Do Cane Toads (*Rhinella marina*) Impact Desert Spring Ecosystems?

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Abstract

Since their introduction in 1935, cane toads (*Rhinella marina* (Linnaeus, 1758)) have established and spread throughout north and north-eastern Australia. Cane toad impacts on terrestrial ecosystems are well documented, but impacts on aquatic ecosystems are less well known. We investigated the diet of cane toads collected from warm Great Artesian Basin-fed springs on Edgbaston Reserve in central Queensland, Australia. A higher proportion of aquatic invertebrates to terrestrial invertebrates was found amongst their alimentary canal contents. Aquatic taxa consumed included molluscs (Gastropoda), insects (Coleoptera) and crustaceans (Amphipoda). Given this diet, the presence of cane toads at Edgbaston Springs, and the high endemicity of the aquatic biota of these springs, we conclude that *R. marina* present a threat to the conservation of desert spring ecosystems.

Keywords: Queensland, Edgbaston, spring, Great Artesian Basin, aquatic invertebrates, pest, invasive species

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Introduction

The cane toad *Rhinella marina* (formerly *Bufo marinus* (Linnaeus, 1758)) is an amphibian native to Central and South America belonging to the family Bufonidae. This species was introduced to coastal Queensland in 1935 as an ultimately unsuccessful biological control agent for sugar cane pests (Freeland, 1984; Lever, 2001). Since then, it has spread widely throughout north and north-eastern Australia (Sutherst et al., 1995; Urban et al., 2007), causing significant negative impacts on Australian ecosystems (Phillips et al., 2003; Shine, 2010).

Cane toads are opportunistic generalist feeders (Zug & Zug, 1979; Reed et al., 2007; Heise-Pavolv & Longway, 2011) and are able to withstand a wide range of climatic conditions (Lever, 2001; Urban et al., 2007). Their resilient nature in combination with the high vagility of adults has enabled the species to expand its range to now occupy over 1.2 million km^2 of Australia. They are predominantly found in tropical and subtropical areas including much of Queensland. There is potential for this range to further expand to over 2 million km^2 across all mainland states (Urban et al., 2007).

Like many introduced species, cane toad populations in Australia are exposed to few of the predators, parasites and pathogens present in their native range (Speare, 1990), reducing the impacts of predation and disease on population size and life expectancy. Furthermore, all life stages of the cane toad (from egg to adult) contain toxins such as bufotoxins and bufogenins, which deter predators (Alford et al., 1995). Having not historically encountered these toxins, Australian fauna lack behavioural or physiological mechanisms to alleviate either exposure or the toxic responses to exposure (Lever, 2001).

While the ingestion of cane toad toxins threatens a variety of Australian fauna (Doody et al., 2009; Phillips et al., 2003; Shine, 2010), the direct consumption of native fauna by the cane toads is also a threat. Cane toads are indiscriminate feeders able to form large populations, which can consume large quantities of invertebrates (Zug & Zug, 1979; Freeland et al., 1986; Shine, 2010; Heise-Pavlov & Longway, 2011).

The adult cane toad diet has been studied extensively, with alimentary canal contents dominated by terrestrial invertebrate prey (e.g. beetles, termites and ants) (Freeland, 1984; Strüssmann et al., 1984; Freeland et al., 1986; Reed et al., 2007; see also Shine, 2010). Current evidence is lacking regarding adult cane toads specifically targeting aquatic invertebrates, with no previous research into the diet of cane toads inhabiting springs. There are, however, documented cases of aquatic macroinvertebrates, such as beetles from the families Hydrophilidae and Dytiscidae, being consumed by cane toads (Hinckley, 1963), indicating this species is a potential threat to aquatic ecosystems. Aquatic predators are further threatened by cane toads as the consumption of cane toad eggs and tadpoles can be fatal due to their toxicity (Crossland & Alford, 1998; Somaweera & Shine, 2012).

