Cane toad control should be based on evidence not guesswork

Submission to Inquiry into controlling the spread of cane toads

Professor Rick Shine
December 2018

Abstract

Extensive scientific research (mostly, funded by government) has been conducted into methods to limit the spread and impact of cane toads in Australia. Control efforts that ignore that knowledge base are unlikely to be useful. The impact of cane toads on native wildlife has often been exaggerated; the impact is devastating but is limited to a small group of species (apex predators) and to a relatively short timescale. Thus, control of toads over large areas where they already occur would have little benefit for biodiversity, and likely is impossible without resorting to methods (e.g., genetic manipulation) whose risks outweigh the benefits. The huge clutch sizes and great mobility of toads render localised control efforts ineffective within the toads' main range in tropical Australia; vast effort (primarily into hand-collecting) has failed to slow the march of the toads, or to decrease their abundances. In contrast, control of toads is feasible in isolated populations on islands, and/or near the southern edge of the species' distribution. Such populations have been successfully extirpated by using a combination of methods including hand-collection, fencing of waterbodies, trapping of adult toads, and pheromone(chemical)-based trapping of tadpoles. Cane toads frequently are translocated to sites far outside their main range (usually by hiding in cargo in trucks), so we need effective methods to eradicate such satellite populations before they can spread. I identify four priorities for future investment: (1) new pheromone-based techniques for tadpole eradication; (2) deployment of aversion-inducing stimuli to train vulnerable predators not to eat toads; (3) a recently-identified pathogen that causes lethal amoebic dysentery to cane toads in Australia; and (4) plans to exclude toads from the Pilbara by restricting their access to water along the dryland corridor south of Broome.

Introduction

The spread of cane toads (*Rhinella marina*, formerly *Bufo marinus*) through Australia has been the subject of very extensive research; indeed, this may qualify as the most comprehensively-studied and best-understood biological invasion of any species worldwide (e.g., Rollins et al. 2016; Shine 2014, 2018). That research has documented severe ecological impacts of cane toads on Australian wildlife, which in turn has stimulated a massive expenditure of public money on attempts to control toads and to reduce their impact (Peacock 2007; Shine 2017). Sadly, however, much of the extensive funding for toad control has been wasted on inappropriate and ineffective activities (Shine and Phillips 2014). We now know enough about the toad invasion, and about the effectiveness (or lack thereof) of alternative methods of control, to identify the most productive way forward.

This submission briefly reviews major results from research on cane toads in Australia, and identifies profitable avenues for further investment into tackling the problem.

The ecological impact of cane toads in Australia

Cane toads are the alien invaders that Australians love to hate, with the result that the magnitude and duration of the ecological impact of cane toads has frequently been exaggerated (Shine 2010, 2018). Cane toads have not caused the extinction of any native wildlife species in Australia. Their arrival at a site reduces the abundance of a few species (mostly, large-bodied "apex predators") which are fatally poisoned when they attempt to eat the highly toxic toads. However, that mortality of apex predators leads to a corresponding increase in the abundance of other species that were formerly consumed by the toads' victims. Thus, for example, most frog-eating snakes become more common, not less common, after the arrival of cane toads (Brown et al. 2011). Many other Australian wildlife species (such as birds, native rodents and insects) can consume toads without ill-effect, so the toad invasion constitutes a source of additional food rather than an ecological threat (Cabrera-Guzman et al. 2012, 2015).

For the apex predators most at risk of toads, however, the impact is devastating. In some areas, more than 95% of goannas (*Varanus* spp.), bluetongue skinks (*Tiliqua scincoides intermedia*), freshwater crocodiles (*Crocodylus johnstoni)* and northern quolls (*Dasyurus hallucatus*) are killed as soon as toads arrive (O'Donnell et al. 2010; Price-Rees et al. 2010; Somaweera et al. 2011; Ward-Fear et al. 2016). Encouragingly, however, that impact is short-lived; some of the most vulnerable species are common (and coexist with toads) in areas where toads have been present for several decades (Shine 2010). This resilience is mostly due to behavioural shifts (a refusal to eat toads) rather than increased physiological tolerance of toad poisons (Llewelyn et al. 2014). Some native predators also exhibit rapid evolution in response to toad invasion, facilitating coexistence with the toxic invader (Phillips and Shine 2004, 2006).

