiversity remains unmet. One key area is economics: many economies remain blind to the huge value of the diversity of animals, plants, and other life forms and their role in healthy and functioning ecosystems, from forests and freshwaters to soils, oceans, and even the atmosphere.* [<http://www.cbd.int/gbo/gbo3/doc/GBO3-final-en.pdf>]

The NRS is proud of its multifaceted role in the conservation of California's natural heritage and is proud to be a signatory to the UN's Countdown 2010. In a world where so much is working against protecting and promoting global biodiversity (including the ongoing environmental tragedy that continues to afflict the Gulf of Mexico), NRS reserves are currently hosting more than 50 research projects directly related to biodiversity science. NRS reserves are also hosting key educational programs on biodiversity issues, especially for underserved schoolchildren. A quick scan of individual reserve websites brings this point home (links via: <http://nrs.ucop.edu/>.)

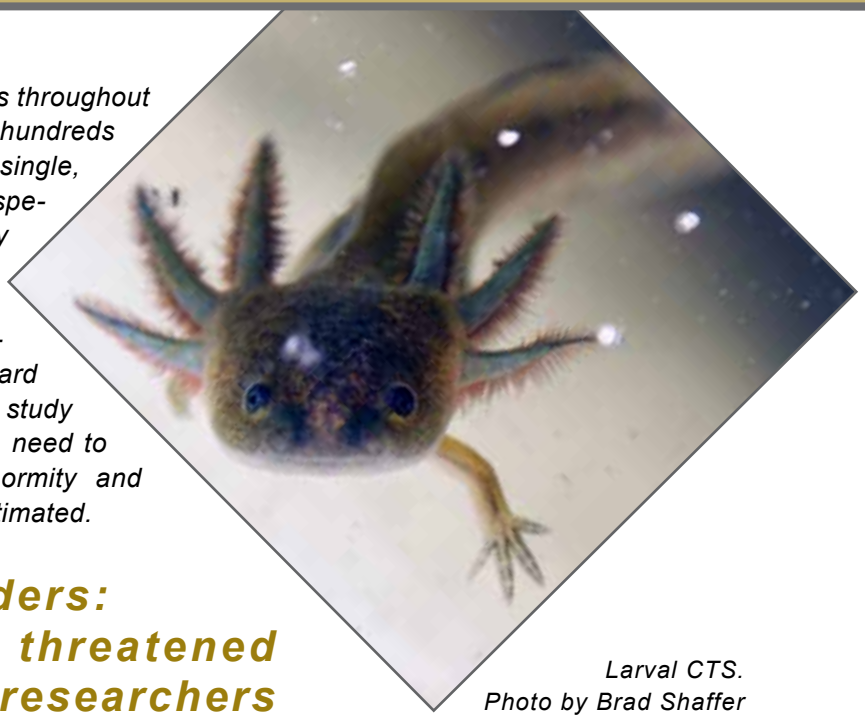
As director of the NRS, I am working across the UC system to ensure continued commitment not only to the UN's biodiversity goals, but also to the NRS mission:

> *To contribute to the management of the Earth and its natural systems by supporting university-level teaching, research, and public service at protected natural areas throughout California.*

I welcome any and all suggestions and ideas, as I anticipate a long-lived and world-class partnership.

— Peggy L. Fiedler, Director
UC Natural Reserve System

Editor's note: The NRS conserves critical habitats throughout California where researchers and students study hundreds of species. The following article focuses on a single, long-term research team working with a single species: the California tiger salamander. While every investigative situation differs in its details, this piece will give readers some idea of the difficulties involved in studying biodiversity, both generally throughout a region and specifically with regard to an individual species that is already difficult to study in the first place. Though we often speak of the need to conserve/manage/promote biodiversity, the enormity and complexity of the endeavor must not be underestimated.



Larval CTS.
Photo by Brad Shaffer

California tiger salamanders: The secret life story of a threatened species revealed by NRS researchers

California tiger salamanders (*Ambystoma californiense*) have a striking appearance. Adults, which grow up to 10 inches long, have stocky black bodies dotted with creamy yellow spots. Unfortunately, few people ever see this California native because of its extremely secretive lifestyle and the fact that its range is limited by access to isolated seasonal ponds.

Such characteristics also make these amphibians remarkably difficult to study. Hovering at the extreme edge of suitable salamander habitat, they have adapted to California's long, dry summers by spending almost their entire lives underground in small-mammal burrows. They emerge only on a few rainy nights each year to change burrows or migrate to nearby ponds where they mate and lay eggs.

