

A phylogenetic tree and map of genetic divergence in a desert spider species complex. The tree represents how different genes at particular sites in the genome diverge between two related species. The map shows that divergences between the two species are concentrated along the Colorado River.

See endnote.

H. BRADLEY SHAFFER

## Field of Genes

A conservation genomicist looks at nature

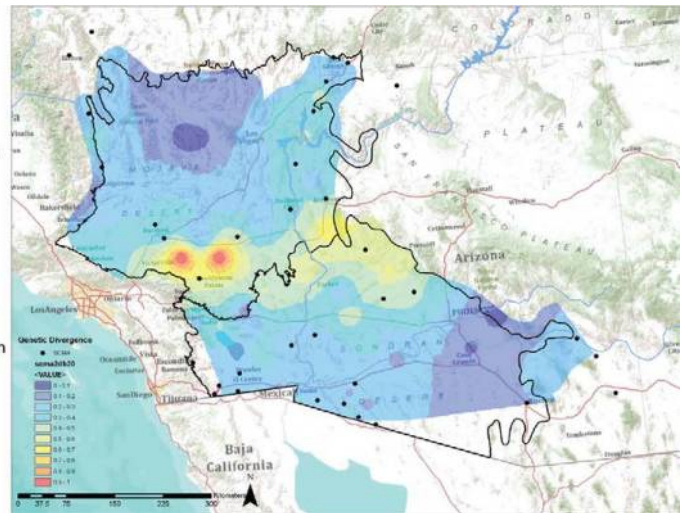
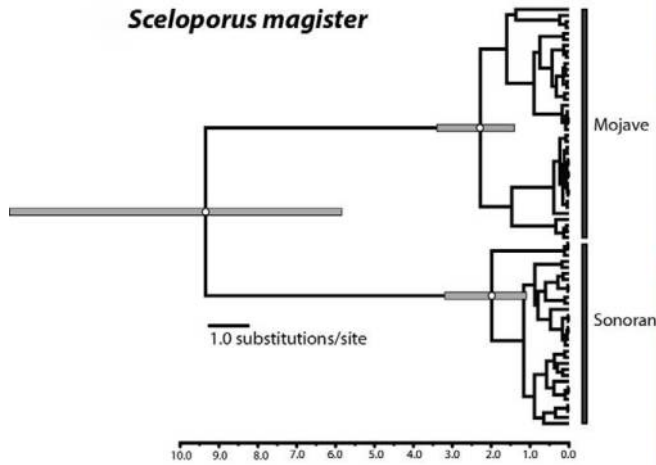
I am a herpetologist. I'm a lifelong fan of reptiles and amphibians. It's how I was born. And now I study them.

I am also an evolutionary biologist and a conservation biologist. I'm fascinated by how animals evolved to mesh with their ecosystems, and I hope that I can help conserve them to keep them from going extinct.

I am also a genomicist. Genomics is genetics on steroids. Geneticists often study animals one gene or a few genes at a time. Genomicists study lots of genes all at once, sometimes whole genomes—all of the genes in a single organism or species—and sometimes the genomes of multiple species in an ecosystem.

I like to think about the stories that plants and animals can tell me—with a little help from their genomes—about where they came from, how they make a living in

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A phylogenetic tree and map of genetic divergence in desert spiny lizard populations. The tree and map represent how different genes at particular sites in the genome diverge between populations in the transition zone between the Mojave and Sonoran Deserts. See endnote.

nature, and why they do the things that they do. By thinking about organisms as both players in their ecological communities and as bags of DNA that can be analyzed, I see a different view of the world around me and the animals I love. Thinking about genomes may seem like a stark, scientific vision of nature at odds with a love of the outdoors. I see it as an incredibly exciting view that allows me to ask very specific questions of plants and animals, and get answers back. The effect can be pretty amazing.

Evolutionary biologists since the mid-twentieth century have realized that to understand how plants and animals adapt and evolve one has to understand the environmental challenges they face and how, genetically, species have changed in the face of those challenges. Genetics helps us understand how the fittest parents pass on their features to their offspring and, therefore, how lineages and populations adapt to environmental changes over time. Genomicists use some new tools and fancy computer programs, but we still build on basic genetic information to understand how animals and plants survive and breed in their habitats. Like geneticists, we care about how evolution occurs and enhances survival. Unlike traditional genetics, genomics allows us to understand evolution at multiple levels.