In summary, the invasion of cane toads has had dramatic negative impacts on a few species of apex predators (in southern as well as northern Australia: Jolly et al. 2015) but most native species are unaffected or indeed, have benefitted (Shine 2010, 2017). Even vulnerable species recover within decades. We DO need to control cane toads – massive mortality rates of apex predators are a huge conservation problem – but we also need to see that problem in perspective. For example, "solutions" to cane toad invasion that involve unacceptably high risk to Australian ecosystems – such as some genetic-manipulation approaches – cannot be justified based on the level of damage inflicted by toads in Australia (Shine 2018).

Alternative methods of controlling toads

Most of the effort and funding devoted to toad control occurred before research provided robust evidence as to effectiveness of alternative methods. When it finally became available, that evidence was disappointing. The methods most commonly used (hand-collecting and trapping) have no impact on toad abundance except at a very small spatial scale and over very short timescales (e.g., Somaweera and Shine 2012). Fortunately, researchers developed methods with higher success rates: notably, trapping of larval toads (tadpoles) using toad-derived chemicals as the "bait" in funnel traps (Crossland et al. 2012). These methods have had broad uptake by community groups (McCann et al. 2018a,b; Shine 2018).

The aim of toad control should be to decrease the ecological impacts of the alien amphibians on native wildlife (rather than a simplistic "we need to get rid of as many toads as possible"). Two factors make it difficult to achieve this aim. One factor is the biology of the toad; these are robust, highly mobile animals with extraordinarily large clutch sizes (sometimes, more than 40,000 eggs in a single clutch: Lever 2001). As a result, local eradication of cane toads almost inevitably is followed by remigration into the area that has been controlled; and removal of less than 100% of animals leaves a few individuals that (because of their rapid reproduction) can rapidly restore toad abundances to previous levels (Somaweera and Shine 2012). Thus, the key to toad control is to prevent recruitment. Killing adult toads will have no impact if reproduction can continue. This insight has stimulated research that provided effective new ways to curtail or eliminate toad recruitment, using pheromones (chemicals) produced by the eggs and larvae of cane toads (Crossland et al. 2012; Clarke et al. 2015, 2016).

The second factor involves the mechanism by which cane toads affect native wildlife. By far the most important impact comes via lethal toxic ingestion: individuals of several species of frog-eating apex predators die within minutes if they eat a single adult cane toad (Shine 2010). Unfortunately, a given area contains only a small number of apex predators; and those predators are adept at finding prey (and toads are easier to locate than most native frogs). As a result, the presence of even a few adult cane toads in an area is fatal for most of the vulnerable predators. This means that decreasing toad abundances by 90% may have no actual benefit in terms of saving predators. Even if only a few toads remain, the predators will soon find them, eat them, and die.

In sum, then, we need ways to eradicate toads, not just to reduce their numbers. Eradication is feasible in isolated sites with no remigration pathways, such as offshore islands, habitat "islands" within terrestrial systems, or at the edge of the main geographic range of toads within Australia. Conversely, eradication is not feasible within areas where toad densities are high across the landscape, and where immigrants can rapidly move in to areas where control efforts have depleted the abundance of toads (Somaweera and Shine 2012).

The most cost-effective efforts at toad control thus will focus on the edges of the current range of the species within Australia – especially at the southern front in northeastern New South Wales, where low ambient temperatures reduce toad activity and reproduction to hotter times of the year. The other potentially cost-effective expenditure would be to prevent toads penetrating south of Broome along the "waterless corridor" (and thus, exclude them from the Pilbara region) by restricting access to artificial water sources in this arid hostile landscape (Tingley et al. 2013).