John Edward Gray, Keeper of Zoology at the British Museum in London, England, wrote the first general description of the species in 1853, based on a specimen submitted by a collector. However, it took the better part of a century for Tracy Irwin Storer, founder of the zoology department at UC Davis, to follow up in 1925 with a paper that outlined the animal's habitat and lifestyle. By then, agricultural and urban development throughout the state was so far advanced that large portions of the species' original habitat — grasslands and foothills with access to long-lasting vernal pools — had already been compromised.

That was about the extent of our knowledge of California tiger salamanders (or CTS, as researchers often call them) when newly hired faculty member Brad Shaffer arrived at UC Davis in 1987. Shaffer had studied tiger salamanders in Mexico as a graduate student and was interested in finding out more about the California species. "At the time, we knew incredibly little about CTS," he recalls. "Bob Stebbins [UC Berkeley zoology professor Robert C. Stebbins] had sounded an alarm in a white paper that the species was in trouble. And I had done some molecular work that showed it was a valid species — there had been some question about that — and evolutionarily distinct from the other 14 species in the tiger salamander complex. But, beyond that, we knew very little."

For his first sabbatical, in the fall of 1991, Shaffer, his wife, and his two-year-old son moved into a cabin at the NRS's Hastings Natural History Reservation in Monterey County, where he worked with Walt Koenig, a long-time research scientist at the reserve, to establish a CTS research project. "Walt and I set up the first drift fence at Blomquist Pond on the Oak Ridge Ranch, adjacent to the Hastings property," Shaffer explains, "and I started marking salamanders as they came in to breed."

Though it takes a lot of work to build drift-fence arrays, they have proven to be one of the most effective tools for sampling populations of small animals in an open environment. In this case, as the salamanders moved between their burrows and the pond, the fence blocked their movement, diverting them to pitfall traps spaced on the inside and outside of the fence. Each morning,

Shaffer or a colleague would check the traps to measure, tag, and release each captured animal.

When Shaffer began his work at Hastings, scientists knew relatively little about the population biology of any amphibian in the western United States. Elsewhere, amphibian declines were becoming a huge issue, and he wanted to establish a multiyear, population demography study to complement similar studies being conducted in the eastern United States. It soon became apparent that this would not be an easy task, because California tiger salamanders are not only secretive — they are also very long-lived. Most individuals don't become sexually mature for four years, and many live ten years or longer. This meant that any study intending to get a true sense of their population dynamics must also be long term.

Walt Koenig's involvement in the project proved critical at this juncture, because he lived at the reserve and could supply a steady stream of field assistants. "Walt was tremendously important in helping to keep the monitoring going year after year," Shaffer recalls. "He provided time for his field assistants (mostly undergraduates who lived at Hastings) to check our pitfall traps every day. I got down there when I could, and I contributed a little money to pay them, but Walt's input was incredibly important."

Several years into the study, Pete Trenham, a new graduate student in Shaffer's group, took over the Hastings project. "Pete matured the study into a multisite project," Shaffer observes. "He summarized our old data, collected a great deal of really important new data, and really matured the system."

Through radio-tagging, Trenham discovered that the animals were moving up to 250 meters (nearly 274 yards) away from the ponds each spring, but the technology was limited. "The devices were installed surgically," Trenham explains, "and they lasted only as long as the batteries lived. So if you began tracking them at the end of the breeding season, you could follow them only during the first three months of dispersal. And it turns out, they don't breed every year, so that made it even more difficult."

The transmitters were also relatively heavy and could be installed only in adults. This was frustrating, because Trenham suspected the juveniles might be traveling a lot farther than the adults. "They don't become sexually mature and migrate back to the pond for four years," Trenham explains. "So they're spending that time in the uplands, gradually moving further and further away from their original pond." Tantalizing clues slowly built a case for Trenham's idea. He began seeing tagged salamanders visiting multiple ponds. Juveniles were regularly being caught in small mammal traps on other portions of the reserve, and CTS roadkill were occasionally found far from any known ponds.

"Our early focus was really on getting general population parameters," Shaffer explains. "Basic things, like: how long do they live? what is the survival rate? how often do females breed in their lives? how far do they move from the pond where they were born? Pete's work with radio-transmitters gave us the ability to track individual animals, and that gave us a lot of good information."

The challenge of working on private land

Just as the team was getting answers to their first sets of questions, they discovered another major difficulty in studying their chosen subjects: virtually all prime California tiger salamander habitat throughout the state is privately owned, which means that researchers' access can be denied at any point. Ten years into the Hastings study, the owner of the Oak Ridge property told the team they could no longer work on his ranch. "We had to leave," Shaffer recalls sadly. "It was devastating after all that time, but we had no choice."