R. marina was recently identified as a potential threat to the unique Great Artesian Basin (GAB) spring wetland communities in Queensland (Fensham et al., 2010), including the Pelican Creek spring complex, partially located on Edgbaston Reserve. The spring wetlands within Edgbaston Reserve represent a permanent source of water in a semi-arid region, and their long isolation has resulted in a diverse and endemic GAB spring community of fish, aquatic plants and aquatic macroinvertebrates (Ponder & Clarke, 1990; Wager & Unmack, 2000; Fensham et al., 2010). All GAB spring communities are listed as Endangered under the Australian *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act), with several endemic species also individually listed as endangered or vulnerable (of particular note are the red-finned blue-eye (*Scaturiginichthys vermeilipinnis*) and the Elizabeth Springs goby (*Chlamydogobius micropterus*)). As available sources of water in often arid or semi-arid regions, GAB springs inherently attract a range of fauna including introduced species such as feral pigs and cane toads (Fensham et al., 2010; Fensham et al., 2011). While the permanency of surface water in springs provides opportunity for cane toads to persist in this dry landscape, the underlying processes and mechanisms of their potential impacts are yet to be quantified.

This paper presents an initial investigation of the adult cane toad diet within a GAB spring wetland at Edgbaston Reserve in central Queensland. It was hypothesised that given the opportunistic feeding habits of adult cane toads and the limited surface water in these regions, adult toads will be consuming aquatic invertebrates from GAB springs. If so, this poses a threat to the endangered GAB spring community within Edgbaston Reserve, in particular the rare and endemic aquatic invertebrates.

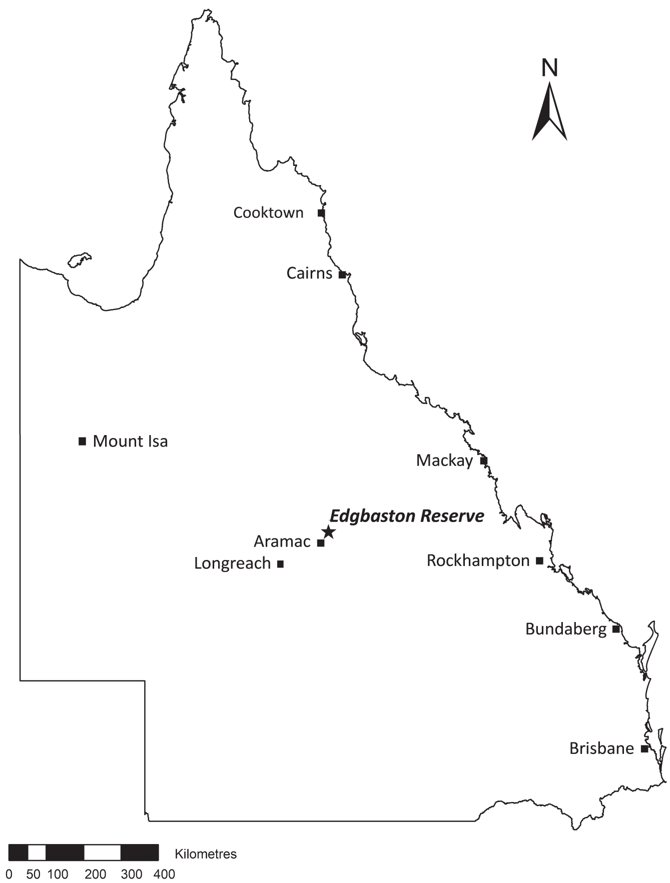
Materials and Methods

Study Location

Toads were collected from one GAB spring located within Edgbaston Reserve (Figure 1) approximately 32 km north-east of Aramac, in central Queensland, Australia (22.735218°S, 145.421172°E). The spring is located on the eastern side of Edgbaston Reserve at the base of the Desert Uplands escarpment, on the north-eastern side of the GAB (Kerezsy, 2011). There are up to 180 springs in the complex (Fensham & Fairfax, 2009) with varying surface extent. These contain the highest number of endemic macroinvertebrates of all the spring complexes in Australia (Ponder et al., 2010) and are home to two endemic fish species – the endangered red-finned blue-eye (*S. vermeilipinnis*) and the vulnerable Edgbaston goby (*C. squamigenus*).

