Government of South Australia
South Australian Arid Lands Natural Resources Management Board

CARING FOR OUR COUNTRY

October 2013

South Australian Arid Lands Natural Resources Management Board

Cane toads and South Australian Arid Lands geomorphology

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CANE TOADS AND SOUTH AUSTRALIAN ARID LANDS GEOMORPHOLOGY

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October 2013

Report to the South Australian Arid Lands Natural Resources Management Board

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This report may be cited as:

Wakelin-King, G.A., 2013. Cane Toads and South Australian Arid Lands Geomorphology. Report by Wakelin Associates to the South Australian Arid Lands Natural Resources Management Board, Port Augusta.

Cover image:

L) Cane Toad [Credit: David Peacock]

R) Cooper Creek's North West Branch is a complex of discontinuous distributary channels, set amongst dunefields, alluvial flats, lakes and swamps. [Image prepared by Gresley Wakelin-King, Wakelin Associates, using part of the Strzelecki Rural 2001 orthophoto. Orthophoto custodian: South Australian Department of Environment, Water and National Resources, Adelaide.]

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Introduction

During 2011-2012, the South Australian Arid Lands Natural Resources Management Board (SAALNRM) undertook the (Caring for our Country) Cooper Creek project “Managing the high ecological value aquatic ecosystems (HEVAE) of the Cooper Creek catchment (SA section)”. As part of the sub-project “Geomorphological assessment and analysis of the Cooper Creek catchment (SA section)”, this report considers the feral cane toad and how the study area’s landforms contribute to or detract from its possible invasion paths and habitats. The area covered by this report encompasses the Cooper's catchment within South Australia, and also considers an area extending northeast ~400 km upstream from the South Australia-Queensland border (where the geomorphology is of direct relevance to the aims of this project).

This report on cane toads is a partner to the report “Geomorphological assessment and analysis of the Cooper Creek catchment (SA section)” (Part 1: “Geomorphology Report and Recommendations” and “Part 2: Technical Report”) (Wakelin-King 2013).

Summary and Recommendations

Cane toads are an invasive species whose range in Australia is rapidly increasing, and whose effect on ecosystems derives from toad toxicity to predators (Shine 2010). In the high-value aquatic ecosystems of refuge waterholes, animals (including fish, Greenlees & Shine 2011) are at risk from eating the highly toxic eggs and less toxic tadpoles. Though in other locations larger fish and turtles are protected from the toxic eggs because of the eggs’ emplacement in shallow water, the Cooper’s succession of flood peaks risks washing eggs into deeper waters where larger animals can eat them. The rich riparian zones of refuge waterholes are equally important to land animals, who will be at risk from predation on the terrestrial adult toads. Established toad colonies along the Cooper are clearly undesirable.

It is less obvious that unsuccessful toad colonies may also be highly detrimental to Cooper Creek ecology. Toad colonies may not be able to establish if their breeding ponds – on the floodplain – are only temporary. The toads might lay eggs, but perhaps the shallow water will not persist long enough to grow adult toads able to migrate. However, that brief time of floodplain inundation is an important time in fish ecology. Fish escaping from their refuge waterholes seek the floodplains as an opportunity to feed, grow, and find new breeding grounds. Thus, toad eggs may pose a new threat at a time which is critical for the genetic diversity of arid-zone fish.

The cane toad life cycle consists of breeding, eggs, tadpoles, metamorphs, and adults. Breeding must take place at the water’s edge, and the eggs and tadpoles are aquatic. The metamorphs and adults are terrestrial, and risk drowning in deep water. The adults are extremely tough, can travel long distances (up to 1.3 km in a night), and can tolerate some desiccation, but they must rehydrate every couple of days. The metamorphs are highly vulnerable to desiccation, and must stay close to water. For the cane toad invasion front to establish in a new location, the key habitat requirements are water for rehydration while travelling, daytime shelters, and suitable breeding habitat.

Across Australia, the cane toad invasion front has recently increased in rapidity, and by virtue of both behavioural change and genetic alteration the toads are increasingly able to occupy challenging habitat. Fortunately, cane toad dispersal takes place by movement of the terrestrial adults, not by swimming of the aquatic stages, so the recent wet years may not have promoted toad expansion beyond what has been observed in drier years. They have reached southwestern Queensland, and there is no reason why they can't penetrate further down Cooper Creek. Published models of cane toad expansion, which conclude that South Australia is too dry for cane toad populations to establish, are based on a poor understanding of Channel Country rivers and are certainly incorrect.