Needing a site where they could securely conduct a long-term, landscape-scale study, Shaffer and

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Adult CTS emerging from burrow. Photo by Vide Ohlin

CTS: The secret life story

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Trenham focused on another NRS site, the Jepson Prairie Reserve. This 1,566-acre remnant of the native prairies that once covered most of California's Central Valley is owned by the Solano Land Trust, protected by the land trust and The Nature Conservancy, and co-managed by UC Davis. The reserve protects Olcott Lake and one other large vernal pool, both of which evaporate each year, making them perfect habitat for California tiger salamanders.

At Hastings, the team had worked with drift fences that completely surrounded the main pools. But Olcott Lake was too big to encircle, so they built a fence along a portion of the lake, then added additional fences at 50-, 100-, 200-, and 400-meter distances away from the pond edge. "Our goal was to get a sense of salamander movements in the uplands," Trenham notes, "and when we found salamanders moving around at 400 meters, we built another fence at 800 meters — and we still found them." His suspicion about the mobility of juveniles also received new confirmation when tagged juveniles were found in traps a kilometer — 1,000 meters — away from the nearest pond.

"Using large arrays of drift fences, like the ones we have at Jepson, was a key innovation that has proven invaluable," says Shaffer. "It's a lot of work. Each morning, we have to walk something like 14 kilometers (about 10 miles) just to check the fences. However, it has provided us with some of the most valuable, unique information available on the age-specific dispersal of the animals."

Long-lived study for long-lived creatures

Shaffer and his colleagues have now worked on CTS for more than two decades. The longevity of these investigations has been critical to enabling deep understanding of such secretive, long-lived animals. Over the years, Shaffer has worked diligently to keep his studies going, piecing together funding during dry times and regularly finding new money for expanded studies. In fact, he recently received funding to continue his work at Jepson for an additional three years.

Drift fence, set up in a field and ready to direct on-the-move salanders toward the can (or pitfall) traps at its end. Photo by Adam Clause

During Shaffer's two decades of CTS research, a generation of graduate students and postdoctoral researchers has passed through his group, contributing to the studies both in the field and in the genetics laboratory. Chris Searcy is the latest graduate student to continue Shaffer and Trenham's pioneering fieldwork using the drift-fence array at Jepson Prairie. One of his foci is getting a better sense of CTS density and the extent of their range. Having fences at ten different distances allows Searcy to calculate the density of salamanders at each distance and then use regression lines to estimate their distribution farther out. "Currently, we're still catching a lot of CTS one kilometer from the pond edge," he notes, "which leads us to project that they are going out 2 to 3 kilometers (2,000 to 3,000 meters). That range is a bit problematic," he admits, "because it is a projection. We don't have any traps out that far, because it's off the edge of the reserve, but it's probably a pretty good estimate of how far they're traveling. Other teams have seen a few individual CTS that are up to 1.3 miles (well over 2,000 meters) from the nearest breeding pond that anybody knows about."

Recently, Searcy has begun using pattern-recognition technology to follow individual salamanders. Each time a team member captures a CTS, he or she takes a photo of the animal's body. Because every adult CTS is marked with a unique pattern of spots, the software can identify individual salamanders and how many times they've been captured. "This tells us that an individual can move a specific distance in a particular night," Searcy explains. "We know they need to spend a certain amount of time in ponds to breed … and, on either side of that, we know how many rainy nights are available for movement… . So, from that, we can estimate how far that

CTS would move throughout the season. And it seems like just over 2 kilometers (2,000 meters) is very reasonable, because they can go 180 meters in a single night without getting exhausted."

Even getting an estimate of population size can be difficult. "The hard thing about figuring out the population size is that it's hard to separate real change from just a detectable change, since you only find them when they're on the surface," notes Searcy. "We know that the amount of rain affects the population, because if the ponds dry out too early, then there's no recruitment. All the larvae die if their pond dries too quickly, because they need three months to get the energy in order to metamorphose. The year of 2006-07 was a really dry one. The pond dried out by mid-April, so there weren't any recruits. Then you lose a whole year of young, and that obviously has an impact on the overall population."

