

TOAD KILL

The cane toad invasion could spread as far as Melbourne and Perth, but Rick Shine says their ecological impact may not be as apocalyptic as has been feared.

Kenneth Grahame's classic children's tale *Wind in the Willows* is about delightful little creatures in the English countryside – Rat, Mole, Badger and so on. The central creature is Mr Toad, an extravagant creature with a penchant for wandering. Toad's great obsession in life is to go to places he's never been and to get there as fast as he can.

Wind in the Willows was written almost 100 years ago, but Mr Toad's descendants, particularly the American branch of the family, are continuing to spread and travel rapidly across the globe.

Mr Cane Toad (*Bufo marinus*, although the taxonomists have just changed it to *Chaunus marinus*), comes from the Central and South American branch of the toad family, and was introduced to Australia in 1935 in an attempt to control beetles that were destroying sugarcane. Mr Cane Toad and his relatives have been spreading across the Australian tropics ever since. In the process they have encountered landscapes very different from the original landscapes of Central and South America.

Large adult toads can eat all sorts of things, and may compete with native frogs. Females can produce in excess of 30,000 eggs in a single clutch, making control of their numbers incredibly difficult. The eggs hatch into little metamorphs that crawl around the edges of the pond.

The cane toad has a huge parotid gland full of toxic poison that can kill you if you try to eat it. These guys are

toxic at just about every stage in their life cycle. The metamorphs are about the right size for the average native predator, which would die as a result of eating them.

We recently found that the cane toad invasion may even reduce mosquito numbers, while Mrs Death Adder and Mr Toad have had a pretty nasty encounter, with fatal consequences for both of them.

Is Evolution Too Slow for Conservation?

One of the more unusual beings that Mr Toad has encountered as he has reached the suburbs of Darwin is a group that calls itself "Team *Bufo*", a bunch of biologists, ecologists and evolutionary biologists based at the University of Sydney who are conducting a study at Fogg Dam and its environs on the Adelaide River flood plain.

I started the work about 25 years ago, focusing on the ecology of snakes. Because we know our study site backwards, it is an incredible opportunity to find out what effect toads are having.

So, as soon as the first toads arrived at our study site in 2005, we began to catch toads, strap little radiotransmitters to them and follow them around. For the past few years a small army of postdocs, PhD students and Honours students have waded through the swamps trying to avoid crocodiles, mosquitoes and heatstroke, and trying to work out exactly what the toads are doing.

The unusual part of my group's



A cane toad photographed near Fogg Dam, 50 km south-west of Darwin. Photo: David Nelson

approach is that we also take an evolutionary perspective. We are exploring the possibility of rapid evolutionary changes, both in the toads and in the native systems that they are impacting.

Conservation biologists don't usually worry about evolution because of the feeling that evolution is a very slow process. It is very good at explaining why dinosaurs evolve, but it is very bad at explaining anything about what happens when you cut a forest down. Our conservation problems and challenges seem too urgent for the living systems involved to adapt quickly enough for it to really matter.

From an evolutionary perspective, however, any conservation challenge is just another selective force. If there are individuals in the population with genes that make them less vulnerable to the new source of mortality, those genes should increase in frequency relative to the others, and the system should adapt to deal with the new challenge. If the system is capable of adapting to a new challenge then we may not need to spend too many of our scarce conservation resources on meeting that challenge.

Therefore the possibility of an evolutionary response is critical to setting

our conservation priorities. The issue is whether it is happening fast enough and whether we can detect the signature of evolutionary change in real conservation problems.

Who Eats Who?

Funding agencies have poured tens of millions of dollars into research on cane toads, but almost none of that has gone towards understanding anything about them. The focus has been very simple, like: “We don’t want to measure toads or understand them. We just want to kill them.”

So there is a cane toad army raging through tropical Australia and we don’t know what resources it needs, where it breeds, what it eats or what effect it has. Instead, we spend our time and money trying to come up with ways to kill toads. The unusual thing about Team *Bufo*’s approach is that we are trying to understand the biology of toads and what their effect is.