Whether water is available for rehydration of toads travelling down moisture corridors of the Cooper depends on 1) how far apart water bodies are, and 2) the hydrology at the time in question (how long since the last flood; the degree of floodplain inundation). In order to prioritise likely cane toad invasion pathways and identify “weakest link” reaches for targeted toad control, it is desirable to document for various flow conditions the locations of permanent, semipermanent, and temporary waters, and what their upstream-downstream distance relationships are.

There is no shortage of landforms and landscape elements that could serve as toad shelters during the day (Fig. 1). This is not a limiting factor to cane toad invasion and establishment. As well as natural features, toads are good at exploiting human habitat, and community engagement will be an important factor of their control.

 

Fig. 1 Potential daytime shelter for toads: left, bank tree roots near Tilcha Waterhole; right, a distributary channel offtake with vegetation.

There are many potential breeding sites available to invading cane toads (Fig. 2, Table 1). Cooper Creek's hydrology is not dependent on locally-derived rainfall; much of its water comes from the semi-tropical north. Current hydrological investigation indicates that (Justin Costelloe, pers. comm. 2012):

- under the current evaporation rate and inflow frequency, many waterholes and lakes persist for years to decades (Table 1);
- the longest period of probable no flow in the Cooper since 1939 was 21 months, and waterbodies >4 m in depth should retain water for longer than that period;
- Coongie Lake has probably only dried twice, briefly, in the last 40 years
- upstream from Coongie Lake (Northwest Branch) and Embarka Waterhole (Main Branch) there are a string of essentially permanent waterholes all the way up to the upper catchment;
- downstream of these locations, the waterbodies would periodically dry out and could remain dry for several years.

In fact, the waterholes of the Coongie Lakes area already support Central Australia’s richest frog community (Reid & Puckridge 1990). There are also many artificial water sources from human-built infrastructure: short-term but numerous over a wide area (e.g. borrow pits) and long-term to permanent (evaporation ponds, dams). Higher salinity or lower pH may be detrimental to toads, and a more detailed picture of the Cooper Creek’s and the lakes’ water chemistry would assist in prioritising control areas.

Some potential breeding sites are along the Cooper Creek Fan distributary channels, thus ideal sites for radial dispersal (Fig. 2). Others are landforms along the banks, or upstream-downstream margins, of high-value aquatic ecosystems such as the Coongie Lakes, Tirrawarra and other swamps, Lake Hope, and the Cooper Creek waterholes. In wet years, natural breeding sites may bring toad populations within reach of isolated artificial permanent waters, where (should they become established) they may survive through droughts to re-infect the catchment later.