Cane toads and macroinvertebrates were collected from spring NW30, which is situated in close proximity to other springs in the northern section of the spring complex within Edgbaston Reserve. NW30 is one of the larger springs in the complex, with a surface extent of 2723 m^2 at the time of sampling (mean extent within complex = 1155 m^2) (Blessing et al., 2012). Harsh weather conditions characterise the semi-arid climate in this area. Mean annual rainfall is 692 mm, while mean annual evaporation is over 1997 mm (EHP, 2009). Mean minimum and maximum temperatures in the area (Barcaldine) for the month of sampling (July) are 7.9°C and 22.6°C, respectively (Bureau of Meteorology, 2012). Spring NW30 is fed by warm groundwater and has a daytime water temperature range of 20–33°C throughout the year (Fairfax et al., 2007).

Figure 1. Cane toads and macroinvertebrates were sampled from within a Great Artesian Basin spring wetland located on Edgbaston Reserve, Queensland.



Sample Collection

Cane Toads

Cane toad specimens were collected during a two-person, 15-minute spotlighting survey in and around the entire extent of spring NW30 (Figure 2), during the late evening in early July, 2011. All specimens were euthanised and frozen prior to transportation to the laboratory.

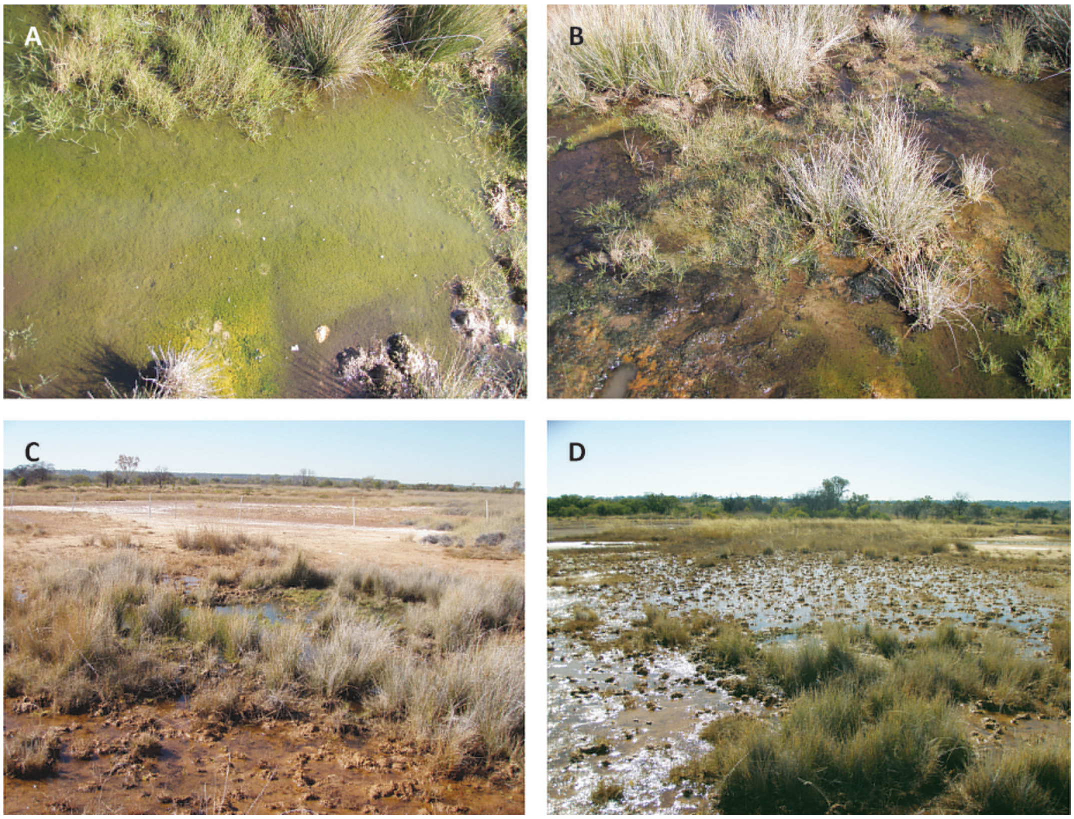
Aquatic Macroinvertebrates

Aquatic macroinvertebrates were collected from spring NW30 using a 250 µm mesh dip net. Five metres of spring habitat were sampled using a combination of short lateral sweeps (approximately 30 cm each) and vertical lifts. Macroinvertebrates were live-picked in the field and preserved in 100% ethanol for transportation. Specimens were typically identified to the taxonomic level of family, with the exception of Chironomidae (identified to subfamily), Acarina, Hirudinea, and Oligochaeta (identified to subclass), and Ostracoda (identified to class).

Laboratory Analysis of Cane Toads

Cane toads were defrosted prior to laboratory analysis, blotted dry with paper, weighed to the nearest 0.1 g, and snout-urostyle length (SUL) (mm) recorded prior to dissection. The length of the alimentary canal (mouth to anus) was removed, measured and placed onto a Petri dish lined with 1 mm graph paper. Visual assessments of both the stomach and intestinal tract were made to determine the fullness of each using the following categories: 1) Empty; 2) Little (<25%); 3) Some (25–75%); and 4) Full (>75%).

Figure 2. Photographs of a Great Artesian Basin spring wetland within Edgbaston Reserve showing (A, B) a warm spring vent; (C) spring vent encompassing the area sampled for cane toads and aquatic macroinvertebrates; (D) cooler spring outflow area – no cane toads were captured in this area.



