Toad stopper. Shine is on friendly terms with this cane toad, but he wants to protect Australia from its relatives.

PROFILE: RICK SHINE

The Reluctant Toad Killer

Australia's cane toad problem has distracted Rick Shine from the animals he truly loves, but the biologist may have an effective way to slow their invasion

While growing up in Brisbane in the 1950s, Rick Shine chased big bluetongue lizards in the neighbors' yards. By high school in Canberra, he was bringing home deadly brown snakes. "I can only wonder at my parents' forbearance," he says.

When Shine began college at Australian National University, he didn't yet know what he wanted to do in life, but then zoologist Richard Barwick showed him an appealing future. "Dick was the first professional reptile biologist that I ever met," Shine says. "The light went on quite brightly when I recognized that there was such a thing as a career studying reptiles."

Shine, also smitten with the ideas of Darwin and the other giants of evolution, decided to pursue research and was soon applying evolutionary theory to the reptiles and amphibians that had fascinated him from a young age. In the 1980s, by then on the faculty at the University of Sydney, Shine set up a research station at Fogg Dam near the aptly named Australian town of Darwin, where he could study the ecology of the local pythons year after year.

And then, in 2004, the cane toads came to Fogg Dam.

Cane toads (*Bufo marinus*) have spread west from the Queensland coast since 1935, when Australian sugar growers, desperate to control beetles that were eating their crops, released several thousand young toads into their fields. The toads, native to Central and South America, had reportedly eaten enough similar beetles in Hawaii to improve sugar yields there, and they were considered less destructive than chemical pesticides. But Australia, with no native toads and plenty of suitable habitat, proved to be cane toad heaven. That soon created a new problem: The foreign amphibians produce a toxin that is deadly to many of the native predators that gobble them up. As the toads spread, a wave of death struck snakes, freshwater crocodiles, and other Australian animals. Today, cane toads are one of the continent's worst invasive species and number in the hundreds of millions.

Finding himself on the leading edge of the invasion, Shine knew the toads would likely eradicate many of the animals he had studied for decades, so he reluctantly turned his attention to the unwelcome guest. "It was an extraordinary opportunity for a scientist," he says, but it was also "so very bittersweet. … I thought we'd find out a lot about toads and do some great science, but we'd have very little actual management impact."

Less than a decade later, Shine's research has paid off, with dozens of findings covering basic toad biology and how the toads interact with Australia's native fauna, and even the discovery of a potentially new mechanism of evolution. Shine "is carrying on first-class 19th century natural history using 21st century techniques," says John Endler, a veteran evolutionary biologist at Deakin University in Victoria, Australia.

But the 62-year-old herpetologist's biggest breakthrough may be a recently devised strategy to turn the toad's own toxins against the invader. Shine has explored other ways to stop the animal's spread, but this time he believes he has struck gold. "I think that this will be the centerpiece of future efforts to control invasive cane toads," he predicts.

Team *Bufo*

Walk into Shine's Sydney lab and you'll see a place full of the critters he would have loved to collect as a kid—snakes, frogs, lizards, a chameleon, and, of course, a couple of cane toads, including one named Gwendolyn. Shine spends less time in the lab and the field than he once did—"I probably just get in the way," he says—but he has successfully resisted calls to pull him into university administration. Still, now that he is at the forefront of Australia's cane toad problem, Shine frequently finds himself in front of television cameras and community groups. He also spends a lot more

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time writing about cane toads for journals and magazines these days. "I enjoy the process of writing," he says. "I suspect I would've been writing trashy crime novels if I hadn't been a professional scientist."

That love of writing certainly helped Shine produce the more than 750 papers he's authored in his career. Shine also modestly credits many of his published findings to the "sheer luck" of being in the right place at the right time, as well as having a small army of students and collaborators—he currently supervises about 20 scientists, including some postdocs and research assistants who have each stuck around for more than a decade.

Shine chooses hard-working, motivated people and then guides them softly, says Ben Phillips, an evolutionary biologist at James Cook University in Townsville, Australia, and a former Shine student. Phillips describes his mentor as "quite unbosslike" and "very easygoing." Shine is constantly listening to the people in his lab, Phillips says, and then "he puts a lot of effort into trying to improve what you're doing."

"Team *Bufo*," as Shine's group is sometimes known, has garnered respect from the invasion biology community. "Shine's involvement in [cane toad research], with his laboratory and his linkages and his way of working, where he gets on with many people, has vastly improved our knowledge of the biology of the toad," says veteran invasion biologist Tony Peacock, CEO of Australia's Cooperative Research Centres Association.

Shine says he approaches topics with a willingness to be wrong. "I'm still appalled at my own inability to guess the right answer before we actually gather the data."