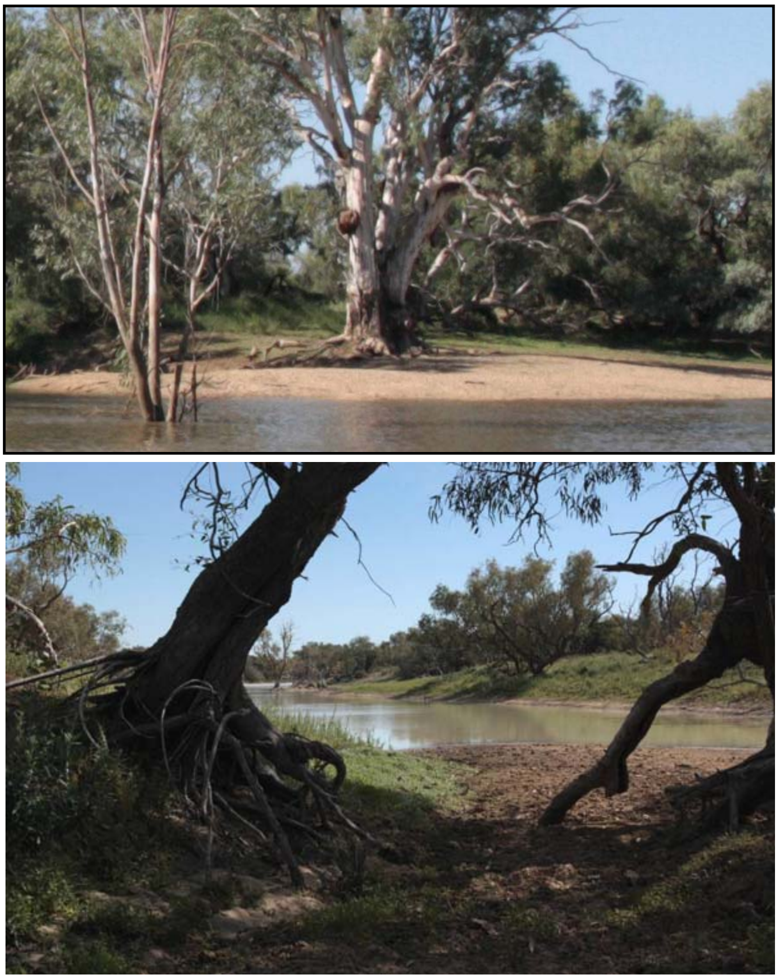

Fig. 2 Potential toad breeding sites with access to shelter, water and clear, gently-sloping water edges: top, a sandy bar at the offtake leading to Napeowie waterhole and the Coongie Lakes; bottom, at Gidgealpa Waterhole a small fan of sediment extends into the waterhole from a stock pad and gully.

It is highly desirable that the cane toad invasion front should be slowed and intensively managed while it is still in Queensland. Failing that, it is extremely desirable that the cane toads be intensively managed along the reaches of Cooper Creek which flow through the Innamincka Dome (Nappa Merrie, Cullyamurra, down to Burkes waterhole). The narrowness of the floodplains, the flanking hills of gibber, and the good road access makes these appropriate control points. If the cane toads get as far as the Innamincka town common, they will have access to a radial, distributary river network, from which they will have access to the rest of Cooper Creek and the Strzelecki Creek.

Locations	Maximum Cease-To-Flow Depth	Water persistence without inflow (y)	Inflow frequency /a
Murken waterhole (Qld) #	5.14	2.2	<1
Yalungah waterhole (Qld) #	4.31	1.9	<1
Meringhina waterhole (Qld) #	4.50	2.0	<1
Nappa Merri waterhole	11.71	5.1	<1
Cullyamurra waterhole	25.0	10.9	<1
Minkie waterhole	6.35	2.8	<1
Coongie Lake	1.80	0.75	<1
Tirrawarra swamp*	<1.8?	0.75?	<1
Embarka waterhole	3.80	1.7	1
Gidgealpa waterhole	4.07	1.8	3.6-5.7
Lake Hope	6.80	3.0	3.6
Lake Kilamperpunna	No information	<2?	5.7
Yaningurie waterhole	3.00	1.3	8.0-13.3

Table T1 Persistence of water in the Cooper Ck landscape: approximate values for selected water-retaining landforms, indicating (per annum) how long water persists after a fill event, and how frequently new flows may come in (Justin Costelloe, pers. comm. 2012). Note that these recurrence intervals are indicative only, and cannot fully express the variability of the flow patterns in this catchment; see Costelloe, 2012. # Data from: Hamilton et al. 2005. The mean annual open water evaporation loss at Moomba is 2.285 m y-1.

Recommendations

1. **Development of a strategy for management of the cane toad invasion.** Management of the cane toad invasion front may be more successful in the Queensland reach of Cooper Creek (Windorah to Nappa Merrie) than it has been in the Top End, since the invasion front would only be as wide as the inundated parts of the Cooper floodplain. In combination with maps of dispersion pathways, it may be possible to develop a strategy of slowing or holding the toad front in “weakest link” reaches, by dry-year toad busting and tadpole trapping along key landforms in the primary dispersion paths. If the toads reach the Innamincka Dome, the pinch points near Nappa Merrie and Cullyamurra waterholes are tightly constrained between waterless uplands, and may represent the best places for toad call monitoring, and the best opportunities for defensive toad busting and tadpole trapping.

2. **Better understanding of the cane toads of southwestern Queensland.** Working with the Queensland Desert Channels Group and toad ecologists, establish

the location of the Jundah toad front since the 2010-2012 wet years, and verify the habitat preferences, dehydration and temperature tolerances, and capacity for overland travel of this population of toads. Particular attention should be given to investigating toad exploitation of landform elements that they have not previously encountered: gilgai macropores (“crabholes”), GAB springs, waterhole splay channels, etc.

