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INCREASED MORTALITY OF NAIVE VARANID LIZARDS AFTER THE INVASION OF NON-NATIVE CANE TOADS (*BUFO MARINUS*)

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Abstract.—Exotic animal and plant species introduced into the Australian continent often imparted catastrophic effects on the indigenous fauna and flora. Proponents of biological control introduced the South American Cane Toad (*Bufo marinus*) into the sugar cane fields of Queensland in 1935. The Cane Toad is one of the most toxic bufonids, and when seized by naïve Australian predators, the toxin usually kills the attacker. One group of Australian squamate reptiles that are very susceptible to Cane Toad toxins is varanid lizards. Prior to Cane Toad invasion of our study area, the Adelaide River floodplain of the Northern Territory of Australia, annual mortality of adult male radio-tagged Yellow-spotted Goannas (*Varanus panoptes*) was very low (two deaths recorded among 20 lizards over three years). After the arrival of the toads in October 2005, all radio-tracked goannas were found dead in August 2006 (nine out of nine lizards), most likely after attempting to feed on toads. Our results suggest that invasive Cane Toads place naïve adult male Yellow-spotted Goannas at risk of possibly > 90% mortality. This increase in mortality could reduce the genetic diversity and hamper long-term survival of these large carnivorous lizards.

Key Words.—Cane Toad; *Bufo marinus*; naïve predator mortality; Yellow-spotted Goanna; *Varanus panoptes*; Australia

INTRODUCTION

Human introduction of numerous exotic animal and plant species into the Australian continent has often resulted in catastrophic effects on the indigenous fauna and flora (Flannery 1995; Low 2001). A relatively recent introduction was the release of the South American Cane Toad (*Bufo marinus*) into the sugar cane fields of Queensland in 1935. A year later, Reginald Mungomery, the person in charge of the introduction, stated that “This introduction into Queensland was made only after a careful analysis of the pros and cons, and, according to the behaviour of the toad up to present, there appears to be no reason for the assumption that we have made an error in our judgement.” Seldom has a statement been based on such a massive error of judgement. Since their introduction, the range of Cane Toads has spread at an alarming rate into tropical and subtropical Australia (Freeland 1985; Lever 2001). In suitable habitats, cane toad populations reach very high densities (> 2,000 toads/ha; Freeland 1986). Furthermore, the Cane Toad is one of the most toxic bufonids: the main toxic component is an ouabain-like molecule, which acts as a sodium pump inhibitor (Else 1994) that is unique to toads (Daly et al. 1987).

The processes and outcomes of ecological invasion vary considerably among eco-systems, but one of the more problematic issues involves invasion by a toxic prey into a naïve predator fauna (Brodie and Brodie 1999). Without native bufonids in Australia (Cochran 1961) to drive natural selection, potential predators may

lack adaptations to deal with ingesting Cane Toad toxins. Indeed, Cane Toads have devastating effects on some native Australian predators, such as carnivorous marsupials (Oakwood 2004; Oakwood, M. 2004. Report to Kakadu National Park pp. 2. Ecosystem Management, University of New England, Armidale, Australia). Based on a long-term radio-telemetry study of the largest and most common varanid lizard in the Top End of Australia, the Yellow-spotted Goanna (*Varanus panoptes*), we explored the impact of Cane Toads on a population of this carnivorous lizard on the Adelaide River floodplain in the Northern Territory of Australia.

MATERIALS AND METHODS

Study area.—The Adelaide River floodplain is situated 60 km southeast of Darwin, in Australia’s Northern Territory. The vegetation on the floodplain consists of grasses (*Oryza*, *Echinochloa*, *Paspalum*, *Coelorachis* and *Sorghum*), sedges (mainly *Eleocharis*) and herbs, such as *Passiflora foetida*. The floodplain is bordered by higher forested ground to the northwest and to the northeast by the Adelaide River (for a more detailed description of the study area, see Madsen and Shine 1996). The study area lies within the “wet-dry” tropics. Monthly temperatures are uniformly warm (mean daily maximum air temperature > 30°C); whereas, precipitation is highly seasonal, more than 75% of the total annual rainfall (1,300 mm) falls in the brief wet season from December to March (Coastal Plains Research Station, Middle Point Village, Queensland).