Searcy is also studying the CTS larvae in the ponds to see what impact their presence or absence has on the densities of the other creatures living in the ponds. "Since they are the top predator, they should have a pretty large effect on everything else," he notes. "Similar experiments with eastern tiger salamanders found that they have a very large effect on that community. The tiger salamander larvae eat both large and small invertebrates, but they prefer the larger ones. When the salamanders are present, they keep the invertebrates at low-enough densities that there is a lot of algae, and the algae in turn keep the level of phosphorus low. When the salamanders are removed, the number of invertebrates goes up, especially the large ones, while the amount of algae subsequently decreases due to consumption by the invertebrates, and thus the amount of phosphorous can increase. In short, you have a three-level trophic cascade, with the salamanders directly influencing the invertebrates, then indirectly affecting the algae and inorganic nutrients below that."

To get at these questions, Searcy has built a series of pens in the vernal pools at Jepson Prairie. Some of these pens are exclosures from which he's removing CTS larvae; others are enclosures to which he's adding additional larvae; another set consists of control plots in which he's not changing the numbers at all. The experiment is just getting under way, and Searcy doesn't have any results yet, but already he knows one thing: managing the enclosures and exclosures requires a lot of work. "Designing and maintaining these enclosures and exclosures has been my biggest problem throughout grad school," he admits. "Something always goes wrong. The problem at Jepson is that it's so windy. As soon as you tie the cloth to the rebar, it rubs against the metal in the wind and gets holes from the wear."

Searcy is just now in the planning stage for a new three-year grant that will continue after he receives his PhD in 2011 and begins work as a postdoctoral researcher. "I'm really interested in the major size differences in the metamorphs from year to year," he explains. "Some years, the average mass of all of the metamorphs in a cohort is 6 grams, while in other years the average mass is 15 grams. That is the variation between the average of entire cohorts, so there is even more variation between individuals within those cohorts."

This size difference can have a critical impact on the rest of the salamander's life cycle. Larger juveniles have a higher probability of surviving into adulthood, and they disperse farther from the pond. Rather than conducting this experiment in the field, Searcy will set it up on campus using 40 to 50 water tanks, each with a capacity of 300 gallons. "We'll have different larval-density treatments, different prey-density treatments,

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CTS researchers in the field: (left) Brad Shaffer. Photo courtesy of Brad Shaffer (above) Chris Searcy. Photo by Jerry Booth

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and different water-temperature treatments," Searcy explains, "and see what combination of those factors creates this difference in how big the larvae are when they emerge."

The genetics perspective

As director of the UC Davis DNA Sequencing Center, Shaffer has long balanced his team's fieldwork with genetics studies that have been critical in supporting the team's conservation efforts. Eighteen years ago, in 1992, Shaffer wrote the first scientific justification for obtaining federal and state protection for the California tiger salamanders. Opponents held up the listing for years, and one of their arguments was that the species couldn't be endangered because it ranged over such a large territory.

In response, Shaffer's team did a genetic analysis of CTS from different parts of their range. The results were illuminating. "We found that that there were at least three, and possibly as many as six, distinct population segments that can and should be managed separately," Shaffer explains. "This finding formed the foundation for treating the Sonoma and Santa Barbara populations as 'Distinct Population Segments' separate from the rest. It also taught us about the role of habitat fragmentation over the last million years in California and how it impacts species like CTS."

When the genetics work revealed that the Santa Barbara and Sonoma populations were distinct, Shaffer was able to make the case that these isolated populations were especially threatened and required a higher level of protection, because their territories were extremely limited and under intense pressure from development. This analysis has led to the federal designation of the Sonoma and Santa Barbara populations as endangered, while CTS in the remainder of their range are considered threatened. State designations have not been finalized; however, the Fish and Game Commission approved similar protections earlier this year. "From a science perspective, it was absolutely clear that the species should have been listed back in 1992," Shaffer maintains. "The science behind the listing just kept piling up as more populations were lost. Our understanding of the area required by a healthy population increased in size as our work at Jepson developed. And the scope of the hybrid invasion of non-native genes in the Central Coast region grew ever larger. Eventually, as the case worked its way through the courts, the science also became more convincing. However, it has always required a lot of strong science to back up a listing, and probably during the wait, the science did accumulate to help the case."

The hybrid invasion to which Shaffer refers is a more recent threat to CTS throughout their range. In the 1960s, a Salinas Valley bait dealer brought in a supply of barred tiger salamander (*Ambystoma tigrinum mavortium*) larvae — a related, but distinct species from Texas — and dumped them into local ponds. The imported larvae proved to be excellent bait, adapted well to their new environment, and soon started breeding with the native CTS. Where most animal hybrids are not able to sustain themselves, these hybrids thrived and spread their genes throughout much of the native CTS population. Genetic studies initiated by Ben Fitzpatrick, a former student who is now on the faculty at the University of Tennessee, Knoxville, and expanded by Jarrett Johnson, a postdoctoral researcher in Shaffer's lab, revealed that hybrid salamanders possessing a mix of native and non-native genes grew more quickly, attained larger size, and could move farther than native CTS. Another team member, graduate student Maureen Ryan, then conducted further analysis that revealed the hybrids also tend to be more active and efficient predators with, in general, a higher level of fitness than the entirely native salamanders.