An indirect volumetric method was used to assess the relative contribution of food items in the alimentary canal as per Hyslop (1980). Alimentary canal contents were placed onto a Petri dish sitting on top of 1 mm graph paper and compressed to a constant depth of approximately 1 mm thickness. Each food item was scored according to the number of graph paper squares covered, and expressed as a percentage of the total number of squares covered. The volumes of large items that could not be compressed were estimated.

Food items were categorised into: unidentified material, detritus and sand, aquatic invertebrates, and terrestrial invertebrates. Where possible, individual specimens were further identified to class, order or family level, and the number of each noted. Coleoptera were identified to family where possible; however, in the case of detached elytra, these were classified as 'aquatic' if they were visually identical to the elytra of beetles in the corresponding aquatic macroinvertebrate sample or to other identified aquatic specimens within the toad alimentary canal contents. Two detached elytra were counted as representing a whole specimen.

Results

Cane Toads

Thirteen cane toads (12 male and 1 female) were collected from spring NW30 during the survey, all of which were found within 3 metres of the spring vent despite the total surveyed area being larger. The mean defrosted specimen weight was 45 g (range 24.7–134.3 g); mean SUL was 76 mm (range 64–111 mm); and the mean alimentary canal length 282 mm (range 198–414 mm). Three toads had empty stomachs, while the remaining 10 contained 'little' stomach matter (i.e. <25% full). Intestinal tract fullness consisted of 4 toads with 'little' content and 9 with 'some' content (i.e. 25–75% full).

Sixty-five percent of the volume of material identified from cane toad alimentary canal contents fell into the category of 'detritus and sand' (Figure 3). Less than 2% of the material was categorised as 'undetermined digested material' that could not be identified, and this was recorded in only three of the toads. The remaining 34% of the alimentary canal contents was identified as invertebrates, represented by 15 aquatic and four terrestrial taxa. Of this volume of invertebrates, aquatic taxa made up 29.5%, whereas terrestrial invertebrates made up only 4%. Aquatic Coleoptera represented 15.8% of the volume, aquatic Gastropoda 11.4%, and the remaining 2.3% of aquatic invertebrates consumed was comprised of Acarina, Amphipoda, Diptera, Epiproctophora, Hemiptera, Hirudinea, and Oligochaeta (Table 1). On average, toad alimentary canal contents contained approximately 40 individual aquatic organisms (dominated by Coleoptera and Gastropoda) and 2 individual terrestrial organisms (dominated by the family Formicidae, i.e. ants) (Table 1).

