The Cane Toad in Australia: Invasion Biology and Control Efforts

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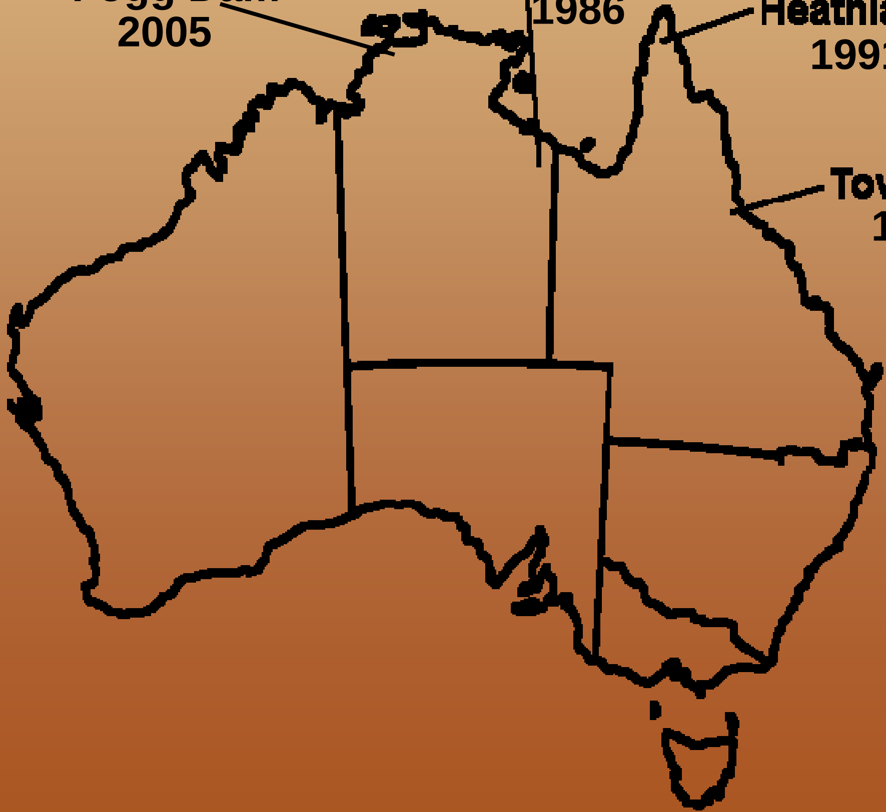
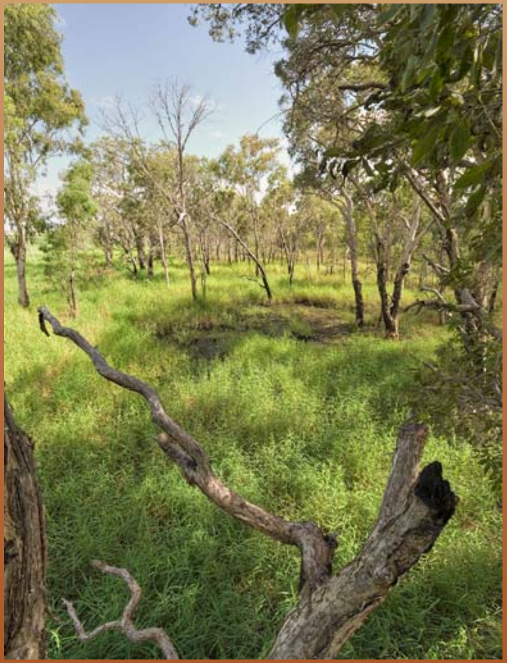
Background

- Cane toads, *Chaunus (Bufo) marinus*, native to South and Central America
- Introduced from Hawaii in 1935
- 6 stages in life history
  - egg, hatchling, larva, metamorph, juvenile, adult
  - each with different ecology
- Map: study sites and dates invaded