Fitzpatrick and Johnson have both been instrumental in tracking the spread of non-native genes through the CTS population. Their recent work has focused on "super-invasive" genes that are charging across the entire range at a truly impressive rate. This invasion is of extreme concern to Shaffer. "We need to better understand, at a mechanistic level, why some genes do so well in hybrids compared to others," he notes. "It is at the core of trying to control the hybrid invasion, and I'd like to understand it better."

Genetic analysis has also helped the team understand landscape-scale issues. "We developed tools that allowed us to study the movements of salamanders across local landscapes using genetic approaches — so-called landscape genetics," notes Shaffer. "Ian Wang, a PhD student in the lab, has taken a leading role in much of that work, allowing us to compare observed movements from the field to inferred movements from the analysis of genes." As an example of this type of work, Shaffer cites Wang's least-

cost, path-analysis work that reveals that CTS in coastal Monterey County are much more likely to cross chaparral — a prickly, spiny vegetation type that a human would hate to walk through — than they are to cross grassland or oak woodland.

Future studies

For over two decades, Shaffer and a host of colleagues have transformed our understanding of California tiger salamanders. Yet Shaffer's quest to know more only seems to grow, and he finds that new questions continue to arise. This ongoing avalanche of questions promises great fodder for future PhD theses, increasing the chances that future generations will learn to co-exist more successfully with these secretive salamanders. — *JB*

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Researcher Chris Searcy and his assistant, Shawn Lockwood (wearing cap), at Jepson Prairie Reserve, working with an enclosure and seine in a vernal pool to capture and examine immature California tiger salamanders.
Photos by Jerry Booth

Documenting a fossorial lifestyle

What have Brad Shaffer and his colleagues discovered over the past two decades about the lifestyle of the California tiger salamander (CTS)? Plenty. Graduate student Chris Searcy describes a typical year that starts with the first November rains: "By December, the ponds start filling, and the adults emerge from their burrows and migrate towards the water. The males arrive first and wait. Once the females arrive, the males do a courtship dance to attract a mate. If a female is interested, she follows directly after the male who walks one body length, puts down a spermatophore (a sperm capsule), and walks forward another body length. She follows him and stops so that she's positioned right above the spermatophore, which she picks up."

"The salamanders have internal fertilization," Searcy continues, "so the female fertilizes her eggs and then distributes them around the pond. Most salamanders of this group lay a huge cluster of eggs in one mass. But CTS lay one or two eggs at a time, attaching them to twigs and grass across the bottom of the pond. Each female lays about 800 eggs, and once she lays them, she leaves the pond. The males leave after the females. Altogether, the females spend three weeks in the pond, the males spend about six weeks, and all of the adults are back in their burrows by the end of February."

The life cycle of a California tiger salamander (CTS) resembles that of a frog: hatching in freshwater, beginning life as a fully aquatic larva with gills, growing limbs and reabsorbing its gills as it gradually develops sufficiently to leave the water and live on land as a mature, air-breathing ambiphian: (above) an "adolescent" CTS with four legs, but still living in the water and breathing with gills; and (below) a land-dwelling adult CTS. Photos by (top) Adam Clause and (bottom) Jerry Booth

The timing of the adults' return to their burrows is a subject that intrigues Searcy. "They're always gone by the latter half of February," he observes. "Even if it rains after that, they're not active. I think it must be because, in some years, it really doesn't rain after the end of February, so not being in your burrow by that time is really risky. CTS must have some other sense — maybe it's day length — but it tells them that by this time of year they need to be back in their burrows."

After returning to their burrows, the adults remain underground pretty much all of the time. "They only come up to the surface on rainy nights, because that's the time when it's wet and cool enough for them to be active on the land," notes Searcy. "Most salamanders are more active because they live in much wetter environments. The highest diversity of salamanders in the world is found in the mountains of North Carolina, where you get 20 species living sympatrically [all in the same geographic area], but it's woodland and they get 80 inches of rain per year. Jepson gets something like 19 inches, while in the Central Valley down near Fresno, they get 12 inches, all concentrated in a particular part of the year."