3. **Database and map of prioritised toad dispersion pathways in southwestern Queensland: finding the “weakest link”**. To manage toad populations before they get to high-value waterholes in South Australia, it would be necessary to work with Queensland agencies to identify pathways along the river network where waterholes or other water sources are close enough together that cane toads may travel downriver. From this information, key locations (“weakest link” reaches) for monitoring, fencing, and toad busting may be selected, such that denying toads this water will break the upstream-downstream dispersion path. A database constructed from geomorphic, hydrologic, landholder and historical data would be used to map spatial relationships of accessible water locations at various flood heights. Water locations would be assessed with respect to toad-travel distances; ideally this work would be done in partnership with toad physiologists and modellers. A GIS dataset of waterhole locations and attributes is already available (Silcock 2009).

4. **Stakeholder engagement with cane toad control in South Australia and Queensland.** Cane toads are known to be particularly successful in exploiting human habitats. If cane toads successfully invade the Strzelecki plain, local control of artificial permanent water and shelter will be very important, especially during dry-year targeted toad control. Measures will include fencing evaporation ponds, monitoring and toad busting dams and borrow pits, and restricting access to daytime refuge sites. The cooperation of the hydrocarbon exploration and extraction industry is particularly important, because their infrastructure is widespread and closely-spaced, and also because their type of work makes toad stowaways a strong possibility.

5. **Document water chemistry in the Cooper and its lakes.** The present information merely covers total solutes expressed as conductivity. A survey of solute type and concentration, pH and other relevant information would assist in prioritising vulnerable areas, and would improve understanding of the nature and causes of down-gradient salinity change.

6. **Landform/habitat mapping of key locations in South Australia and Queensland.** Targeted pest control will be aided by detailed landform mapping to identify likely toad habitat. This will be of assistance in managing toad populations over large waterholes with limited budgets and staff. It is likely to be a very important precursor to toad busting and tadpole trapping in locations of complex geomorphology, such as distributary offtake valleys or complex shallow reaches.

Appendix 1: Technical Background

Cane Toads

The daily cycle of the adult cane toad revolves around hydration and sheltering from desiccation. Toads are nocturnal: they spend daylight hours out of sight, sheltering in small confined spaces (burrows, deep soil cracks in black-soil country, small gaps between rocks) or beneath the cover of vegetation (Tingley & Shine 2011). Their refuge spaces can include apparently quite unfavourable situations (such as hiding beneath a sheet of corrugated iron exposed to the sun, Steve Wilson, ex-Desert Channels Queensland, pers. comm., 2012). At dusk toads emerge from their shelters, to rehydrate by immersing their ventral surfaces in shallow water (they don't drink), and to move around either locally (established populations) or away from the day's refuge site (advancing invasion front). During the night's movement, the toads feed (primarily on insects, but they will eat anything; CSIRO 2003). Males may congregate around a suitable breeding location (open ground around the edge of shallow water) and call to attract females; females may be more widely dispersed away from the breeding locations. Cane toads are known to be very successful at exploiting human environments for shelter and rehydration, utilising sub-floor spaces, pet-food bowls, and drip patches beneath air-conditioners or leaking taps (Matt Greenlees, University of Sydney, pers. comm., 2012).

Cane toad life cycles are dependant upon the availability of warmth and water, but it is important to note that

- the adults are largely terrestrial and their original native range includes seasonal dryness,
- in Australia, they are increasingly occupying zones where conditions are more extreme than those of their native range (Urban et al. 2007),

- their adaptive behaviours have allowed them to be increasingly well-adapted to seasonal drought in the Top End (Brown et al. 2011),
- they have demonstrated plasticity in cold tolerance, allowing them to invade colder regions of south eastern Australia (Kolbe et al. 2010),
- and (most importantly) cane toads at the invasion front also display genetic adaptability, displaying longer legs (fast forward progress, therefore better access to new breeding sites) (Philips et al. 2007), enhanced dispersal abilities (Alford et al. 2009) and greater ability to deal with arid conditions (more rapid water uptake, better ability to travel long distances while dehydrated) (Tingley et al. 2012).