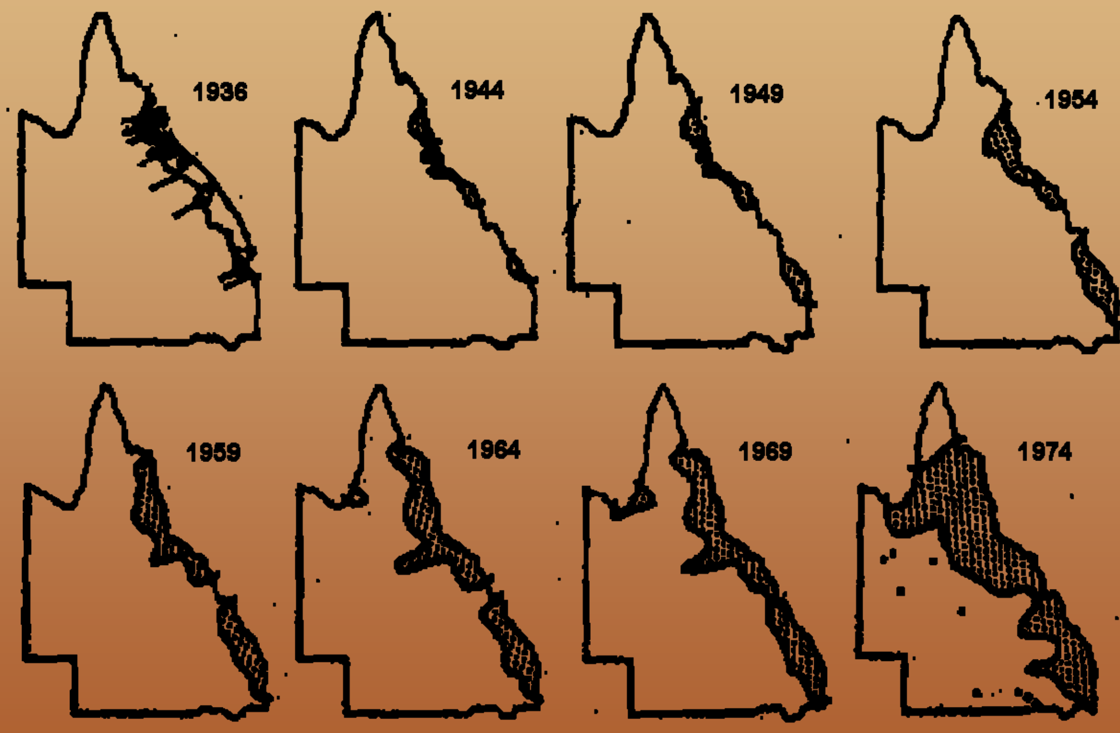


Typical Australian toad habitats



The toad invasion

- Juveniles released at 12 locations on Queensland coast in late 1936



- Range boundary expanded ~30 km/yr in 1980s and 1990s, is now expanding 50+ km/yr

Does nothing control their numbers?

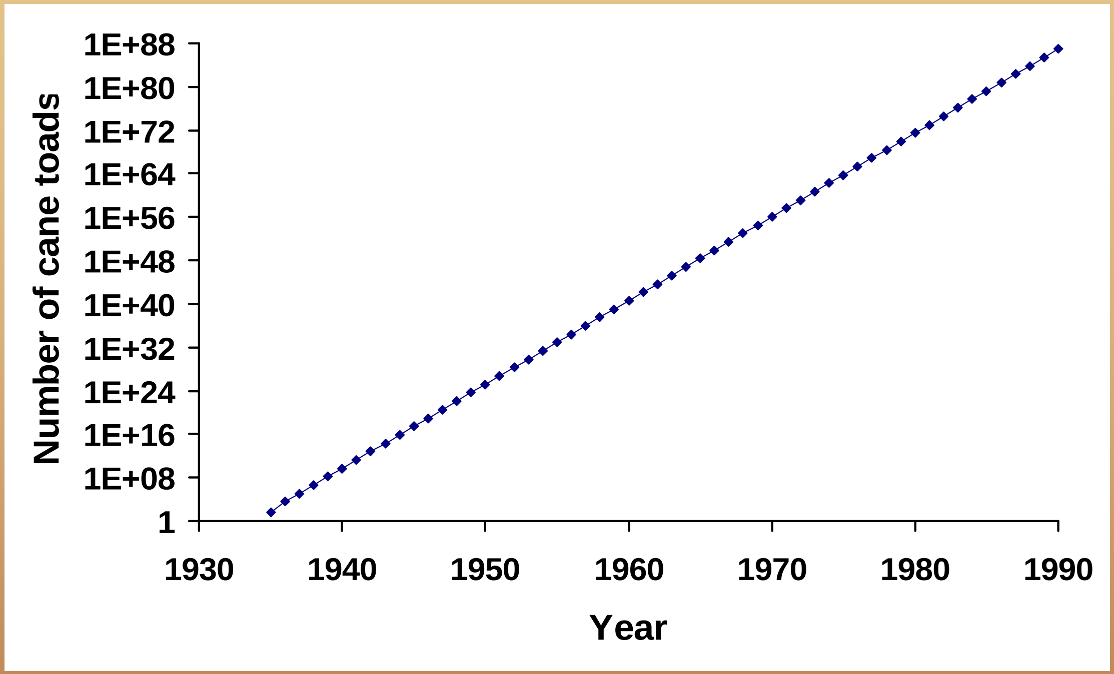
- "The toads are poisonous, so nothing will eat them." http://darwin.bio.uci.edu/~sustain/bio65/lec09/b65lec09.htm
- Females lay 7,000-30,000+ eggs

Does nothing control their numbers?

- **Thought experiment: what would have happened if only 1% of eggs (70/female) survived to adults?**

Year	Number of cane toads
1935	100
1936	3500
1937	122500
1938	4287500

Does nothing control their numbers?



With 1% survival egg to adult, by 1986, there would have been 10^{80}

- as many cane toads as there are atoms in the universe
- A ball of cane toads 2,000,000,000 light years in diameter, ca. 24,000 times as large as the Milky Way Galaxy
- obviously, far more than 99% die before reproducing

Actual survival rates

- 50 female toads introduced in 1935
- Ca. 100,000,000 female toads in 2005, 70 years later
- This would happen if each female toad leads to 1.235 female toads in the next year
- Long-term average mortality rate from egg to adult is really around 99.97%
  - A tiny increase would control or reduce their numbers
  - However, actual survival rates vary enormously, are much higher at the invasion front

Local populations can increase rapidly

- Egg, hatchling survival from <1% to 90%
  - depending on predator levels
- Tadpoles
  - mean densities high enough to cause inter- and intra-specific competition
  - Survival through the tadpole stage 0.1% to 10% (100X variation)
    - depends on levels of competition and predation
    - Intraspecific effects important

(Hearnden 1991; Alford 1994; Alford et al 1995)

Metamorph growth and survival

- Metamorphs (10-25 mm) remain near water, are active during day
- Higher than average densities reduce survival drastically
- First colonists experience low densities