Searcy picks up the story of the eggs the females have left behind. "After two to three weeks, they hatch out into larvae that have external gills and tail fins. At Jepson, the larvae spend three to four months in the pond, feeding on daphnia and tadpole shrimp (a large, one- to two-inch, endangered crustacean). In other parts of their range where there are no tadpole shrimp, I think they pretty much eat anything they can fit into their mouths. I'm about to do some stomach-pumping studies in other areas, so we'll have a better idea about that soon."

This is the stage of the CTS life cycle that ties them so closely to vernal pools or isolated stock ponds. The larvae spend the next three to four months intensively feeding in the ponds. Crayfish, fishes, and other introduced predators that would prey on the larvae

can't survive in seasonal pools that dry out each season. "The ponds are great resources," explains Search, "because they're filled with little crustacean prey that allow the larvae to grow really fast. They [the salamanders] hatch out really tiny, but in three to four months they get up to three to six inches."

An adult female CTS, diving down a burrow. Photo by Chris Searcy

This year has been very wet, and the vernal pools at Jepson were remarkably full. But, in most years, the ponds dry down quickly, and by mid-May, the larvae are ready to metamorphose into salamanders. Again, the consistency of the timing amazes Searcy. "It doesn't matter whether breeding occurs in December or February; somehow the larvae start to metamorphose in mid-May. We think it's probably because, during the winter, the pond is really cold, so it's only in the spring, when the water warms up, that all the development happens. So as long as the pond doesn't dry up before then, the salamanders start metamorphosing – they reabsorb the gills and lose the fin on their tails. When they're done, they look pretty much like small adults but they don't have the spot pattern yet. They're just sort of a mottled gray color."

The first CTS start leaving the ponds on May 15, give or take a few days, and they continue coming out until the ponds dry. "The bigger individuals tend to come out first," Searcy says. "The smaller ones wait until the very last second when they have to get out before the water is gone. This is the only time in their lives that they have to walk across the ground when it hasn't rained, and it appears to be a high-mortality event. You can't count on a rain event in May or June. During the middle of the day, it could be 80, 90, or even 100 degrees. So a few come out each evening, even if it hasn't rained the night before, and they need to get to a burrow. If you walk the shoreline at that time of year, you find dried-out salamanders that didn't make it."

The juveniles spend the hot summer months underground in their burrows. Then, once it starts raining again in the fall, they often move farther away from the pond, apparently in search of a better burrow. This process also amazes Searcy. "I always wonder how they find the burrows," he says, "because each one seems like a small target, and if you watch them, there's no sign that they know where they're going. But they must have a way of finding it, because they do. I also don't know how they find their way back to the pond each year, because, at a salamander's height, they obviously can't see it. Most salamanders use some sort of olfactory cue, so maybe they smell it."

The average juvenile CTS spends four years maturing before it's ready to mate, though some larger individuals are ready sooner. How do they spend those years? "You still catch them moving around on rainy nights," notes Searcy, "but I'm not sure if that's to switch burrows or to forage for food."

So what do CTS do underground in the burrows all those months and years when they're not being seen? Scientists once thought they were estivating (a "summer sleep" or animal dormancy, similar to winter hibernation), but today they're beginning to think the salamanders are more active. "I don't see any reason why they wouldn't be active and hunting things down there," argues Searcy. "A lot of insects would fall into the burrow or use it as a refuge, so a CTS could catch plenty of food without having to come up to the surface. In general, they have really low metabolisms, so they're probably not burning huge amounts of energy and are probably as active as salamanders ever are when they're not making a migration. I would think they would move around and hunt in the burrow system." —JB

An adult CTS, exposed on a wet and sandy bank. Photo by Peggy Fiedler

Endangered frog released in native habitat at NRS site

The endangered mountain yellow-legged frog took a major jump toward recovery on April 15, when scientists reintroduced its eggs into its former habitat at the NRS's James San Jacinto Mountains Reserve. This first-ever reintroduction was carried out in collaboration with the U.S. Geological Survey (USGS), USDA Forest Service, U.S. Fish and Wildlife Service, and the San Diego Zoo's Institute for Conservation Research. The James San Jacinto Mountains Reserve, located near Idyllwild in Riverside County, was selected for the reintroduction because this protected area contains ideal frog habitats that occur within the species' former range.

Once common throughout much of Southern California, the mountain yellow-legged frog has been decreasing in numbers since the 1970s, due to what scientists call the "perfect storm" affecting frog populations around the globe: decreasing habitat, increasing pollution, invasive species, the spread of the deadly chytrid fungus, and the effects of climate change. Today only a small wild population of less than 200 individuals can be found in the San Gabriel, San Bernardino, and San Jacinto Mountains.