We radio-track not only toads but also many predators, like death adders, so we can see what happens when the toads turn up. Our study is based on the Adelaide River floodplain, between Darwin and Kakadu. Our work is concentrated around Fogg Dam and Beatrice Hill, a beautiful place about an hour out of Darwin.

The first question I want to ask is: what native species of fauna will be affected by toads? If you ask that question in a pub almost anywhere in Australia, people will talk about an ecological catastrophe as toads leave a trail of death and destruction. But is it true? Our field and laboratory trials are telling a different story.

Most native species are not directly affected by the arrival of cane toads. If you don’t eat frogs you are probably not going to try to eat a toad, and that cuts out a huge number of species. Toads do eat invertebrates and they do compete with frogs, but our studies show that the effects are quite small. The toads are not a big deal in these



A cane toad with a tiny metamorph on top, hatched from one of the female’s 30,000 eggs. Photo: Travis Child

two situations.

The big deal is toads poisoning animals that try to eat them. If you are a frog-eater you are potentially at risk, but if you are not a frog-eater you are probably fine. Even among the frog-eaters, though, many species really aren’t at risk because they are closely related to Asian species that still have the genetic baggage to be able to process toads and to deal with the toxins, or to recognise that you shouldn’t eat them.

For example, one of the most common snakes at Fogg Dam is the keelback, a snake with Asian ancestors that can eat toads without problems. There are also a lot of pythons that are physiologically very susceptible to toads but they just don’t want to eat them.

The snakes that are really in trouble are our venomous snakes, the elapids. In particular, king brown snakes and death adders experience high mortality when the toads arrive. We also see about 90% mortality in some goanna species, and significant mortality in frogs.

Overall, though, the effects have been very patchy. For example, some native frogs try to eat small toads and

die, whereas other species just ignore the toads or spit them out as soon as they grab them – and therefore survive.

The one group of Australian animals that the Toad Doomsday people don’t talk about is the birds. In Australia there are a lot more people watching birds than there are watching frogs, snakes or quolls, yet there are many anecdotal reports of quolls and snakes going downhill when toads arrive but there is nothing about birds.

The reason appears to be because birds don’t have any problems with cane toads. Since birds are so mobile there is probably so much genetic interchange with Asian populations that they have “tricks” to deal with the toxic toads. The arrival of cane toads is probably just an extra food source for birds, and not a big deal.

How about the poor native predators that aren’t in any of these happy categories? Quolls are the species most often implicated as the victim when the cane toad arrives. The evidence is still circumstantial but it really does look as if quoll populations plummet when toads arrive.

But what about the other dasyurid marsupials like planigales? These small,



Suicide pact: a death adder, dead, after trying to eat a cane toad. Photo: Greg Brown

shrew-like animals are voracious predators and are common on the floodplain, but nobody has ever looked to see what happens to them when toads arrive. Our prediction was that since they are related to quolls, and since they eat frogs, they would probably try to eat the first toad they met and thus would die very quickly. It would be an ecological catastrophe.

We tested our prediction by putting captive planigales with baby cane toads. To our astonishment (and delight), almost all of the planigales survived. Because they began to eat the toad from the nose first, they soon stopped eating before they had received a fatal dose of poison.

And when we put toads in a second time the planigales wouldn't go anywhere near them. After one trial they had learnt that toads are not to be eaten. Planigales are used to encountering toxic insects and frogs, and they now know that toads fit into this category.

Can Natives Adapt?

The toad invasion is only going to affect a small proportion of the native frog-eaters rather than creating across-the-board mayhem. But suppose you are a predator who is not very good at

learning and you don't have any relatives from Asia. The elapid snakes, particularly our death adders, are the best example of this.

But all is not lost. If rapid evolutionary change could do something when toads arrive, what traits would you expect might help a snake to survive? The most obvious one is feeding responses. For example, if there is a gene that says "recognise a toad and don't eat it", it should increase in frequency. Also, physiologically we would expect that snakes would evolve tolerance to the toxin of the toads.

Our best data comes from the red-bellied black snake. Ben Phillips of Team *Bufo* took advantage of the fact that some populations of black snakes have been overrun by toads while others have not. By comparing toad-naïve snakes with toad-experienced snakes, Phillips found highly significant changes in feeding responses and tolerance to toad toxin.