Take away the cane toad research, and Shine's resume is still full of first-class natural history discoveries. By studying the ecology and life histories of snakes in Australia and around the world, for example, he has provided fresh insight into the evolution of live birth (most reptiles lay eggs, but more than 2000 species give birth) and why male snakes are bigger than females in certain species, while the opposite is true in others (males tend to grow larger in species whose males have to fight other males during the mating season). Shine "really observes and thinks about what the animals are doing and … lets the hypothesis be generated by their natural world, which is the characteristic of a real scientist," Endler says.

In 2008, Shine and former student Daniel Warner, now at Iowa State University in Ames, finally provided experimental evidence for a 1970s-era theory for why some species have temperature-dependent sex determination. In certain reptiles—including all crocodilians, for example—nest temperature skews offspring gender ratio. Evolutionary biologists Eric Charnov and James Bull posited that there must be an evolutionary benefit for letting environmental conditions determine gender instead of genetics, but no one had been able to confirm that, in part because the phenomenon occurs in mostly long-lived animals.

But Shine, who had been a postdoc in Charnov's lab, and Warner turned to the Jacky dragon, an Australian lizard with a life cycle of only a few years in which both sexes are born if nest temperatures are between 27°C and 30°C, but only females are born if it's colder or hotter. Hormonally manipulating the eggs in one experiment so that males were born outside the intermediate temperature range, the pair maintained those Jacky dragons in enclosures and showed that they didn't reproduce as well as typical males, an evolutionary disadvantage expected under the Charnov-Bull theory. "The sons that had been produced at the temperatures that normally produce sons were far more successful than sons that had been produced at any other temperature," Shine says. "And the reverse went for the girls."

Snake study. Much of Shine's career has focused on Australia's native animals, such as pythons.

Killer robot toads

For almost a decade, cane toads have distracted Shine from the Jacky dragon, snakes, and other native animals he loves to study. Fifty years ago, no one would have thought that the cane toads would make it to his research station in Fogg Dam so quickly. The toads had initially traveled west steadily at about 10 kilometers per year. But then the amphibians at the front of the invasion began to change with every generation. The new offspring developed longer legs that enabled them to hop farther. And they didn't rest as much, hopping more frequently than previous generations of the toad, and thus moving longer distances on average. They also followed straighter paths and had greater endurance than the toads in the east—they could travel a kilometer or more each night. "You get these bizarre, robot cane toads that are designed to do nothing but hurtle as fast as possible, as straight as possible, across the landscape," Shine says.

The adaptations carried a price—about 10% of these toads now develop spinal arthritis—but the result was an invasion front that is now moving at a rate of 50 kilometers each year. "I've come to have a sneaking admiration for the toads," Shine says. "They're an extraordinary invasion machine."

The longer Shine and his colleagues studied the toads, the more they became convinced that the amphibians' evolution was more complex than natural selection alone. They concluded there was another mechanism at work, one that Shine last year dubbed "spatial sorting" in an article in the *Proceedings of the National Academy of Sciences*. If you look at the population of cane toads spreading from east to west, toads at the front of the invasion in the west are the ones that have dispersed most quickly. When these toads on the leading edge breed, some of their offspring are naturally even faster dispersers, and they soon become the front of the invasion. When they breed and produce even faster offspring, the cycle continues, and the front moves more quickly every year. That's spatial sorting, "evolution through space, not time," Shine says. In other words, it's survival of the fastest, not the fittest, when it comes to cane toads.

Spatial sorting potentially has implications beyond invasion biology—species move all the time, driven by changes in climate or the opening of landscapes. And evidence of spatial sorting can be seen in other species; wood butterflies at the edge of their range expansion in England, for example, have stronger flight muscles.

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Not all evolutionary biologists are convinced that spatial sorting is a novel concept in their field; "I'd just call it gene flow," says Mark McPeek of Dartmouth College. But some say it does appear to have been largely forgotten until Shine's work on cane toads. "Spatial sorting is a new component of evolution that people had ignored," Endler contends. "It's a fundamental additional process of evolution."

Toxic backlash

Understanding why cane toads have become such a problem is all well and good, but spatial sorting doesn't offer an obvious way to stop their spread across northern Australia. Farmers, volunteer groups, and government scientists have tried to get rid of the toads by manually removing eggs from ponds or physically killing adults, but both tactics have proved woefully inadequate. Attempts to identify or create a virus or other biocontrol agent that would wipe out the whole cane toad population have not borne fruit yet, either. Shine's group, for example, is still looking into using parasitic lungworms for cane toad control.