Aquatic Macroinvertebrates

Fourteen taxa were represented in the aquatic macroinvertebrate sample collected from spring NW30 (Table 1). Specimens from the Families Dugesiidae, Leptoceridae, Culicidae and from the class Ostracoda were present in the macroinvertebrate sample but not found within the alimentary canal contents. Conversely, terrestrial invertebrates and several aquatic macroinvertebrates were found exclusively in the cane toad alimentary canal contents.

Discussion

Previous studies have identified terrestrial invertebrates as the dominant prey items of toads, though as opportunistic feeders they have the ability to impact significantly on taxa that would normally comprise only a small part of the diet (Shine, 2010). Alimentary canal contents from this study confirmed this, as, with the exception of detritus and sand, invertebrates made the largest contribution to the diets of *R. marina* collected from a GAB spring within Edgbaston Reserve. This was in terms of both contributions to alimentary canal volume and the number of individual prey items consumed.

Figure 3. Mean percentage of food items found in cane toad alimentary canal contents (n = 13). Standard error bars (±1 standard error) are shown.

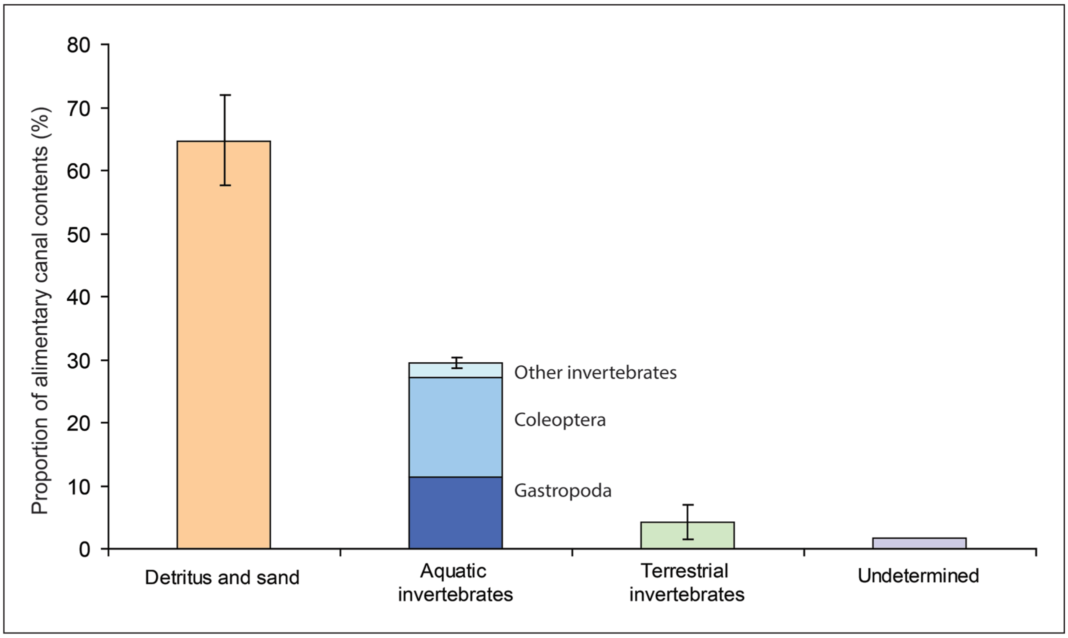


Table 1. Aquatic and terrestrial invertebrate taxa recorded from cane toad alimentary canal contents and the aquatic invertebrate sample collected from the corresponding GAB spring. Mean abundances of invertebrate taxa consumed per cane toad are shown, with ranges (minimum and maximum) in brackets.