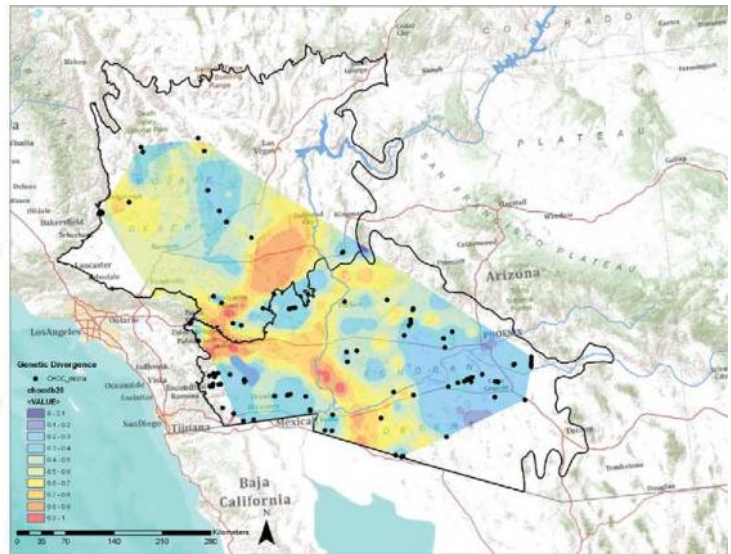
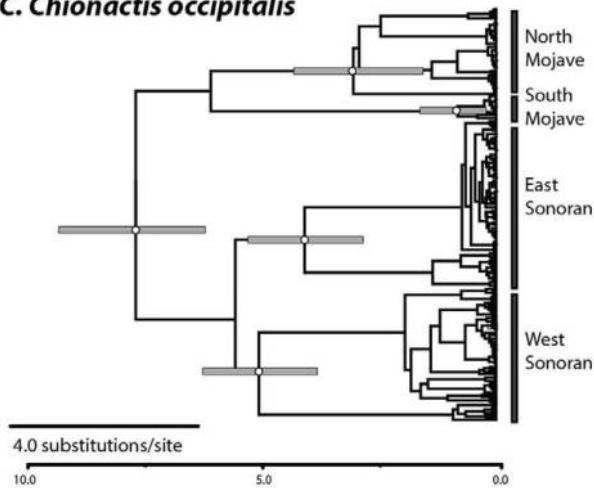
Take one of my favorite animals: the desert tortoise. A desert tortoise has roughly three billion nucleotides—single bits of genetic information—in its genome. A population genomicist might study a million of those nucleotides

or maybe even go after all three billion. Genomics offers the possibility to understand vastly more about that tortoise’s family history, its physiology, and its ability to adapt than is conceivable when studying only a few genes at a time. Genomics opens windows of understanding into the lives of plants and animals—understanding that is critical to our ability to conserve species in the face of ever-growing threats and challenges from human incursions into their habitat, climate change, and other environmental degradation.

My work on animals and natural history has taken me to some of the most pristine places on earth and some of the most modified. In the past year, I snorkeled for mata mata turtles in the remote Rio Negro in the Brazilian Amazon, netted salamanders and frogs in the Hamptons on Long Island, and noosed chuckwalla lizards in the virtually untouched Old Woman Mountains of the Mojave Desert. My students and I collected endangered California tiger salamanders at a huge landfill in the Salinas Valley, at “Machine Gun Flats” on a decommissioned military base near Monterey, and in cattle ponds in the San Joaquin Valley. It’s all part of nature, and both endangered and common species are there to be studied, admired, and, hopefully, conserved.

To take one example that is near and dear to my heart, consider the California tiger salamander, an endangered species that is restricted to California’s Central Valley and

### C. *Chionactis occipitalis*



A phylogenetic tree and map of genetic divergence in Western shovel-nosed snake populations. The tree and map represent how different genes at particular sites in the genome diverge across Mojave and Sonoran Deserts and the Colorado River. See endnote.