(Cohen 1995; Cohen and Alford 1993; Alford et al 1995)

Growth to adult size

- Egg to adult, during 1987-92
  - Northern territory, ca 1 year
  - Townsville area, ca. 1.5 - 2 years

(Cohen 1995; Alford et al 1995)

First immigrants are larger, and their offspring grow quickly

- Calvert Hills
  - 1986-87, males and females ca. 20mm longer than Townsville
  - 1988, both sexes smaller on average than Townsville toads
    - offspring of original immigrants
  - 1989-1992, almost exactly same as Townsville

- Townsville
  - Both sexes 104 - 106mm mean size, 1986-1992

(Cohen 1995; Alford et al 1995)

Numbers at old and new sites

- New populations reach high densities in the first year
  - Typical numbers near water ca. 1 per 10-40 m^2
  - No consistent differences between new and old populations
- All populations variable, depend on wet and dry season quality

(Cohen 1995; Alford et al 1995)

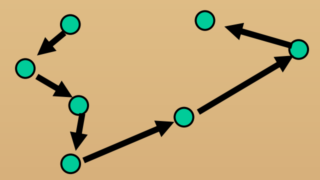
How they invade

How they invade: movement in old vs. new populations

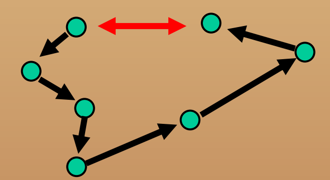
- **Toads fitted with transmitters, located daily in retreat sites**

How they invade: movement in old vs. new populations

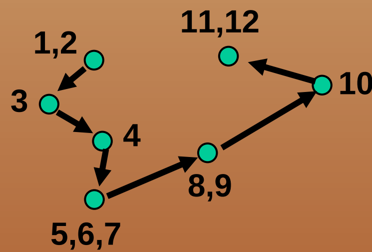
- What we measure
  - Distance moved per day
    - Total track/number of days toad moved



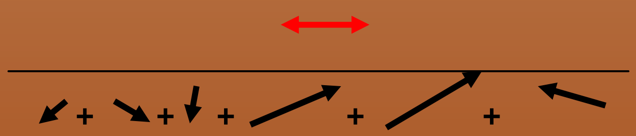
  - Mean daily displacement
    - Distance from first to last point/number of days



  - Probability of changing shelter site
    - Number of sites/number of days



  - Straightness
    - Total displacement/total track



(Schwarzkopf and Alford 2002; Alford et al 1995)

How they invade: movement in old vs. new populations

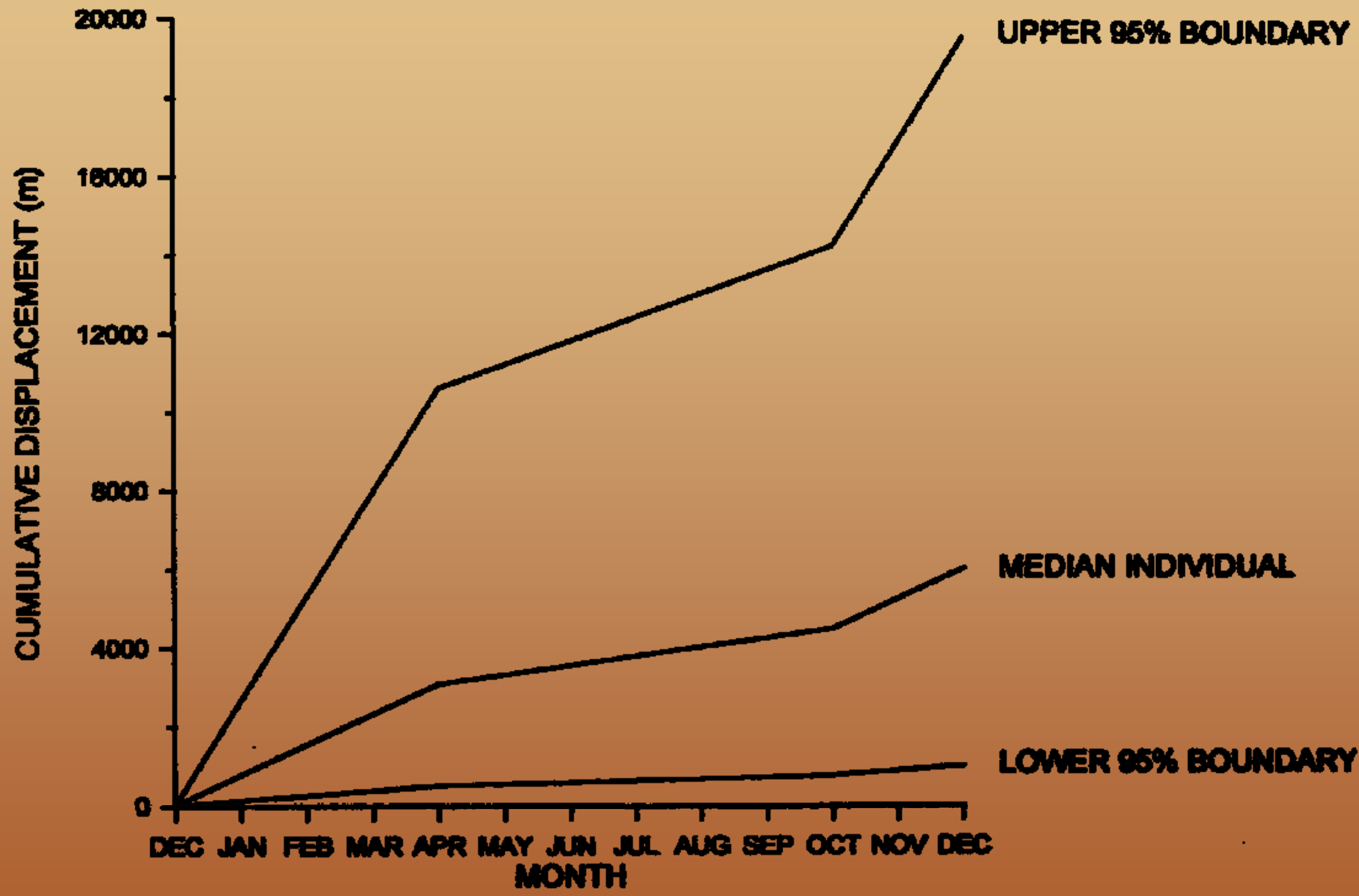
- Gradient from oldest (Townsville, invaded 1940s) through medium (Heathlands, 1991) to newest (Fogg Dam, NT, 2005) populations