Taxonomic group	Taxon	Present in aquatic invertebrate sample	Present in cane toad alimentary canal	Mean abundance per cane toad
Aquatic				
Acarina	Acarina	✓	✓	0.23 (0–2)
Amphipoda	Hyalidae	✓	✓	0.38 (0–2)
Annelida	Hirudinea	✗	✓	0.46 (0–6)
	Oligochaeta	✗	✓	0.08 (0–1)
Coleoptera	Dytiscidae	✓	✓	0.62 (0–5)
	Hydraenidae	✓	✗	0
	Hydrochidae	✗	✓	0.08 (0–1)
	Hydrophilidae	✓	✓	0.77 (0–4)
	Undetermined aquatic Coleoptera	✗	✓	9.54 (0–40)
Diptera	Chironomidae	✗	✓	0.08 (0–1)
	Culicidae	✓	✗	0
	Stratiomyiidae	✗	✓	0.15 (0–1)
Epiproctophora	Libellulidae	✓	✓	0.08 (0–1)
Gastropoda	Bithyniidae	✓	✓	0.62 (0–3)
	Hydrobiidae	✓	✓	25.23 (0–102)
	Planorbidae	✓	✓	1 (0–7)
Hemiptera	Corixidae	✗	✓	0.31 (0–4)
	Pleidae	✓	✓	0.08 (0–1)
Ostracoda	Ostracoda	✓	✗	0
Platyhelminthes	Dugesiidae	✓	✗	0
Trichoptera	Leptoceridae	✓	✗	0
AQUATIC SUBTOTAL				**39.71**
Terrestrial				
Araneae	Araneae	✗	✓	0.08 (0–1)
Hemiptera	Aphididae	✗	✓	0.08 (0–1)
	Other terrestrial Hemiptera	✗	✓	0.23 (0–2)
Hymenoptera	Formicidae	✗	✓	1.38 (0–10)
TERRESTRIAL SUBTOTAL				**1.77**
TOTAL				**41.48**

Cane toads were found to consume a large proportion of the available aquatic taxa, with eight of the 11 orders of aquatic invertebrates found in the corresponding macroinvertebrate sample also found in alimentary canal contents. Previous studies have shown that toads will preferentially consume small-bodied terrestrial invertebrates (Strussmann et al., 1984); however, they have also been shown to have opportunistic generalist feeding habits (Zug & Zug, 1979; Strussmann et al., 1984; Reed et al., 2007; Heise-Pavolv & Longway, 2011) which these results support. The categorisation of over half the alimentary canal contents as 'detritus and sand' (mainly sand) demonstrates the 'sloppy' feeding style of toads (Zug & Zug, 1979), which results in their often ingesting large amounts of superfluous material such as sand and detritus when capturing their prey (Hinckley, 1963; Zug & Zug, 1979).

Aquatic beetles (Coleoptera) and snails (Gastropoda) accounted for the majority, by volume and number, of the aquatic taxa consumed. Of the toads examined, 85% had aquatic beetles in their alimentary canal contents. Although gastropods were not identified to species level for confirmation of endemicity (due in part to damage during digestion), it is likely endemic species were consumed since all six snails within the family Hydrobiidae found at Edgbaston Springs are endemic, as well as one species of Bithyniidae and several species of Planorbidae (Ponder et al., 2010).

The distribution of material in the alimentary canal showed digestion of prey had already progressed beyond the stomach to the intestine, meaning soft-bodied taxa such as flatworms (the only planarian found at Edgbaston is the endemic *Dugesia artesiana* (Sluys et al., 2007)) could potentially have been consumed but already digested beyond identification (Heise-Pavlov & Longway, 2011; Zug & Zug, 1979). To minimise this, future studies could consider instant freezing using liquid nitrogen or the in-situ removal of the alimentary canal prior to transportation to the laboratory for processing.