In 2006, scientists collected mountain yellow-legged frog tadpoles from the remaining wild populations in the San Jacinto Mountains and took them to the San Diego Zoo's Institute for Conservation Research where, for the first time, specialists were able to establish a captive breeding program for the species. This year's reproductive season at the zoo was so successful that scientists decided to go forward with a reintroduction into the wild.

There are 61 mountain yellow-legged frogs at the San Diego Zoo's Institute for Conservation Research. In January, scientists attempted to spur breeding by placing half of that population into coolers, mimicking high-mountain winter conditions. The chill induced the frogs to hibernate. When the frogs were taken out of their coolers in early April, they displayed breeding behaviors within a few days.

Assessing the experimental procedure of frog-chilling, the institute's Research Coordinator Jeff Lemm said: "It has been wildly successful, and as a result, we could reintroduce about 500 eggs into the San Jacinto Mountains."

The mountain yellow-legged frog is one of three Southern California frog or toad species on the federal endangered species list. USGS biologists carried out the initial phase of the reintroduction, releasing egg masses into deep permanent pools. They will release additional tadpoles later this year, then closely follow the success of the reintroduction. It will take two years for the tadpoles to morph into adults. However, as this is not a migratory species, the frogs are likely to stay in the creek within the bounds of the protected James Reserve where they can be easily monitored. — *JB*

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Editor's Note: In June and July, Becca Fenwick, director of the James Reserve, issued updates on this reintroduction effort: "The eggs have hatched. We got about 40 tadpoles from around 600 eggs," and "I just heard that the USGS is planning on releasing an additional 50 tadpoles mid-August." The James Reserve's "Creek Cam" can be accessed at: <http://www.jamesreserve.edu/webcams/creek/creek1.html>.

(Above) Scientists reintroduce mountain yellow-legged frog eggs at the James Reserve.
(Below) The first eggs hatch!
Photos by Becca Fenwick

New leadership called to serve at NRS systemwide

As 2009 drew to a close, Dr. Alexander Glazer returned to full-time research after serving for twelve years as director of the NRS. When 2010 began, the NRS set sail with a new leader at its helm: Dr. Peggy L. Fiedler.

Dr. Fiedler earned her BA from Harvard University in 1976, then went on to receive an MS and a PhD from UC Berkeley in Wildland Resource Science, concentrating in the field of plant evolutionary biology. She joined the faculty at San Francisco State University and was promoted to full professor in 1997. At SF State, she initiated the first Conservation Biology master's degree program of its kind in the United States.

In 2000, Dr. Fiedler left SF State in order to become more directly involved in hands-on conservation, working as an environmental consultant in rare plant protection and ecosystem restoration. In this capacity, she led or co-led multidisciplinary teams in the design, permitting, and implementation of multimillion-dollar restoration projects. She worked extensively with federal, state, and local governments, large corporations, architectural and law firms, non-profit organizations, and individual landowners.

Dr. Peggy L. Fiedler became director of the UC Natural Reserve System in January 2010. Photos (left) by Catherine Watters and (above) by Stephen D. Hopper

Dr. Fiedler's research on California species of *Calochortus* (Liliaceae) and her writings on the more theoretical aspects of conservation biology have earned her an international reputation as an authority in conservation biology and rare-plant ecology and management.

She has written two textbooks on conservation biology, has held long-term editorial positions with two major conservation professional journals, *Biological Conservation* and *Journal of Conservation Biology*, and has a long list of refereed journal articles, reports, and book chapters on conservation issues. Dr. Fiedler is a Fellow of the California Academy of Sciences and a Fulbright Senior Scholar.