TABLE 1. Number and fate of 25 male *Varanus panoptes* radio-tracked from September 2002 to August 2006 southeast of Darwin, Northern Territory, Australia.

Year Captured	Number Released	Observed in 2003	Dead in 2003	Observed in 2005	Dead in 2005	Observed in 2006	Dead in 2006
2002	10	10	2	0	0	0	0
2003	10			10	0	4	4
2005	5					5	5

Study species.—The Yellow-spotted Goanna (*Varanus panoptes*), is a large (up to 1.5 m) carnivorous lizard inhabiting woodlands and floodplains in New Guinea and northern Australia (Cogger 2000). In our study area this species exhibits a dramatic sexual dimorphism in body size, males often reaching snout-vent lengths (SVL) of > 65 cm and a mass of > 5 kg; whereas, the largest female captured had a SVL of 50 cm and body mass of 2.5 kg (pers. obs.). The species is a generalist predator, preying upon both invertebrates and vertebrates including frogs, snakes, and rodents (Shine 1986; James et al. 1992; pers. obs.).

Monitoring and radio-tracking.—We caught goannas in daytime using a 6 m long rod with a noose attached to the end. We restrained the legs along the body and tail using strong adhesive tape. On each specimen, we recorded the SVL (cm), tail length (cm), head length (from snout to the anterior part of the eardrum, in mm), head width (measured across the centre of the eyes, in mm), tail circumference (measured close to the vent, in mm), and body mass (g). We used the presence of hemipenes to sex goannas and individually marked each animal by branding symbols on the lateral surface of the tail (see Madsen and Shine 2000 for details). Fieldwork took place from August to November in 2001, 2002, 2003, 2005, and August 2006.

In September 2002, we implanted 150 MHz radio

transmitter (Model # AI-2T; Holohil Systems Ltd., Carp, Ontario, Canada) in ten male goannas, ranging in SVL from 56 to 68 cm and mass ranging from 2,739 to 6,650 g. We anaesthetised them with halothane, and surgically implanted the radio transmitters into the peritoneal cavity. The restrained lizards remained in captivity for four days to facilitate healing of the sutured wound. The transmitters measured 45 x 15 mm (18.5 g) and had a battery life expectancy of 36 months. Reception distance of the telemetry signal ranged from 100 to 700 m depending on the location of the goanna.

We used more powerful transmitters and a different methodology for attachment to goannas in subsequent years. In September 2003, we attached the transmitters (Holohil model # AI-2B; 43 x 15 mm, mass 30 g, battery life expectancy 36 months) to the tails of another 10 male goannas. The SVL of these males ranged from 50 to 66 cm and mass ranged from 2,287 to 6,010 g. In September 2005, we radio-tagged another five males (SVL 58–66 cm, mass 2,875–5,050 g). We anaesthetised the goannas using halothane and drilled two holes, 45 mm apart, through the dorsal part of the tail about 30 cm from the vent. Two plastic cable ties inserted through the holes of the tail and brass casing of the transmitter held transmitters sufficiently tight so that the transmitters remained aligned along the tail. As the dorsal part of the tail consists mainly of cartilage, and very thick keratinous skin, this method resulted in



FIGURE 1. A radio-tracked Yellow-spotted Goanna (*Varanus panoptes*) that we found dead in August 2006 with a dead Cane Toad (*Bufo marinus*) found approximately 20 cm from its head. (Photographed by T. Madsen)

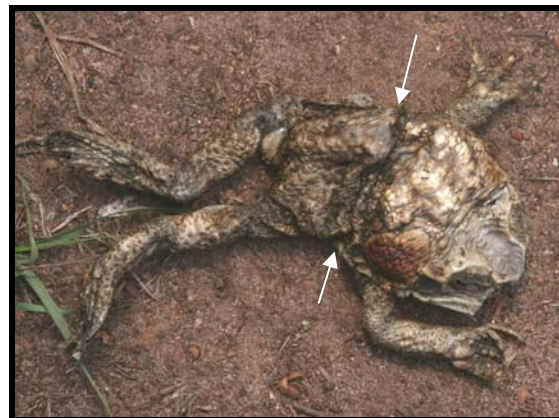


FIGURE 2. The dead Cane Toad (*Bufo marinus*) that was found immediately next to a dead Yellow-spotted Goanna (*Varanus panoptes*; Fig. 1) showing the bite marks across its body. (Photographed by T. Madsen)

minimal bleeding, which stopped within seconds after the transmitter had been attached to the tail. We monitor the goannas daily during our visits to the study area, and noted the location of each lizard on an aerial photographic map (scale 1:5,000). We tested for differences in survival rates of goannas before and after the appearance of Cane Toads in the study area using the two-tailed Fisher's Exact Test (Agresti 1992), with an alpha value of 0.05.