- Oldest have
  - lowest mean distance moved per move
  - slowest accumulation of displacement from start
  - return to same retreat most often
  - move along least straight paths

- Newest have
  - greatest mean distance moved per move
  - fastest accumulation of displacement from start
  - return to same retreat least often
  - move along straightest paths

(Alford et al. 2006, 2008)

How they invade, early invasion front (Heathlands) toads



- **Range expansion rate is consistent with movement rates of individual toads**

(Alford et al 1995)

How they invade: movement in old vs. new populations

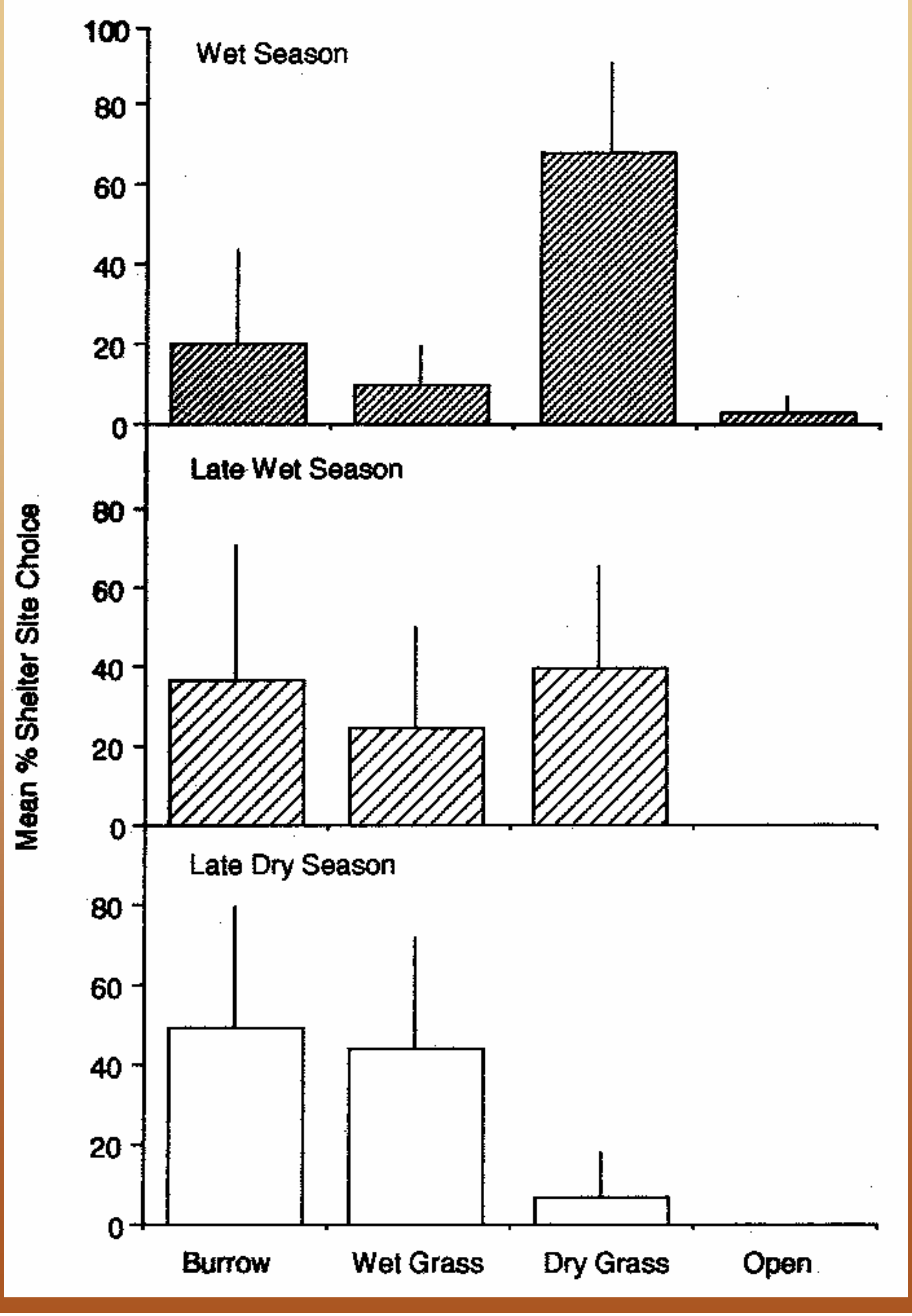
- They invade by being nomadic
  - Much individual variation, but they do not have fixed home sites, once they leave they do not return
- Invasion rate is increasing through time
  - Natural selection: individuals more likely to move reach new areas first, breed very successfully, their offspring that are more likely to move continue the invasion…