Thus, the cane toad life cycle described below should be recognised as being derived from places where the cane toad currently exists. It does not represent factors that can be assumed to limit the toads' ability to expand into South Australia's Arid Lands.

The cane toad life cycle moves through the following stages: amplexus (breeding), eggs, tadpoles, metamorphs, adult toads. Unless otherwise referenced, this information is pers. comm., Matt Greenlees, University of Sydney, 2012.

1. **Amplexus** (breeding). Toads will seek out a suitable breeding site: a body of still or slow-flowing water, with a shallow edge and little surrounding vegetation. They will preferentially seek such a site (Semeniuk et al 2007), even if it requires they move away from the main river (David Peacock, PIRSA, pers. comm., 2012; and see Doody et al. 2006). Males congregate around the edge, calling for females; females range more widely away from the breeding site, and will come in if attracted by a male's call. Amplexus is when the male clasps the female's back, in order to externally deposit sperm on the eggs as the eggs are laid. Ideally this takes place in shallow water with a gently-shelving incline. Amplexus can take place in a vegetated riparian zone, but it is less common. It can take place in deeper water, or on a more steeply inclined bank, however the female toad risks being drowned. Toad breeding sites are characteristically described as shallow ponds, farm dams, roadside culverts, and shallow streams and billabongs (Philips et al. 2007, Kearney et al. 2008, KBT1 2012). *Parameters:* the likelihood of a breeding event is restricted by minimum temperature; maximum temperature has not been known to be a controlling factor.
2. **Eggs** are laid in shallow water: the female toad's feet are touching the ground when she lays the eggs, and her head is above water. The eggs are laid in long neat strings of non-toxic gelatinous material containing of pairs of very toxic tiny black eggs. It is not known whether the egg strands are sticky; it is possible that eggs might float free, or become entwined around vegetation, and they have been known to become stranded by falling water levels. It is

unlikely that the eggs would remain viable if they are out of the water for very long. Two possibilities arise if egg strings become detached from the breeding site and transported elsewhere (for example, by a flood pulse). Firstly, the eggs may be transported to a new hatching location. This will be detrimental if toad control is being targeted around known breeding sites. Secondly, the eggs may end up in deeper water, bringing their toxin within the depth range of larger waterhole fish or turtles. To date, there have been no reports of egg detachment, however the locations of previous studies have not been on rivers whose water levels fluctuate on a day-to-day basis (whereas the Lake Eyre Basin channel country rivers are characterised by complex hydrology and multiple flood peaks). *Parameters:* the time needed between laying and hatching is generally 2-3 days, however that will be temperature dependent, and there are indications that toads are adapting to cooler temperatures. The effect of water salinity and acidity on the eggs is currently being investigated.

3. **Tadpoles** will move between shallow and deep water but are most often seen as swarms in shallow water (close to the ideal metamorph habitat). The time needed between hatching and metamorphosis can be as little as 17 days or as much as 6 months (CSIRO 2003). The amount of time they spend in this stage affects their adult fitness. If they spend a short time as tadpoles, they turn into little metamorphs and are thus less resistant to desiccation, and their fitness as adults is also compromised. *Parameters:* this stage is affected by temperature, feeding, competition, and the presence of predators (fear pheromones lead to faster development, therefore the tadpoles are smaller when they turn into metamorphs). Tadpoles will live amongst emergent vegetation. Tadpole swarms caught up in flowing water might result in dispersal, however if they're not at the water's edge during metamorphosis the metamorphs will drown. The effect of water salinity and acidity on tadpoles is not known.

4. The **metamorphs** are tiny black toadlets. They are very prone to dehydration, and cluster near muddy gently-sloping banks near the edge of shallow water. They don't need to enter water to rehydrate, just press their ventral surface against damp ground. They don't swim well and might drown in flowing water, however they are unlikely to enter the water. If conditions are dry their daily shelter spot needs to be within a couple of metres of their rehydration spot, however if conditions are moist they can go ~100 m from water. Unlike native frogs, they are not known to shelter in toilet cisterns or bowls. There is no information on the limiting parameters of water temperature, air/ground temperature, water salinity or acidity, or length of time to develop into adult toads.