The only technology that might achieve eradication of cane toads over their main range across Australia would be some form of self-disseminating genetic manipulation (such as CRISPR-based gene drive). Such an approach would require substantial development, and may prove to be impossible. Even if the technology were feasible, the dangers of releasing a self-disseminating GMO would be difficult to justify given the minor ecological impact of cane toads in areas where they have already been present for several years. Not only is there a risk of transfer to other amphibian species, but also the risk that any genetic manipulation would find its way to the native range of the cane toad (and related toad taxa) where it could cause catastrophic collapse of an important subset of the world's amphibians. In short, the risks associated with releasing synthetic gene drives in the wild are too great for this to be a sensible approach to the control of cane toads in Australia.

Matching the method to the situation
Cane toads are resilient, and no single method will achieve eradication even of isolated "satellite" populations at the fringe of the species' main range within Australia. However, a combination of methods can achieve this goal. The only well-documented example of successful eradication of a breeding population of cane toads comes from the Sydney suburb of Taren Point, where toads arrived on commercial trucks and bred in at least three summers in an industrial estate (Greenlees et al. 2018). Collaboration between local Council staff, state government authorities and University-based scientists tackled the problem. Adult toads were radio-tracked to locate breeding sites, that were then fenced-off to prevent ingress or egress by toads. Pheromone-based trapping of tadpoles removed thousands of animals, as did hand-collecting of post-larval stages. More than 5,900 toads were removed, and no toads have been recorded at the site (despite continuing surveys) for the last four years (Greenlees et al. 2018).

Another apparent example of toad eradication comes from arid fringes of the toad distribution (e.g., the Tanami Desert), where these amphibians invade during monsoonal conditions but can survive only in the vicinity of permanent water. Having evolved in the rainforests of South America, toads cannot withstand dehydration: they die within a day or two if they cannot access standing waterbodies. Fencing to exclude toads from artificial dams (the only water sources available in the area) killed hundreds of adult toads (perhaps, all of the adults in the area) (Florance et al. 2011). There are no published data on the timescale over which this eradication continued to be successful; presumably, toads re-invaded the site after the next rains fell in the region (and such fences are difficult to maintain longterm; and pose dangers to native fauna).

More generally, local conditions of weather and topography (and attributes of the toads themselves, which differ strongly between populations in eastern versus western Australia: e.g., Hudson et al. 2016, 2018) strongly affect the efficiency of alternative methods for toad control. Experimental studies in eastern Queensland recorded high capture rates in traps (Muller and Schwarzkopf 2017, 2018), but studies in drier parts of Australia have reported very low rates of capture (and worrying levels of bycatch of native fauna). For example, Shine et al. (2018) analysed data on more than 17,500 toads killed by government-employed "toad-busters" in the Kimberley region of Western Australia. Trapping was vastly less effective than hand-collecting; and despite intensive efforts, the rate of removal of toads had no impact on the rate at which the toad invasion spread through this region (Shine et al. 2018). More generally, attempts to capture and kill adult toads do not appear to have had any significant impact on the rate of expansion of the toad invasion front in Australia (Peacock 2007; Somaweera and Shine 2012; Shine et al. 2018).

Priorities for future investment into toad control
Research has identified three areas that warrant further investment:

(1) *Pheromone-based methods to kill eggs and tadpoles.* – Rigorously controlled experiments both in the field and in the laboratory have shown that cane toad tadpoles produce chemicals that, if detected by near-hatching eggs, massively decrease rates of survival and growth of the tadpoles that develop from those eggs (Crossland and Shine 2012; Clarke et al. 2015, 2016). Those chemicals have no impact on native amphibians (Clarke et al. 2016). There is an exciting potential for selective control of cane toads, by preventing recruitment by adding the chemicals to waterbodies. This method may prove to be far more powerful than another method developed by the same research group, whereby toad toxins are used to lure cane toad tadpoles into traps (Crossland et al. 2012). Although progress has been made in translating this more recent research into cane toad control under field conditions (McCann et al. 2018a,b), **we urgently need expanded trials to assess and fine-tune the technology.**