(Alford et al. 2006, 2008)

What limits toads

- Competition with other cane toads in aquatic and metamorph stages
- Relatively poorly adapted to life in semi-arid Australia
  - Low resistance to evaporative water loss (EWL)
  - Rehydrate through ventral skin
  - Require frequent access to moist habitat or standing water

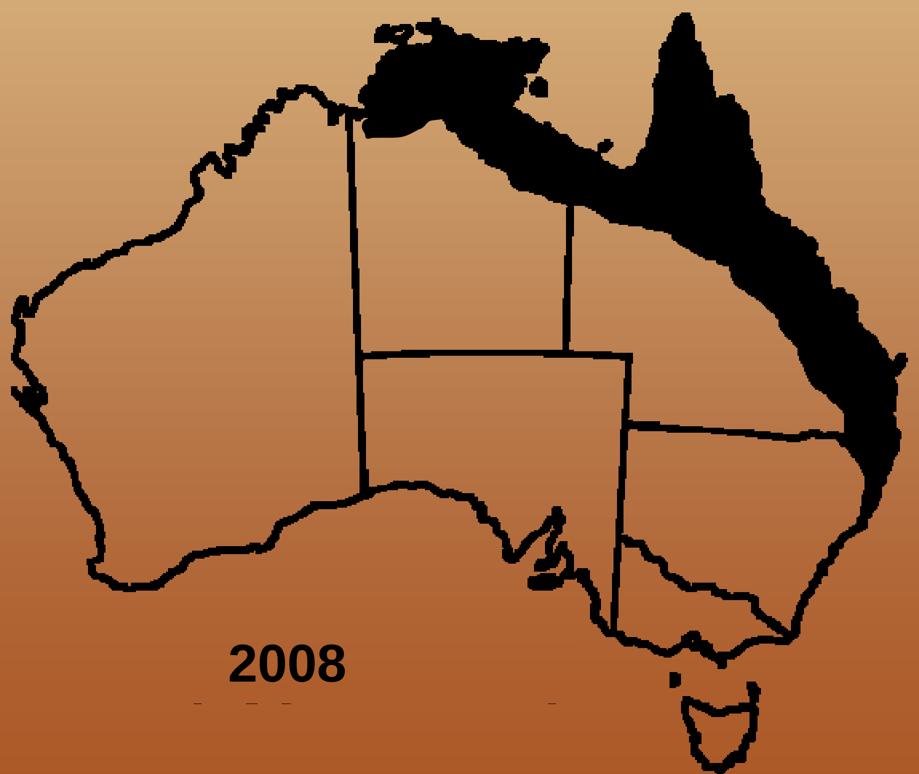
(Alford 1994; Cohen and Alford 1996; Schwarzkopf and Alford 1996; Seebacher and Alford 1999, 2002)



(Schwarzkopf and Alford 1996)

Water is a vulnerability

- Limits their range in the interior
- Provides an opportunity for intensive control during the dry season



Negative effects of toads

- **Toxic to top terrestrial predators**

Toxic to some aquatic species

Predator	Species that prey on			Species negatively affected by		
	eggs	hatchlings	larvae	eggs	hatchlings	larvae
Nepidae	**1/2**	**1/2**	**1/2**	0/1	0/1	0/1
Dysticidae	**4/5**	**4/4**	**4/4**	0/4	**1/4**	**1/4**
Belostomatidae	**1/1**	--	**1/1**	0/1	--	0/1
Odonata	0/1	**2/2**	**2/2**	--	0/2	0/2
Notonectidae	--	**1/1**	0/1	--	0/1	--
Crustacea	**3/3**	**2/2**	**1/2**	0/3	0/2	0/1
Gastropoda	**1/1**	--	--	**1/1**	--	--
Hirudinea	--	--	**1/1**	--	--	**1/1**
Anura	**6/6**	**3/5**	0/5	**6/6**	**3/3**	--
Pisces	**1/1**	--	**2/5**	0/1	--	0/2
Chelidae	--	--	**2/2**	--	--	0/2
Total	17/20	13/16	14/25	7/17	4/13	2/14

- **Negative effects on beetles, snails, leeches, native frog tadpoles**

(Crossland 1998a, b, 2000, 2001; Crossland and Alford 1998)

Altering ecological interactions

- *Bufo* eggs and hatchlings toxic to predatory native tadpoles
- Decrease in abundance of predatory tadpoles leads to increased survival of other natives

(Crossland and Alford *in preparation*)

What limits toads

- Competition with other cane toads in aquatic and metamorph stages
- Relatively poorly adapted to life in semi-arid Australia
  - Low resistance to evaporative water loss (EWL)
  - Rehydrate through ventral skin
  - Require frequent access to moist habitat or standing water
- **Many native predators can eat them, others are adapting to eat or avoid them**
- **Diseases and parasites**
  - **Ranaviruses, many macroparasites including lungworms (*Rhabdias)***

Cane toad control/damage mitigation

- Extensive ecological data shows high intraspecific density-dependence in aquatic and metamorph stages
  - They are poor targets for control measures
- Most control efforts focused on later juveniles, adults