Given the cane toad's toxic payload, Australians have long assumed that the amphibian's native predators were doomed, but it turns out that's not necessarily the case. The cane toad's toxins are "devastating for a small number of species," Shine says, "and really no big deal for most of the others."

Raptors, for instance, have figured out how to avoid the majority of the toad's toxins by eating only their tongues. And Australia's native frogs have quickly learned that cane toads aren't tasty and now avoid them. Shine even taught young captive quolls, native catlike marsupials, that the toads taste bad by feeding them a nonlethal dead toad laced with a nausea-inducing chemical; when released into the wild, those quolls taught their offspring to avoid the amphibians.

This may help native predators to survive, but it can't do too much to slow the toads. "If they can have 30,000 kids a year, then really, you're not going to have too much impact just removing the adults," Shine notes. "It's more like dealing with an insect pest than it is like dealing with the average vertebrate."

That's why an unexpected discovery by Shine's team—that cane toads are sometimes cannibals, with tadpoles of the species consuming cane toad eggs—finally has Shine and others hopeful. What some might have dismissed as a quirk of nature, Shine has turned into a plan to get rid of the toads.

It all started with the observation that native frog tadpoles would munch on cane toad eggs and soon die. When Shine, postdoc Michael Crossland, and their colleagues used those eggs as bait in traps, they found cane toad, not frog, tadpoles by the dozen. Unexpectedly, they found that the toad tadpoles were lured to the eggs by the same toxins the adult toads use to deter and poison predators. Crossland and Shine then used those attractants as bait in funnel traps in ponds and caught tens of thousands of toad tadpoles in just a few days, removing nearly all that were living in a pond, with very few native frog tadpoles, fish, or insects as by-catch.

This "is a testament to the value of pure research," Phillips says. Shine "discovered something that is a chink in the toad's armor and discovered that it can be exploited."

Crossland and Shine have tried the toad toxin–laden traps in a half-dozen ponds so far, including one in Sydney, at the edge of the cane toad's Australian range, and the traps have been a success each time. Shine's team presents the trap results this week in the *Proceedings of the Royal Society B*.

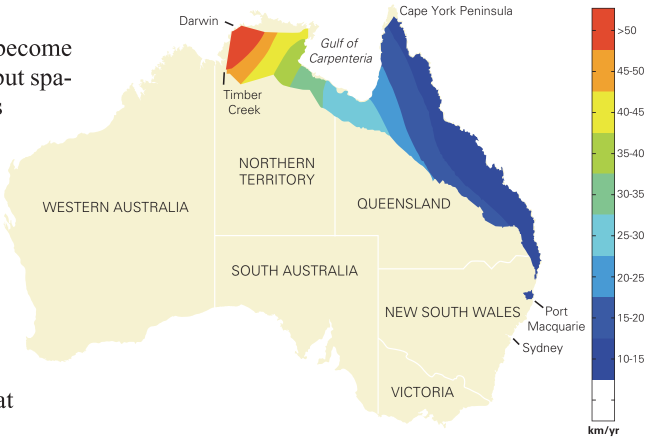
Shine envisions a day when the community groups that currently carry out toad kills are instead enlisted to collect the animals, harvest their toxins, and build tadpole traps. It's still only a local solution, but it could prove invaluable in places such as nature reserves. The trap strategy "seems like it could be very promising at that level," says ecologist David Skelly of Yale University.

But, Skelly adds, "I'm not sure this is something that could knock the invasion wave back." Others say that shouldn't be the key goal. "People always think in terms of 'Wouldn't it be nice if we had some sort of biological control [for cane toads] and knock them all out,' " says invasion biologist Peacock. "Rick is working beyond that. … We should be concentrating on those areas and those ecosystems where the toads do the most damage," such as where they interact with the northern quoll, the species most likely to be driven extinct by the toad invasion.

Shine himself acknowledges that the toxin traps aren't the ultimate toad killers. "We won't have a magic bullet to get rid of cane toads from Australia," he says, "but we now have an approach that can massively reduce their numbers."

That may disappoint some cane toad–busting groups, but it's a hallmark of Shine's "pragmatic" and "clear-eyed" approach to this research, according to Skelly. And even if Shine hasn't found the Holy Grail of cane toad control, he's certainly brought Australia hope. "We really have a much better idea of how one of the classic, textbook invasive species influences environments," Skelly says, "because [Shine has] been willing … and been productive enough to tell the whole story about this species." **–SARAH ZIELINSKI**

Sarah Zielinski is a freelance writer based in Washington, D.C.



Speedy toads. As cane toads have spread from Queensland, their invasion front has quickened (*top*) and local groups aiming to slow the toads (*bottom*) have had limited success.

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