5. **Adult toads** need to rehydrate regularly, but the length of time between hydration depends on activity levels, temperature, and humidity. Toads that are travelling (invasion front) will be in trouble if they can't rehydrate every 2-3 days, whereas toads that are sheltering have apparently been observed to last two weeks without water (KTB1 2012). Toad activity in the Top End is at a maximum in warm, wet, and windy nights (Philips et al. 2007). Because moisture and warmth is so strongly correlated in the Top End, where most of

> the research has taken place, there is little information on other temperature/moisture conditions, however since toads are ectotherms, minimum temperature is likely to be a limiting parameter. Toads move an average of 50-150 m per night (with much higher maximum distances) so presumably the daytime shelter doesn't have to be very close to the rehydration site.

While there is clear evidence that toads hitchhike in vehicles (Shine Research Group 2011a, NT News Photo Gallery 2012), the most recent invasion wave across the Top End has taken place by the efforts of the toads themselves. Toads expanding into new territory along the invasion front move from one water source to another, so tending to travel long moisture corridors such as river primary flow paths. However they travel overland (not by swimming, although they can swim across strongly flowing streams), and can cross very dry or otherwise difficult country (rocky, densely vegetated, very steep, dry black-soil plains) (Schwartzkopf & Alford 2005, Matt Greenlees pers. comm. 2012). Daily travel distances are typically <100-200m, but vary widely according to conditions. Individuals have been tracked at single-night or average-per-night distances of >200m, 750 m, 1 km, 1.3 km, (Schwartzkopf & Alford 2005, Phillips et al. 2007), and toads have been observed colonising artificial watering points up to 9.5 km from permanent natural waters (Florance et al. 2011) . Invasion front toads tend to travel in approximately straight lines, away from their natal pond. They also tend to keep a distance from other pioneer toads, so the end result is a lot of toads all moving in the same direction. Toads prefer to travel along clear pathways such as roads or cleared fencelines, and travel more slowly in heavier vegetation. The toad populations along the invasion front are different in age/size, gender balance, behaviour, and genetics from those resident in established toad territory, and the complex travel patterns appear to differ along gender lines (Schwartzkopf & Alford 2005, KTB2 2012).

A number of studies have attempted to predict the eventual distribution of cane toads in Australia by matching their known habitat preferences and limiting parameters (temperature, water requirements, etc.) to Australian climate zones (Kearney et al. 2008, Urban et al. 2007, Urban et al. 2008, Florance et al. 2011). While well-grounded in literature on toad ecology, they are inadequate as predictive tools because their understanding of arid-zone landforms and hydrology is minimal. A study on the role of artificial watering points as potential toad habitat (Florance et al. 2011) develops a valuable methodology, but its results are compromised because its data sources (intended to show the locations of permanent natural waters) are incomplete and were not ground-truthed. Sophisticated computer models matching toad physiology to bioclimatic conditions (Urban et al. 2007, Kearney et al. 2008) assesses presence/absence of suitable breeding sites in such an extremely simplistic fashion that the Cooper Creek's permanent waterholes and Ramsar listed wetlands are presumed to not exist. Indicative lengths of water retention of some Cooper Creek waterbodies are shown in Table T1. These publications will disadvantage the South Australian Arid Lands Natural Resources Management Board in competitive funding applications on a national level, since they falsely indicate the SAAL NRM area is unlikely to be in danger of cane toad invasion. While the authors would rightly point out that a model is not supposed to be taken seriously beyond the limitations of its input data, the fact remains that readers unfamiliar with or unaware of those limitations will take the conclusions at face value. This has already occurred (see Peacock 2007, Urban et al. 2008, Phillips et al. 2008, Beckman & Shine 2009, Shine 2010, Florance et al. 2011).

Potential toad habitat in Cooper Creek

The key cane toad habitat requirements are water for rehydration while travelling, daytime shelters, and suitable breeding habitat.

For toads to successfully expand downstream Cooper Creek, rehydration of water sites must be no more than 3-4 days toad-travel apart. Any patch of shallow water (or a shallow edge to deep water) is sufficient for adult toad rehydration, so the availability of sites for toad rehydration depends on the current hydrology of the system. In wet years, water is continuous along the channel network and in places the floodplains are inundated, so there would seem to be few limits to toad expansion down and across the Cooper's fluvial network. In light of the recent flow events (2010-2012) (Costelloe 2012), it would be desirable to actively seek information on the current location of the toad invasion front in Queensland.