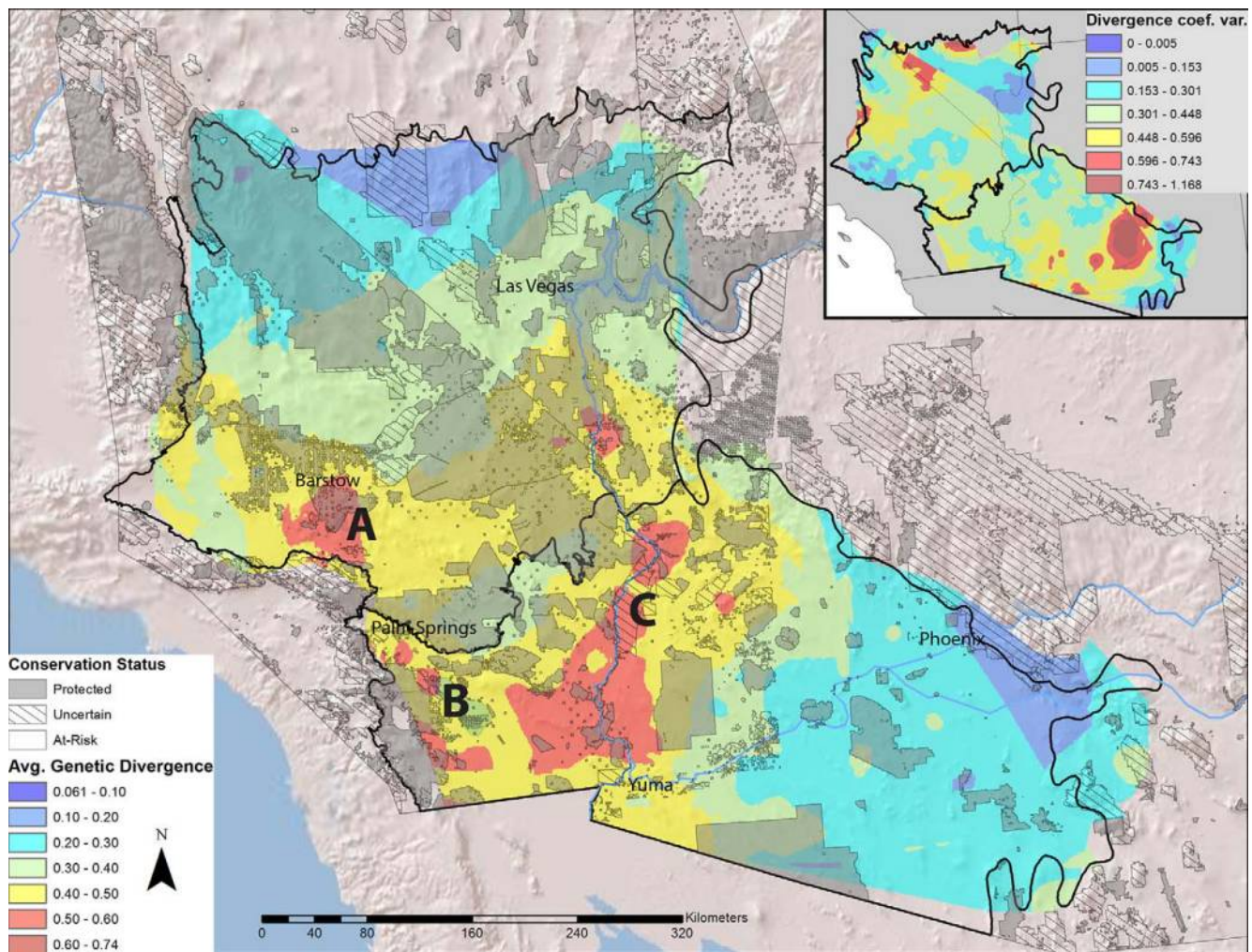
the foothills of the Sierra and Coast Ranges. Adults of the species live underground, emerging on a few rainy nights a year to migrate to their breeding pools; they are otherwise cryptic animals that are incredibly hard to study. The species is listed under both the US and California Endangered Species Acts, and my guess is that fewer than ten university biologists in the world have ever seen an adult tiger salamander in the wild. My students and I have spent twenty years walking literally thousands of miles of trap arrays. We've caught tens of thousands of salamanders in order to learn where they go, when they migrate, how far they move, and how many of them exist in nature. We've made a lot of progress toward understanding these elusive animals by capturing, marking, releasing, and recapturing them. We've learned where they breed, how long they live, who survives, and who dies. That work has taken thousands of hours and several millions of dollars, but we now understand the population biology of the California tiger salamander as well as any amphibian on Earth.