Cane toad control/damage mitigation

- Long term, broad scale
  - Native and exotic diseases, parasites
    - Known diseases and parasites of toads in Australia are shared with native frogs
    - Work on diseases of cane toads outside Australia produced a few possible viruses, initial trials showed they were not toad-specific
    - Future work may concentrate on exotic diseases of other toad species
    - More survey work needed in current Australian toad range
  - Potential for genetically modified "diseases"
    - CSIRO, immunize tadpoles against juvenile proteins

Cane toad control/damage mitigation

- Small scale/short term
  - Identify critical habitat for vulnerable species and reduce or eliminate toads in it
  - Protection of islands of critical habitat that lack toads
    - Actual islands, rock outcrops
  - Slow general rates of spread

Cane toad control/damage mitigation

- **Small scale/short term methods**
  - **Hand collection**
    - **Can work to some extent if carried out when vulnerable, but very labor intensive**
      - Kimberly Toad Busters, 450,000 hours of volunteer effort by 1700 people, have collected over 200,000 adult toads, have only slowed the invasion towards Western Australia
  - **Trapping**
    - **Some success at reducing densities in local areas in the Northern Territory**
    - **Also expensive in effort, more effective traps would reduce this**

Cane toad trap designs

Cage, light, trap door

Cane toad control

- **Trap success might be improved with additional attractants**

- **Olfactory**
- **Acoustic**

(Schwarzkopf and Alford 2006, 2007)

Olfactory Attractants

- **Y-maze**
  - **Male & female cane toads**
  - **Food (Masterfoods™ lamb & marrowbone dog food)**
  - **water**

(Schwarzkopf and Alford 2006)

Olfactory Attractants

Both sexes:

- **Chose same sex**
- **Avoided dog food**
- **Showed no preference for water**

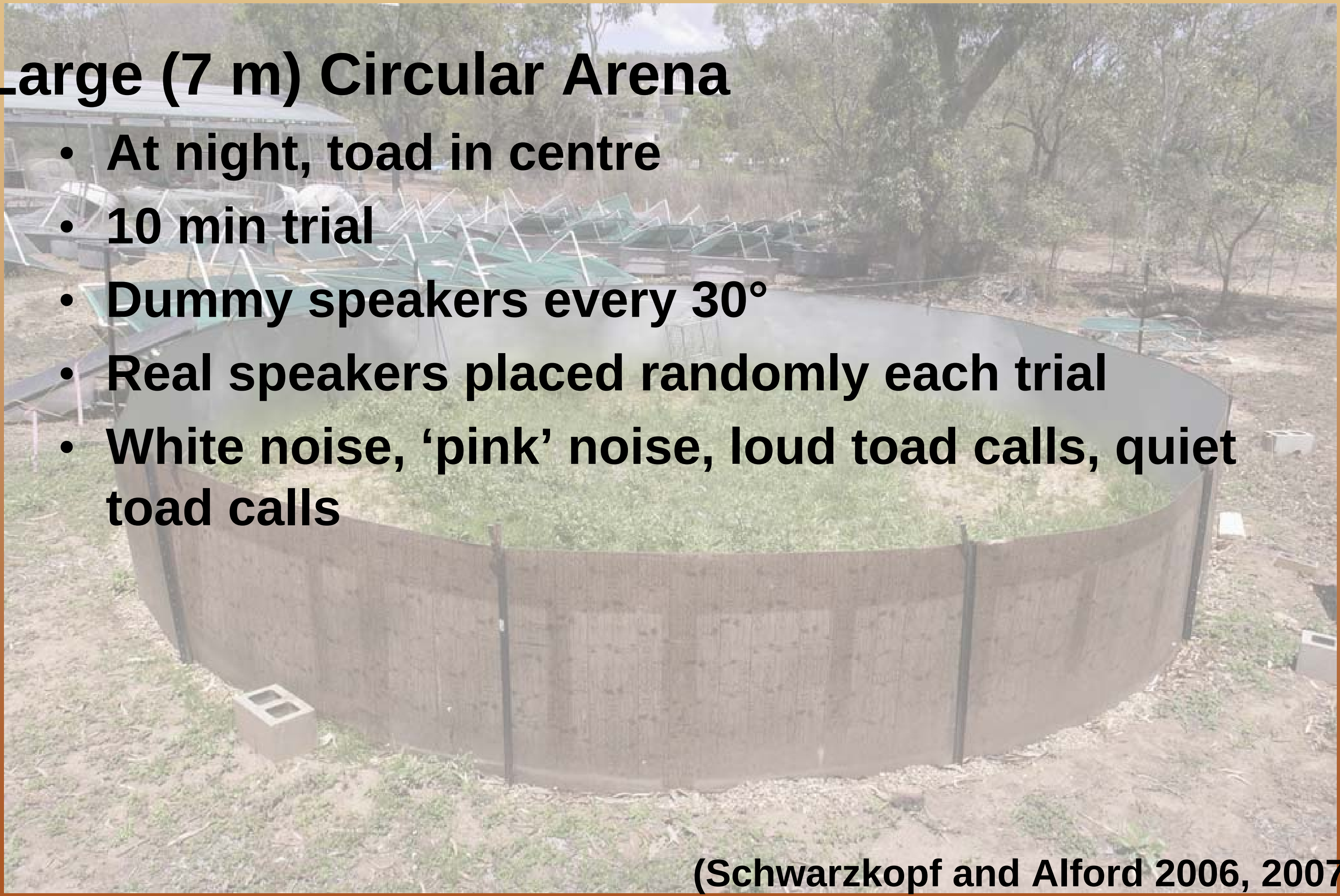
(Schwarzkopf and Alford 2006)