In more dry years, the likely expansion corridors would be more limited. It would be possible to map and prioritise likely dispersion pathways for high-flow and low-flow hydrological scenarios by firstly defining the locations of suitable water, by combining

- geomorphic information (flow paths, permanent and semipermanent waterholes, primary and secondary channels, and using gilgai morphology to map more and less-inundated floodplains)
- hydrological data (Costelloe 2012), and

- landholder data, and historical records of waterhole permanence (Silcock 2009).

Water locations would then have buffer zones established around them to indicate toad-travel distances. Where buffer zones intersect, a potential pathway of toad travel would exist. A simplistic model based on the travel distances measured from the Top End would make that distance 3.9-5.2 km. (More sophisticated models incorporating temperature and other biophysical conditions are described in the literature. To apply them accurately it would be desirable to have specific information from the south western Queensland toad populations to see what distances are travelled, and over what weather conditions.) If it is intended that toad populations should be managed before they get to high-value waterholes in South Australia then it would be desirable to work with the Queenslanders to create such a database. The database could be used to identify those parts of the primary flow path which (during dry years) have the furthest-apart water sources; these would be high-priority targets for cane toad control.

An important factor in toad dispersion pathways is the location of artificial water points. The most important thing to understand about cane toad habitat in South Australia is that even where natural waters are only transient, they may be sufficient to allow invading toad populations to reach artificial permanent waters, from whence they can reinfect the system in the next wet year. In the Strzelecki Plain, there are substantial artificial permanent waters, including

- pastoral dams
- water treatment ponds created to service the hydrocarbon extraction industry.

The location of all artificial waters should be included in potential expansion corridors database.

Wherever there is water in the fluvial system, there would be no shortage of suitable places for a toad to shelter during the day, including:

- the tangles of exposed Coolabah roots along the waterhole banks
- beneath fallen branches and logs along waterhole banks, and in channel beds
- beneath vegetation in gullies cutting through waterhole and channel banks
- dense Lignum thickets along the edges of swamps, or some channel and waterhole banks
- within the deep cracks and crabholes of the black soil swamp country

- under the clusters of boulders, where rocky outcrop is close to the water (for example, at Cullyamurra and Nappa Merrie)

- beneath or within human infrastructure: demountable offices, accommodation blocks, toilet blocks, sheds, storehouses, stockpiles on pallets, shipping containers, garden-supply bins

- in or under human objects: shoes, the holes in bricks and bessa-blocks, cars, piles of mulch, scraps of building materials.

- it would be desirable to examine the Channel Country cane toad populations at the invasion front (currently near Jundah), to ground-truth these assumptions.

The final factor in whether or not cane toads can colonise the Cooper Creek catchment relates to suitable breeding sites. Toads prefer small shallow ponds, which would dry quickly under north-east South Australia's dry climate. Assuming such ponds are fed by local runoff, modelling using SA's rainfall:evaporation ratio has assessed north-east South Australia as being at no risk of cane toad invasion (Kearney et al. 2008, Urban et al. 2007, Urban et al. 2008, Florance et al. 2011). However this assessment is incorrect: Cooper Creek is not dependent upon local run-off for its water supply, so rainfall: evaporation ratio is only one of several deciding factors. In fact, upstream from Coongie Lake (Northwest Branch) and Embarka Waterhole (Main Branch) there are a string of essentially permanent waterholes all the way up to the upper catchment; downstream of these locations, there are waterbodies which would hold water for a time, before drying. The Coongie Lakes are drought refugia and RAMSAR-listed high-value aquatic ecosystems.

Small ponds are not the only landforms which can supply the desirable features for cane toad breeding sites (shallow still water, gentle slope, relatively unvegetated water's edge). Suitable landforms are available throughout the Cooper:

- upstream and downstream edges of feeder channels and splay channels of the permanent waterholes

- margins of secondary and minor channels, also flood chutes, palaeochannels and anabranches

- offtakes and distributary channels along the Cooper Creek Fan

- lake edges

- lake input and offtake channels

- swamp edges

- sandy benches where dunes meet channels, or where stock pads come down to the water's edge
- dam edges
- borrow pits
- culverts and under-bridge areas
- flare pits and evaporation ponds of the hydrocarbon extraction industry.