RESULTS

The ten goannas implanted with transmitters in September 2002 survived through September 2003. However, the largest male (mass 6,650 g) was severely emaciated in November 2003, and it died a few days later (mass 4,750 g). In November 2003, a second goanna died along a dirt road. Its wounds suggested it was killed by a car (Table 1). We did not find any of the remaining eight goannas in 2005 (Table 1), despite extensive searches throughout our study area.

The 10 goannas released in September-October 2003 were still alive September 2005 (Table 1). In October 2005, we observed the first Cane Toads within the Fogg Dam Reserve, and during late November numerous toads (up to 10 toads/night) occurred both within the reserve and on the Adelaide River floodplain. The toad population expanded rapidly, and large numbers of metamorphs were present until late April in 2006 (Greg Brown, Ben Phillips, and Peter Fisher, pers. comm.). Thus, the 2005–2006 wet season was likely the first time that goannas in our study area encountered large number of Cane Toads.

In August 2006, we found four of the goannas released in 2003, and all five released in September 2005 dead on the Adelaide River floodplain (Table 1). The remaining six goannas that we released in 2003 remained unaccounted for. We excluded these six goannas from our subsequent mortality analyses. The difference in goanna mortality prior to (two deaths recorded among 20 goannas during 36 mo) and after the arrival of the toads (all nine were dead during an 11 month period) is significant (two-tailed Fisher's Exact Test, $P < 0.001$).

DISCUSSION

Until November 2005, 80% (8/10) of goannas survived for > 1 yr (released in 2002) and 100% (10/10) for > 2 yr (released in 2003), demonstrating that adult male Yellow-spotted Goannas typically have a very low annual mortality rate. However, between 2005 and 2006 mortality increased significantly (9/9 goannas found dead). The first cane toad known within the Fogg Dam Reserve appeared in October 2005, and during the subsequent 2005–2006 wet season, the toad population

expanded rapidly (pers. obs.). Yellow-spotted Goanna readily succumb to Cane Toad ingestion (Doody et al. 2006; Smith and Phillips 2007), which strongly suggests that the significant increase in goanna mortality recorded between 2005 and 2006 resulted from goannas feeding on Cane Toads. This is supported by observations of mummified adult Cane Toads found next to one of the dead goannas in August 2006. Furthermore, our interpretation of the cause of death is corroborated by a study conducted along the Daly River in the Northern Territory of Australia, where a substantial reduction in goanna numbers (77–92%) accompanied the arrival of Cane Toads (Doody et al. 2006). Our results, unfortunately, also suggest that a large proportion (most likely > 90%) of naive Yellow-spotted Goannas in our study area succumb upon Cane Toad invasion.

Preservation of genetic diversity is crucial to maintain viable wild populations (reviewed in Frankham et al. 2002). However, short or continued periods of small population size (bottlenecks) usually reduces genetic diversity (Frankham et al. 2002). In our study area, the dramatic increase in implied mortality likely due to Cane Toads may substantially decrease goanna population size and genetic diversity. Depending on the magnitude and duration of such a bottleneck, the deleterious effects of low genetic diversity, such as inbreeding depression, may impede the future long-term survival of goannas (Madsen et al. 1996; Madsen et al. 1999; Ujavari et al. 2002). It is critical that further long-term monitoring of demographic and population sizes of goannas continue and that studies take place to investigate the potential reduction in genetic diversity of these lizards induced by Cane Toads in the Adelaide River floodplain.

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Beata Ujvari restraining a noosed Yellow-spotted Goanna (*Varanus panoptes*). Photographed by Thomas Madsen.



Thomas Madsen holding a White-throated Goanna (*Varanus albigularis*) captured in Botswana. Photographed by Beata Ujvari.