Olfactory Attractants

- **Clearly cane toads can use olfactory cues to make choices**
- **More work needed to isolate and understand cues**

(Schwarzkopf and Alford 2006)

Acoustic Attractants

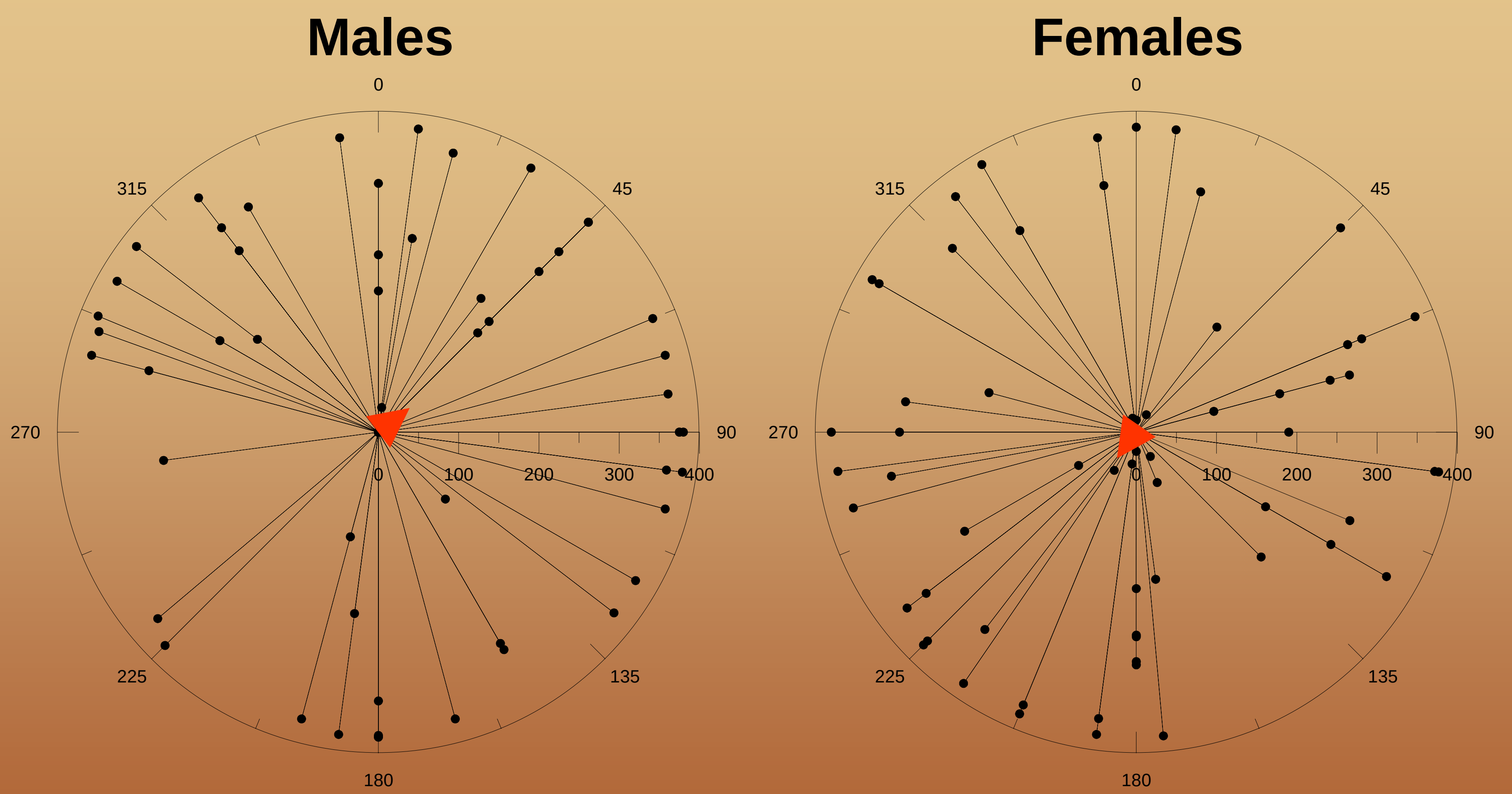


Large (7 m) Circular Arena

- At night, toad in centre
- 10 min trial
- Dummy speakers every 30°
- Real speakers placed randomly each trial
- White noise, ‘pink’ noise, loud toad calls, quiet toad calls

(Schwarzkopf and Alford 2006, 2007)