Furthermore, it has not been established that the absence of ideal spots will completely prevent toads from breeding; their adaptability may include using less ideal sites.

Some landforms may be less suitable for cane toads. Heavily vegetated water's edge areas (like some downstream edges of splay channels) may be less desirable as breeding sites (though toads have been observed calling in well-vegetated ponds). Steep waterhole banks may be poor breeding sites, because of the risk of drowning. Lake shorelines exposed to wave action may be undesirable environments for metamorphs and tadpoles, although the sandy beaches associated with those shorelines may be very desirable as breeding sites. Acidity (low pH) is associated with poor health in fish (D. Schmarr, pers. comm. 2012), and heavily vegetated swamp areas (such as Tirrawarra swamp) with brown peaty water may be unsuitable for tadpoles or eggs. Increasing salinity with decreasing water level or with increasing down-valley distance is also likely to be detrimental.

Toads exploit specific microhabitat in their breeding sites (Semeniuk et al 2007). If specific waterholes or lakes are to be the subject of targeted toad control, it may be desirable to undertake detailed geomorphological mapping as an aid to identifying target habitat areas.

Cane toad control

Cane toad control mechanisms are beyond the scope of this report, however at present the indications are that

- "toad busting" (concentrated removal of toads from particular breeding sites or refuge areas) has not halted the invasion front in the Top End, but may (or may not) have slowed it briefly, and has apparently been successful in clearing specific sites, or reducing toad impact at specific sites (Sawyer & Taylor 2005, Peacock 2007, Shine research group 2011b, KTB2 2011, KTB3 2011);

- biological controls do not currently exist, though work is being done on existing cane toad parasites (Shine research group 2011c) and other things (Shannon and Bayliss 2008), while other avenues remain unexplored (Peacock 2006);
- toads can be successfully excluded from small areas by fencing (Stop The Toad 2010, Florance 2011), although the method will be problematic for many fluvial locations, and may be economically not feasible for pastoralists;
- toads are successfully preyed upon by aquatic insects (Cabrera-Guzman et al 2012), meat ants (Shine research group 2011d), crabs (Matt Greenlees pers. comm. 2012; so possibly they might be preyed upon by yabbies), and especially cane toads prey upon each other;
- toad tadpoles are attracted to toad pheromones (in a predator-prey relationship), and tadpole traps might make it possible to clear tadpoles from waterholes (Crossland et al 2012);
- it is possible that a combined strategy of toadbusting plus tadpole pheromone traps may manage toads in specific places, reducing impact on local predator populations;
- however toadbusting is a very labour-intensive operation which must be repeated regularly – it is outside the scope of pastoral station operations, instead requiring staff or dedicated volunteers, and external funding.

Toad busting of adult toads may be more successful in slowing the invasion front in the Queensland (Windorah to Nappa Merrie) reach of Cooper Creek than it has been in the Top End, since the invasion front would only be as wide as the Cooper floodplain. If the “weakest link” locations could be identified in the primary dispersion pathways, where isolating a few water sources would make it very difficult for the front to progress, it may be possible to slow or hold the toad front. Dry-year toad busting and tadpole trapping along key landforms in the dispersion paths would need to be an ongoing effort, with extra resources allocated during/after wet years.

It would be extremely detrimental if the toads were to invade as far as the high-value waterholes within the Innamincka Dome (Nappa Merrie and Cullyamurra), as they would have access to permanent water in these sites, as well as impacting on refuge fish populations. However, these waterholes are tightly constrained between waterless uplands. The pinch points (where the hills most closely constrain the creek, and the floodplains are narrowest) may represent the best places for toad call monitoring, and the best opportunities for defensive toad busting and tadpole trapping.

If cane toads get past Innamincka, and encounter the distributary channel network of the Cooper Creek Fan, they will be much harder to control. They are likely to be able to extend down both branches of the Cooper, into the Coongie Lakes, Kanowna channel, Lake Hope, Strzelecki Creek, Kopperamanna Floodout, and possibly the margins of lakes Frome, Blanche, Gregory. How permanent those populations are will depend on year-to-year hydrology, and water chemistry (salinity, pH) in the various locations. Across these areas, they are also likely to inhabit permanent artificial waters, particularly in the oilfields.

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