If the abundance of aquatic macroinvertebrates consumed by cane toads continues at this rate, there is potential for cane toads to alter the spring's macroinvertebrate community. The significance of this finding is compounded given that the collection of toads for this study was undertaken during mid-winter when toad activity is suppressed by cold nightly air temperatures (Freeland, 1984) (below 0°C at the time of collection). It is of interest to note that although the sampling area encompassed the entire spring extent, cane toads were only found and collected in close proximity to the spring vent. The temperature of the discharging groundwater was warm (24°C) and remains above 20°C throughout winter (Fairfax et al., 2007). With increasing distance from the spring vent, water temperatures dropped significantly and no toads were detected more than 3 metres from the warm vents. During warmer ambient conditions or periods of higher rainfall, toads may change their diets (possibly to more terrestrial sources, lessening the pressure on the springs) as their ability to feed away from the warm spring water increases. Further diet analyses of additional toads collected from in and around the springs during warmer months and in periods of high rainfall, along with concurrent terrestrial and aquatic invertebrate sampling, are required. This will reveal if cane toads continue to preferentially feed on aquatic macroinvertebrates throughout the warmer/wetter months, exerting ongoing pressure on endemic species and communities.

Modelling using biophysical and climatic data shows that much of Queensland and northern Australia is currently suitable for cane toads, and will continue to be suitable under future climate scenarios (Kearney et al., 2008). Currently found within eastern GAB springs in Queensland (Fensham et al., 2010), cane toads have the potential to continue expanding their range to other GAB spring communities and wetlands in regions characterised by a scarcity of surface water.

This initial investigation supports the notion that cane toads can directly impact GAB spring communities via predation of aquatic invertebrates. It is possible that the local consequences of this could be significant, given the small spring size and the endemicity of the aquatic invertebrate fauna. The trophic cascade caused by the feeding habits of cane toads could also pose a threat to spring communities, as experimental studies have attributed changes to terrestrial/floodplain invertebrate community assemblages to cane toad predation (Greenlees et al., 2006; Shine, 2010). Large numbers of cane toads in areas of the Northern Territory have also been identified as the apparent cause of reductions in both the abundance and species diversity of insectivorous reptiles due to the depletion of their food supply (Catling et al., 1999).

These results suggest that in addition to current practices to manage threats (see Kerezsy, 2011), management of the springs within Edgbaston Reserve could consider incorporating measures to reduce toad abundance or prevent them from accessing springs. That cane toads seem to congregate around the spring vents could also aid in the collection/extermination of toads during the colder months, as the vents act as a lure. Recent advances in cane toad control using fences (Florance et al., 2011) and pheromones (an alarm pheromone and an attractant pheromone can be used respectively to selectively kill or attract the tadpoles) (Crossland et al., 2012; Crossland & Shine, 2012) may provide solutions.

Further research and monitoring is required to better establish the threat the cane toad poses to GAB spring communities. This includes establishing an accurate distribution map of cane toads at GAB springs, as well as establishing if the cane toads are breeding within the springs. In addition to cane toads, the viability of endemic spring species is also at risk due to multiple additional threats, including mosquitofish (*Gambusia holbrooki*) and feral pigs (Fensham et al., 2010). Further research to inform the ongoing management of each individual threat is required to ensure conservation of these unique ecosystems.

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Author Profiles

The authors are aquatic ecologists with an interest in assessing threats to freshwater ecosystems. Sara Clifford, Alisha Steward, Joanna Blessing and Peter Negus (project leader) undertake the Q-catchments Program (formerly the Stream and Estuary Assessment Program) within the Water Planning Ecology Group (WPE) of the Queensland Department of Environment and Science. Q-catchments is a state-wide program which monitors the condition of freshwater ecosystems, specifically relating to anthropogenic risks to condition whilst confirming and improving on current understanding of processes. As Principal Scientist of WPE, Jon Marshall is actively involved in all of the group's projects, including Q-catchments.