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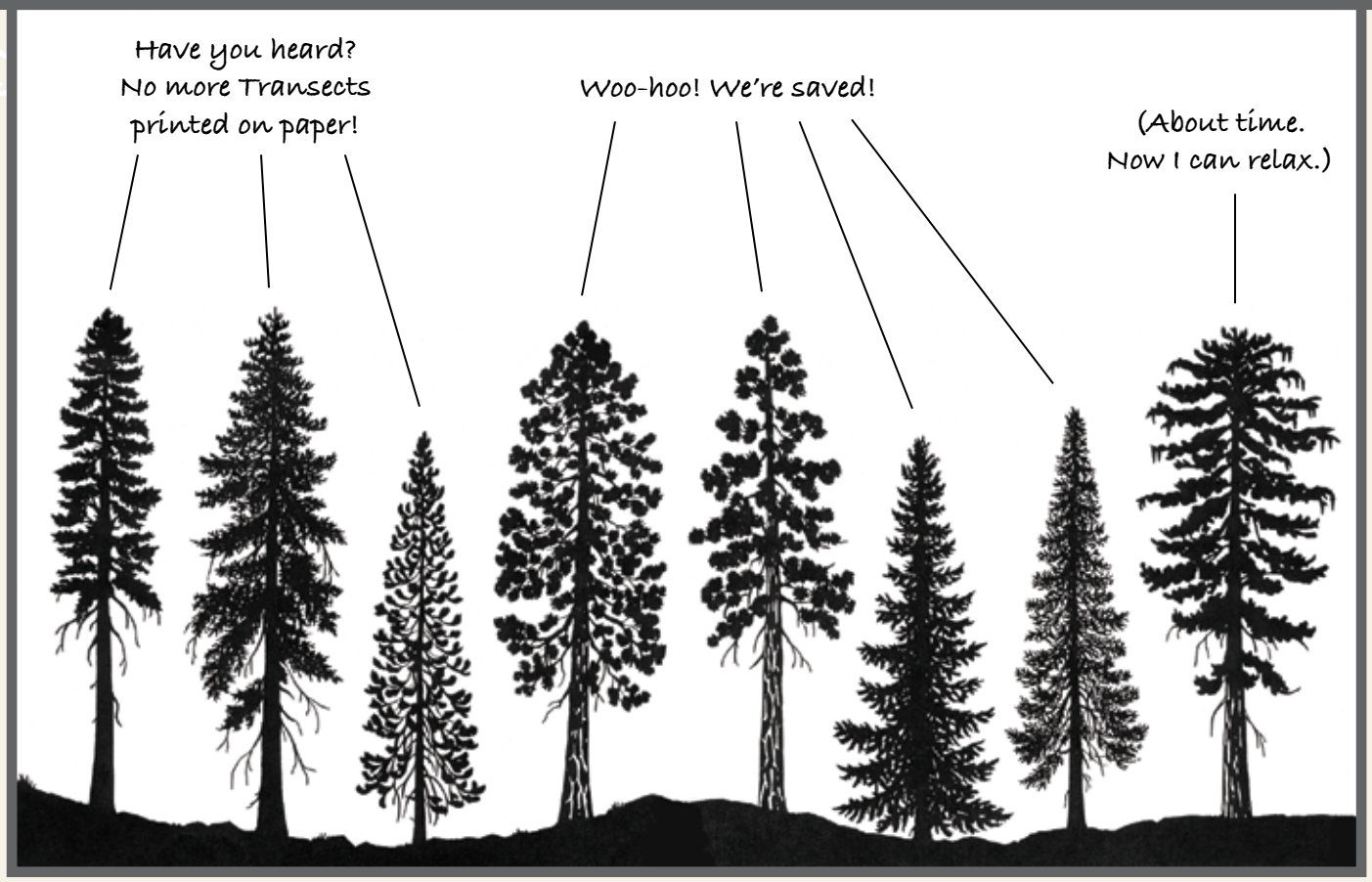
Alexander N. Glazer, international authority on blue-green algae and DNA sequencing, has been a UC faculty member since 1964, first at UCLA's School of Medicine, Department of Biological Chemistry, and later, since 1976, at UC Berkeley's Department of Microbiology and Immunology. In 1997, he was chosen to lead the NRS; he continued as NRS director through 2009. Dr. Glazer is professor of the graduate school in UC Berkeley's Department of Molecular and Cell Biology and co-author, with Hiroshi Nikaido, of Microbial Biotechnology: Fundamentals of Applied Microbiology *(1994, 2nd edition 2007) a textbook used by universities in the United States, Canada, England, and Japan. Dr. Glazer became a fellow of the American Academy of Arts and Sciences in 1996 and the California Academy of Sciences in 1999. In 2001, he was elected to the National Academy of Sciences (NAS), considered one of the highest honors that can be accorded a U.S. scientist or engineer. Photo by Jane Scherr*



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Since the first issue was produced in 1982, the NRS Transect *has always been free of charge and available upon request. It is still free, but now it is* ***available online only****, via the UC Natural Reserve System website:*

<http://nrs.ucop.edu>

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**Jerry Booth, NRS Senior Science Writer since 2001, retired from the University of California in June 2010, followed by best wishes for the success of all his future endeavors from his many colleagues throughout the reserve system.*

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