If you put a black snake from an area that has never met a toad into a cage and you throw a frog in, 100% of the snakes will eat the frog. If you throw a toad about the same size as a frog in with these snakes, about 50% of the snakes will eat the toad and they will almost certainly die. They are very

vulnerable to toad toxin. But if you run the same experiment with a black snake from an area where toads occur, it simply won't eat the toad.

What seems to be happening is that, when the toads arrive, the snakes that eat frogs but not toads are the only ones that survive. They then form the nucleus of the population that begins to recover. So, even among predators that are affected, many will recover.

There are no recorded extinctions of any species in Australia due to cane toads, and there are many stories about native species recovering, such as goannas in Townsville. However, some of the recovering predators are still quite rare.

The March of Toads

Evolutionary thinking predicts that invading species will go faster and faster – it doesn't matter whether we are talking about cane toads, fire ants or pine trees. The reason is that if the front is moving quite quickly, then only the fast-moving individuals, or the individuals that can disperse more rapidly, will be at the front. Only their fastest-moving progeny will be at the front and only *their* fastest-moving progeny will be at the front. Any gene that slows a toad down will be left behind, and the front will be composed of really effective dispersers – a nightmare for conservation.

We've looked at the evolution of leg length and found that toads with really long legs move about 1 km further over 3 days than toads with short legs and the same body size (Fig. 1). It is common for a toad to move 1 km in a night, move every night and keep going in the same direction.

The really fast toads in the vanguard have very long legs. In the early years of the toad invasion, the expansion per year averaged about 10 km; today, the toads are expanding at around 60 km/year.

The conventional way to predict how far cane toads will spread is to

look at the range of climatic conditions tolerated by the toad's ancestors, map that to find out where those conditions occur in Australia and then predict where the toads will end up. But if you add evolution into the mix you end up with a different prediction because toads can adapt.

Thirty years ago, toads in Queensland could have spread into some very hot areas but they didn't go into them. Now they do. They have evolved, and their upper thermal tolerance has increased by a couple of degrees. This means that the area of Australia that toads can potentially exploit is quite different from what we first thought.

Figure 2 shows where toads are now. Everybody accepts that the toads will get through the Kimberley and invade the adjoining area, and most people tacitly assume that that will be the ultimate limit of cane toad invasion in Australia.

But what will happen is that a bunch of toads will end up sitting in the back of a ute coming from a mining camp to Perth for the weekend party – so toads will make it to Perth.

Toads come to Sydney every year and I am sure they come to Canberra every year. Toads are really good at hiding in stuff.

But how far south can they flourish? Mark Urban and Dave Skelly of Yale University, along with Ben Phillips and myself from Team *Bufo*, have modelled the climates where toads are currently found in Australia, as opposed to where



A toad equipped with belt and radiotransmitter attach to monitor movements around Fogg Dam in the Adelaide River floodplain near Darwin. Credit: Ben Phillips

they occur in South America, and asked: where do those conditions occur elsewhere in Australia?

The modelling predicts toads in south-western Australia, large areas of South Australia, and even in Melbourne and patches of NSW.

The toads are evolving to be good little Australians and are grossly expanding their range of tolerance. The toad invasion has really just started.

One hurdle the toads have had difficulty overcoming is the cycle of wet and dry season in tropical Australia. While many native frogs estivate underground during the dry season, toads tend to remain active and tend to decline in condition. By the time the wet season rains come, very few toads have the energy reserves to breed. So the rains come and the frogs breed, but

it's only at the very end of the wet season that we start to see more toads breeding.

The toads are also having more trouble succeeding in the Top End flood plains than I expected. We thought the flood plains would be fantastic for them but they avoid the flood plains like the plague. They go down the edges, through the woodland, but those big black-soil flood plains that you would think would be heaven for a toad, they just stay away from. But give them a while!

Controlling the Invaders

Because toads are such fantastic evolutionary machines, we cannot eradicate them from Australia. Any control technique we come up with will be a selective force, and they will adapt to it. It

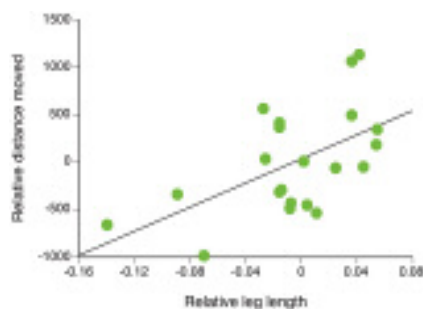


Figure 1. The relationship between leg length and distance travelled by toads.