(2) *Taste-aversion training of vulnerable predators.* – The major ecological impact of cane toads occurs when they first arrive in an area, and fatally poison many of the top-predators. We could eliminate that impact if we could totally eradicate cane toads, but that is impossible within the species' main range. The window of time is brief, with toads expected to reach the western coast of Western Australia within a few years. After that (unless the toads spread to the Pilbara), we will mostly have toads in areas of Australia where they have been present for several years – a situation in which they have little ecological impact (see above). Thus, the priority is to mitigate the catastrophic mortality of native predators in the Kimberley region over the next few years. Even if genetic-manipulation methods were to prove feasible (and safe enough to deploy), there is no possibility of them being ready in time to deal with this invasion timeframe.

    Fortunately, there is an alternative. Field-based trials on the species most vulnerable to toad invasion have shown that predators can coexist with toads if they learn not to eat them. Put simply, a predator whose first encounter is with a small cane toad will become nauseous, and learn not to eat toads. Such a predator will then survive even when it meets larger (potentially fatal) toads. But if the predator's first encounter is with a large toad, it will die as soon as it eats it. Unfortunately, the invasion front is dominated by large adult toads (Hudson et al. 2015). Research has shown that exposing predators to small toads immediately prior to the arrival of the main toad invasion massively increases resilience of the predators involved, in the case of species such as northern quolls (O'Donnell et al. 2010), bluetongue skinks (Price-Rees et al. 2013), freshwater crocodiles (Somaweera et al. 2011) and floodplain goannas (Ward-Fear et al. 2016). The offspring of those "educated" predators can survive without further training, because toads are breeding (providing many small "teacher toads") by the time those offspring are born. A major program to buffer toad impact using this method is now in place in the Kimberley, supported by the Australian Research Council, government agencies, local landowners, and indigenous corporations (www.canetoadcalition.com). Given the potential benefits for biodiversity, **this innovative program should be expanded immediately, to maintain viable populations of vulnerable predators across tropical Western Australia.**

(3) *Exploiting a recently-discovered pathogen.* – At an intensively-studied site near Darwin, researchers began finding dead and dying toads in 2014. The animals were unable to maintain water balance because of an aggressive form of dysentery due to a hitherto-unknown amoeba species (Shilton et al. 2018). **The implications for biocontrol are obvious**.

(4) *Preventing toads from reaching the Pilbara.* – To colonise areas south of Broome, the toads will need to move through a highly arid region where water is available only through artificial bores. If we eliminated leakage from those watering-sites so they were inaccessible to toads (which cannot climb), we might be able to save the highly biodiverse Pilbara from toad invasion (Tingley et al. 2013). Success is by no means assured – monsoonal rains may create suitable corridors, and current expansion of agriculture offers another threat – but there is a possibility of a highly cost-effective tactic that could bring huge benefits to biodiversity. **The idea of restricting the toads' access to water along the coastal corridor south of Broome requires urgent assessment and additional field trials.**

References

Brown, G. P., B. L. Phillips, and R. Shine. 2011. The ecological impact of invasive cane toads on tropical snakes: field data do not support predictions from laboratory studies. Ecology 92:422-431.

Cabrera-Guzman, E., M. R. Crossland, and R. Shine. 2012. Predation on the eggs and larvae of invasive cane toads (*Rhinella marina*) by native aquatic invertebrates in tropical Australia. Biological Conservation 153:1-9.

Cabrera-Guzman, E., M. R. Crossland, D. Pearson, J. K. Webb, and R. Shine. 2015. Predation on invasive cane toads (*Rhinella marina*) by native Australian rodents. Journal of Pest Science 88:143-153.