Now we're beginning to explore what we could do with a genomic sample of each of those salamanders. With a small bit of DNA, we could determine the parents of each animal that we capture, whether it has living siblings, and what genes it has that may enhance or threaten its survival. We could determine whether one or a few salamanders produce most of the successful youngsters in a population,

or if all of the adults that go to a particular pond to breed have equal reproductive success. Tiger salamanders sometimes move more than a mile from their breeding pool to an underground retreat where they spend the rest of the year. I've often wondered if the salamanders that find a home close to the breeding pond are the strongest, most fit individuals, and, therefore, contribute the largest number of offspring to the population. I can't work that out simply by catching salamanders in our traps, but genomic data can help answer these questions. The answers can be found within the DNA from a tiny tip of an animal's tail or a cotton swab wiped across its skin. No fuss, no muss, and no harm or bother to the animal.

Here's a question I'd like to ask the genome of the desert tortoise. How do desert tortoises travel across the Mojave? We know that tortoises are widely distributed across the desert and that they tend to favor certain soils for making their burrows. However, we don't know whether they tend to use certain corridors for movement, or how important such corridors might be for tortoises as they move between protected areas of the desert. The answer to how they move is critical if we want to keep those corridors safe as large, solar power plants and other developments fragment more and more of the Mojave Desert. Genomics can help answer this question in a straightforward way. By measuring the relatedness of tortoises that are distributed across the desert,





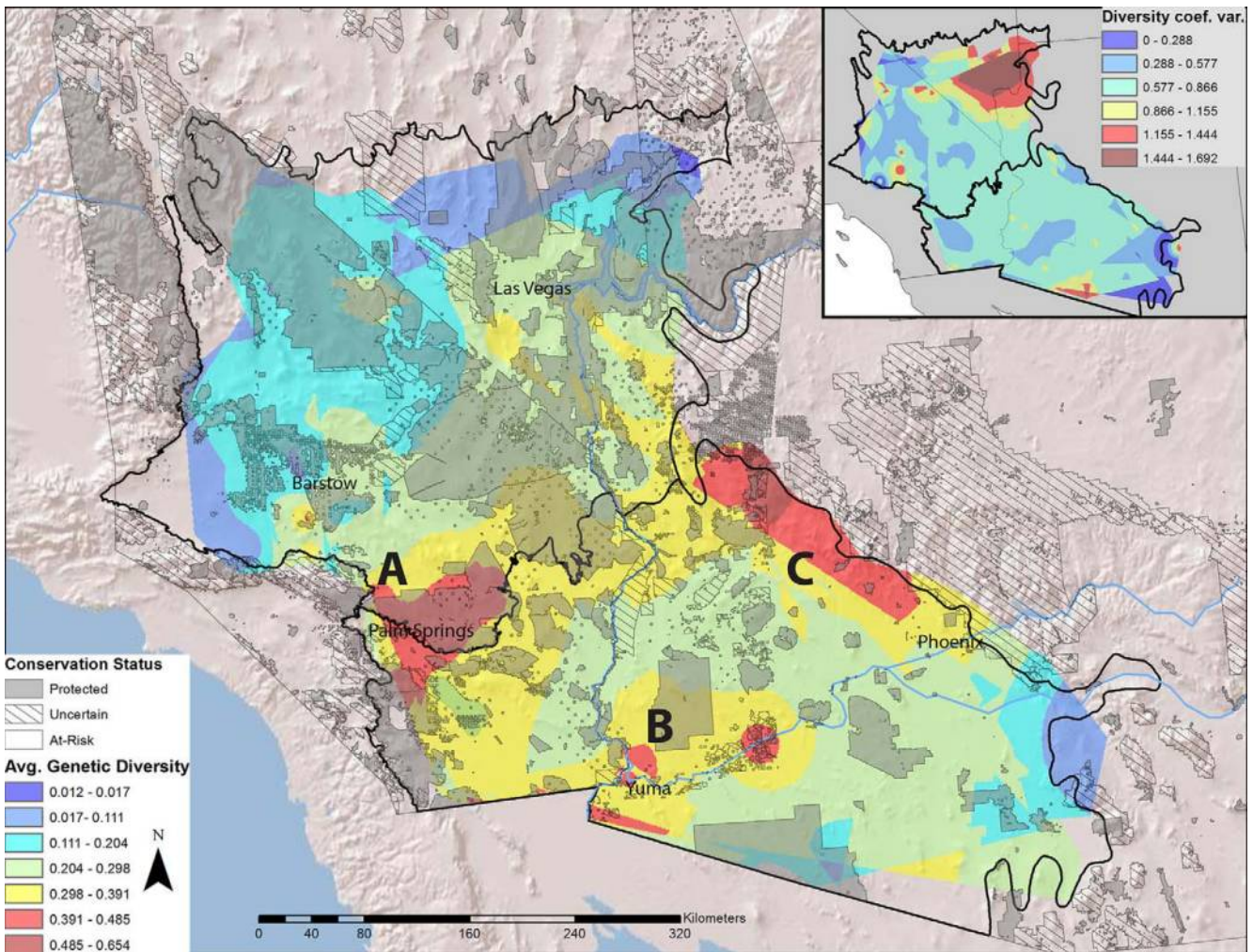
A map of the average genetic divergence of twelve species and the protected status of desert lands in Southern California, Nevada, and Arizona. Hot spots of divergence are in the Lucerne Valley, the Colorado Desert, and along the Colorado River. See endnote.