Source: Phillips, B.L., Brown, G.P., Webb, J.K. & Shine, R. 2006. *Nature*, 16 February.

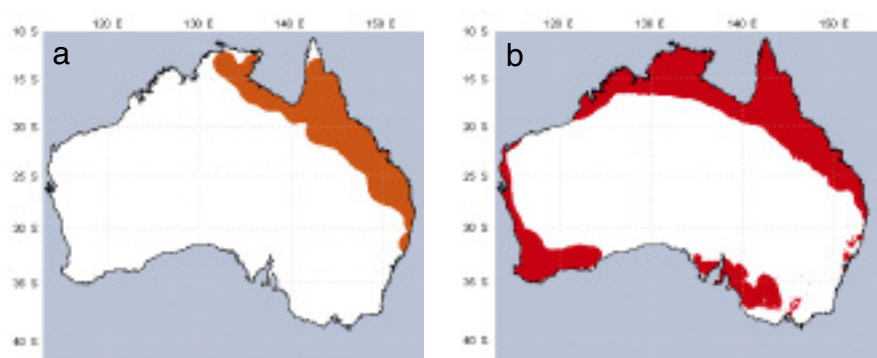


Figure 2. (a) Where toads are now. (b) Predicted eventual range of cane toads in Australia.

Source: Urban, M., Phillips, B.L., Skelly, D.K. & Shine, R. 2007. *Proc. Royal Soc. (Biol. Sci.)*, 274.



The arrival of toads may suppress mosquito numbers. Credit: Greg Brown

doesn't matter if it involves genetic engineering or a magic trap, there will be variance. All we can do is focus on reducing their impact.

Fortunately, evolutionary thinking suggests many novel approaches to toad control. For example, toads are very picky about where they breed, so simple changes to your garden pond (giving it steep edges and letting grass

grow to the water's edge) will keep toads away. Also, a toad's greatest enemy in Australia is likely to be another toad because they compete with each other and cannibalism is common. If we can concentrate toad breeding we can use the toads to control themselves.

Another possibility is behavioural control, using our discovery that toads



The female toad produces two strings of eggs simultaneously (one string from each ovary). Tens of thousands of eggs, which take less than 48 hours to hatch, may be produced in one spawning event. Eggs are wound around aquatic vegetation and debris in shallow water around the edges of ponds. Photo: David Nelson

have a communication system involving alarm pheromones. Fluids from a disturbed or injured toad tadpole vigorously repel other toad tadpoles, but not the tadpoles of native species.

The really exciting thing is that the chemical repels the metamorphs, which are very vulnerable to drying out when they leave the water body. Therefore, spraying the chemical around the water body could drive toads away from their favoured habitats.

Rob Capon's group at the University of Queensland have narrowed the pheromone down to one of four compounds, and are confident that we will soon know the exact chemical composition of the toad alarm system. Maybe in a few years you'll be able to buy "Toad Off" from your supermarket.

Finally, our work shows that the toad invasion front has moved so quickly that important parasites have been left behind, so simply reintroducing those parasites to the invasion front may strongly reduce toad survival, growth and dispersal rates.

The bottom line is that toads are incredibly impressive invasion machines. They are rapidly evolving to adapt to Australian conditions and in response to the invasion process itself. At the same time, the native predators are adapting very rapidly to the presence of the toads in ways that enable them to coexist.

Unless you understand the dynamics of that system, you are not really in a position to do the most effective conservation biology. Australia has spent a great deal of resources on trying to control toads without really understanding them. We can do a better job with new approaches that spring from the evolutionary ideas of the greatest biologist who ever lived: Charles Darwin.

Rick Shine is Professor of Evolutionary Biology at the University of Sydney. This is an edited version of a public lecture given to the Australian Academy of Science (www.science.org.au/events/publiclectures/shine.htm).