Clarke, G., M. Crossland, C. Shilton, and R. Shine. 2015. Chemical suppression of embryonic cane toads (*Rhinella marina*) by larval conspecifics. Journal of Applied Ecology 52:1547-1557.

Clarke, G. S., M. R. Crossland, and R. Shine. 2016. Can we control the invasive cane toad using chemicals that have evolved under intraspecific competition? Ecological Applications 26:463-474.

Crossland, M. R., and R. Shine. 2012. Embryonic exposure to conspecific chemicals suppresses cane toad growth and survival. Biology Letters 8:226-229.

Crossland, M. R., T. Haramura, A. A. Salim, R. J. Capon and R. Shine. 2012. Exploiting intraspecific competitive mechanisms to control invasive cane toads (*Rhinella marina*). Proceedings of the Royal Society (London) B 279:3436-3442.

Florance D, Webb JK, Dempster T, Worthing A, Kearney MR, Letnic M (2011) Excluding access to invasion hubs can contain the spread of an invasive vertebrate. Proc R Soc B 278:2900–2908

Greenlees, M. J., S. Harris, A. W. White, and R. Shine. 2018. The establishment and eradication of an extra-limital population of invasive cane toads. Biological Invasions 20:2077-20889.

Hudson, C. H., B. L. Phillips, G. P. Brown, and R. Shine. 2015. Virgins in the vanguard: low reproductive frequency in invasion-front cane toads. Biological Journal of the Linnean Society 116:743-747.

Hudson, C. M., M. R. McCurry, P. Lundgren, C. R. McHenry, and R. Shine. 2016. Constructing an invasion machine: the rapid evolution of a dispersal-enhancing phenotype during the cane toad invasion of Australia. PLoS One 11:e0156950.

Hudson, C., G. P. Brown, K. Stuart, and R. Shine. 2018. Sexual and geographic divergence in head widths of invasive cane toads, *Rhinella marina* (Anura: Bufonidae) is driven by both rapid evolution and plasticity. Biological Journal of the Linnean Society 124:188-199.

Jolly, C. J., R. Shine, and M. J. Greenlees. 2015. The impact of invasive cane toads on native wildlife in southern Australia. Ecology and Evolution 5:3879-3894.

Lever C (2001) The cane toad. The history and ecology of a successful colonist. Westbury Academic & Scientific Publishing, Otley, West Yorkshire

Llewelyn, J., L. Schwarzkopf, B. L. Phillips, and R. Shine. 2014. After the crash: how do predators adjust following the invasion of a novel toxic prey type? Austral Ecology 39:190-197.

McCann, S., M. Crossland, and R. Shine. 2018a. Using intraspecific chemical cues to control invasive species: the importance of interactive effects. PLoS One, in press.

McCann, S., M. Crossland, M. Greenlees, and R. Shine. 2018b. Invader control: factors influencing the attraction of cane toad (*Rhinella marina*) larvae to conspecific pheromones. Biological Invasions, in press.

O'Donnell, S., J. K. Webb, and R. Shine. 2010. Conditioned taste aversion enhances the survival of an endangered predator imperiled by a toxic invader. Journal of Applied Ecology 47:558-565.

Peacock T (2007) Community on-ground cane toad control in the Kimberley. Review for David Templeman MP, Minister for the Environment, Climate Change and Peel. Invasive Animals Co-operative Research Centre, Canberra, ACT

Phillips, B., and R. Shine. 2004. Adapting to an invasive species: toxic cane toads induce morphological change in Australian snakes. Proceedings of the National Academy of Sciences (USA) 101:17150-17155

Phillips, B. L., and R. Shine. 2006. An invasive species induces rapid adaptive change in a native predator: cane toads and black snakes in Australia. Proceedings of the Royal Society B 273:1545-1550

Price-Rees, S. J., G. P. Brown, and R. Shine. 2010. Predation on toxic cane toads (*Bufo marinus*) may imperil bluetongue lizards (*Tiliqua scincoides intermedia*, Scincidae) in tropical Australia. Wildlife Research 37:166-173.