and simultaneously quantifying the soil, vegetation, and slopes of the intervening areas, we can develop a model that allows us to measure how easy it is for a tortoise to cross an acre of flat sandy wash, rocky mountain slope, and other types of habitats. If a habitat is easily traversed by tortoises, then tortoises that are very far apart geographically but still within that continuous habitat will tend to be relatively closely related; this is because parents and their offspring can move larger distances more easily within the habitat. However, if it is much more difficult for a tortoise to move across a different type of habitat, then individuals separated by short distances may be very distantly related. With the genomic data from a drop of blood and publicly available maps, this kind of information can be collected and used to help minimize the impact of habitat fragmentation on the

connectivity of tortoise populations. We're doing this work right now, and we hope to be able to help solve the problem of how we can produce clean energy without endangering tortoises on the same desert landscape.

Genomics offers insights that were impossible a few years ago. The opportunities to learn about the natural world, to place our observations, thoughts, and guesses into a scientific framework, and to better understand the impact of our human actions on nature can be enhanced by genomics in truly amazing ways. Genomics will never replace going out for a walk with eyes wide open, and it will always rely on people with curious minds and sharp observations to motivate interesting questions and research. But the next time you look in your backyard and see a scrub jay burying an acorn, you might just wonder:





A map of the average genetic diversity of ten species of the protected status of desert lands in Southern California, Nevada, and Arizona. Hot spots of diversity are in the Coachella Valley, along the southern end of the Colorado and Gila Rivers, and along mountain ranges at the eastern edge of the Mojave and Sonoran Deserts. See endnote.

Where did that acorn come from? The oak down the street or a tree twenty miles away? Are the acorns the jay is burying all from the same tree or from trees from all over the city? Are the scrub jays burying acorns in my yard brothers and sisters or unrelated animals that seem to be helping each other out?

A few leaves from some trees, a few feathers from some birds, some natural history observations, and genomics can help answer all these questions and more. The answers can

enrich our understanding of the natural world and help us better manage it. **B**

#### Note

Maps from “Comparative phylogeography reveals deep lineages and regional evolutionary hotspots in the Mojave and Sonoran Deserts,” Dustin A. Wood, Amy G. Vandergast, Kelly R. Barr, Rich D. Inman, Todd C. Esque, Kenneth E. Nussear, and Robert N. Fisher, *Diversity and Distributions* (2012), 1–16, DOI: 10.1111/ddi.12022.