Price-Rees, S. J., J. K. Webb, and R. Shine. 2013. Reducing the impact of a toxic invader by inducing taste-aversion in an imperilled native reptile predator. Animal Conservation 16:386-394.

Rollins, L. A., M. F. Richardson, and R. Shine. 2016. A genetic perspective on rapid evolution in cane toads. Pages 313-327 in Invasion Genetics: the Baker & Stebbins Legacy (S. C. H. Barrett, R. I. Colautti, K. M. Dlugosch, and L. H. Reisberg, eds.). Wiley, Hoboken, NJ.

Shilton, C. M., J. Slapeta, R. Shine, and G. P. Brown. 2018. Invasive colonic entamoebiasis in wild cane toads, Australia. Emerging Infectious Diseases 24:1541-1543.

Shine, R. 2010. The ecological impact of invasive cane toads (*Bufo marinus*) in Australia. Quarterly Review of Biology 85:253-291.

Shine, R. 2014. The ecological, evolutionary and social impact of invasive cane toads in Australia. Pages 23-43 in Invasive Species in a Globalized World (R. Keller and M. Cadotte eds.). University of Chicago Press, Chicago.

Shine, R. 2017. The impact of an invasive amphibian: the cane toad, *Rhinella marina*. In press in Amphibian Biology (H. F. Heatwole and J. J. L. Rowley, eds.). CSIRO Press, Melbourne.

Shine, R. 2018. Cane Toad Wars. University of California Press.

Shine, R., and B. L. Phillips. 2014. Unwelcome and unpredictable: the sorry saga of cane toads in Australia. Pages 83-104 in Austral Ark (A. Stow, ed.). Cambridge University Press, Cambridge.

Somaweera, R., J. K. Webb, G. P. Brown, and R. Shine. 2011. Hatchling Australian freshwater crocodiles rapidly learn to avoid toxic invasive cane toads. Behaviour 148:501-517.

Somaweera, R., and R. Shine. 2012. The (non) impact of invasive cane toads on freshwater crocodiles at Lake Argyle in tropical Australia. Animal Conservation 15:152-163.

Tingley, R., B. L. Phillips, M. Letnic, G. P. Brown, R. Shine, and S. Baird. 2013. Identifying optimal barriers to halt the invasion of cane toads *Rhinella marina* in northern Australia. Journal of Applied Ecology 50:129-137.

Ward-Fear, G., D. J. Pearson, G. P. Brown, Balanggarra Rangers, and R. Shine. 2016. Ecological immunisation: *In situ* training of free-ranging predatory lizards reduces their vulnerability to invasive toxic prey. Biology Letters 12:20150863.

Attachments

Shilton, C. M., J. Slapeta, R. Shine, and G. P. Brown. 2018. Invasive colonic entamoebiasis in wild cane toads, Australia**. Emerging Infectious Diseases 24:**1541-1543.

Shine, R. 2010. The ecological impact of invasive cane toads (*Bufo marinus*) in Australia. Quarterly Review of Biology 85:253-291.

Tingley, R., B. L. Phillips, M. Letnic, G. P. Brown, R. Shine, and S. Baird. 2013. Identifying optimal barriers to halt the invasion of cane toads *Rhinella marina* in northern Australia. Journal of Applied Ecology 50:129-137.

Tingley, R., G. Ward-Fear, M. J. Greenlees, L. Schwarzkopf, B. L. Phillips, G. Brown, S. Clulow, J. Webb, R. Capon, A. Sheppard, T. Strive, M. Tizard, and R. Shine. 2017. New weapons in the Toad Toolkit: a review of methods to control and mitigate the biodiversity impacts of invasive cane toads (*Rhinella marina*). Quarterly Review of Biology 92:123-149.