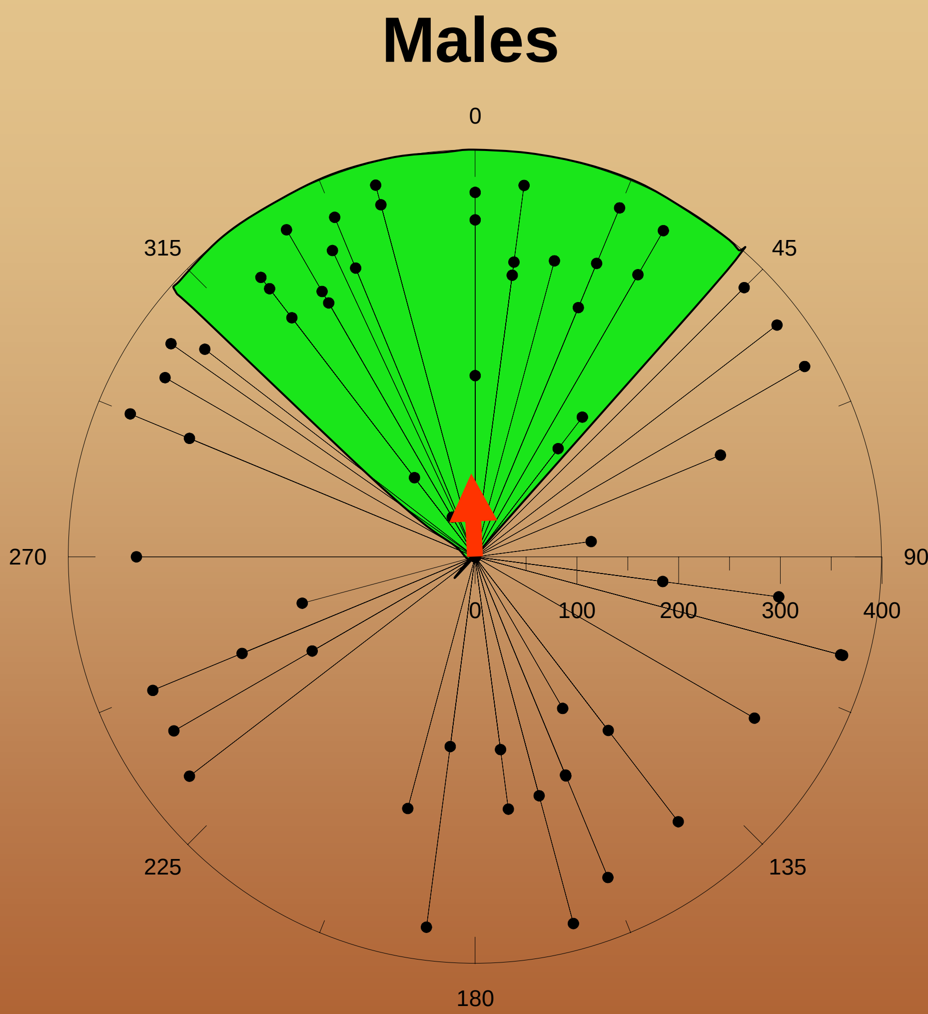
Loud calls

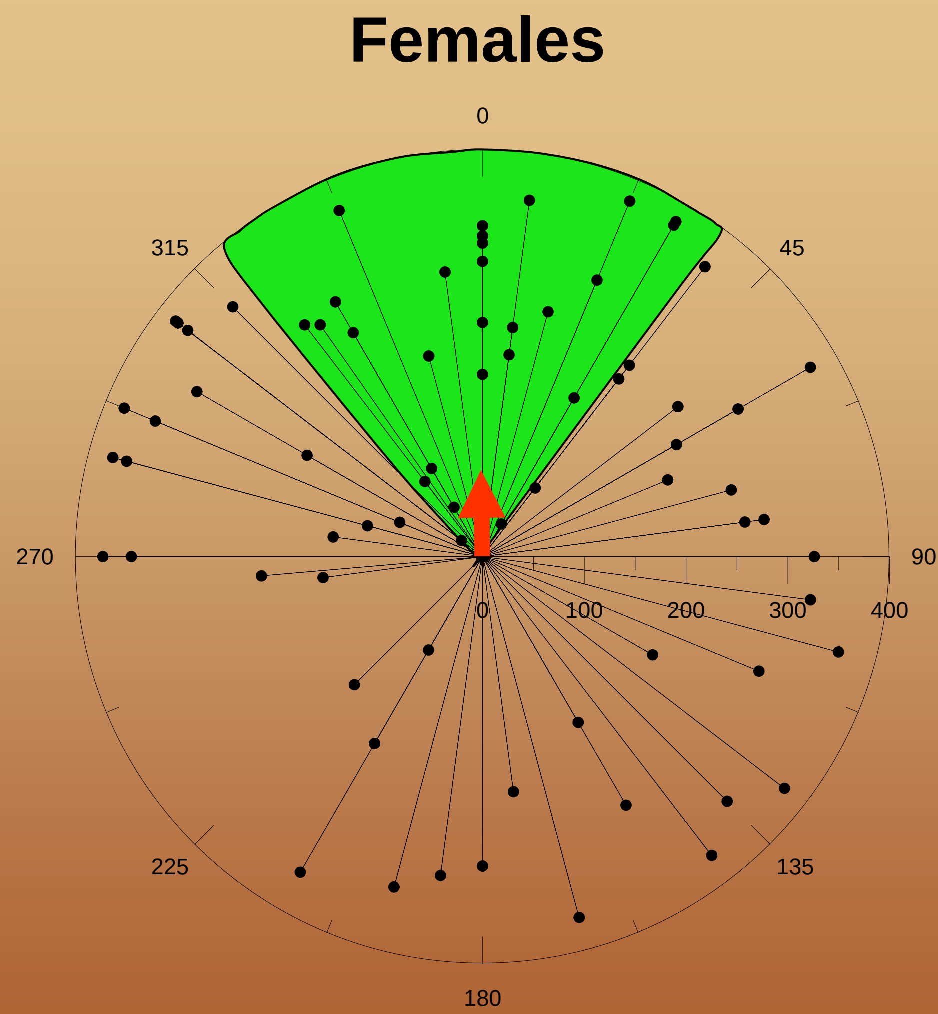


No significant tendency to move towards calls

(Schwarzkopf and Alford 2006, 2007)

Quiet calls





Both have significant tendency to move towards calls

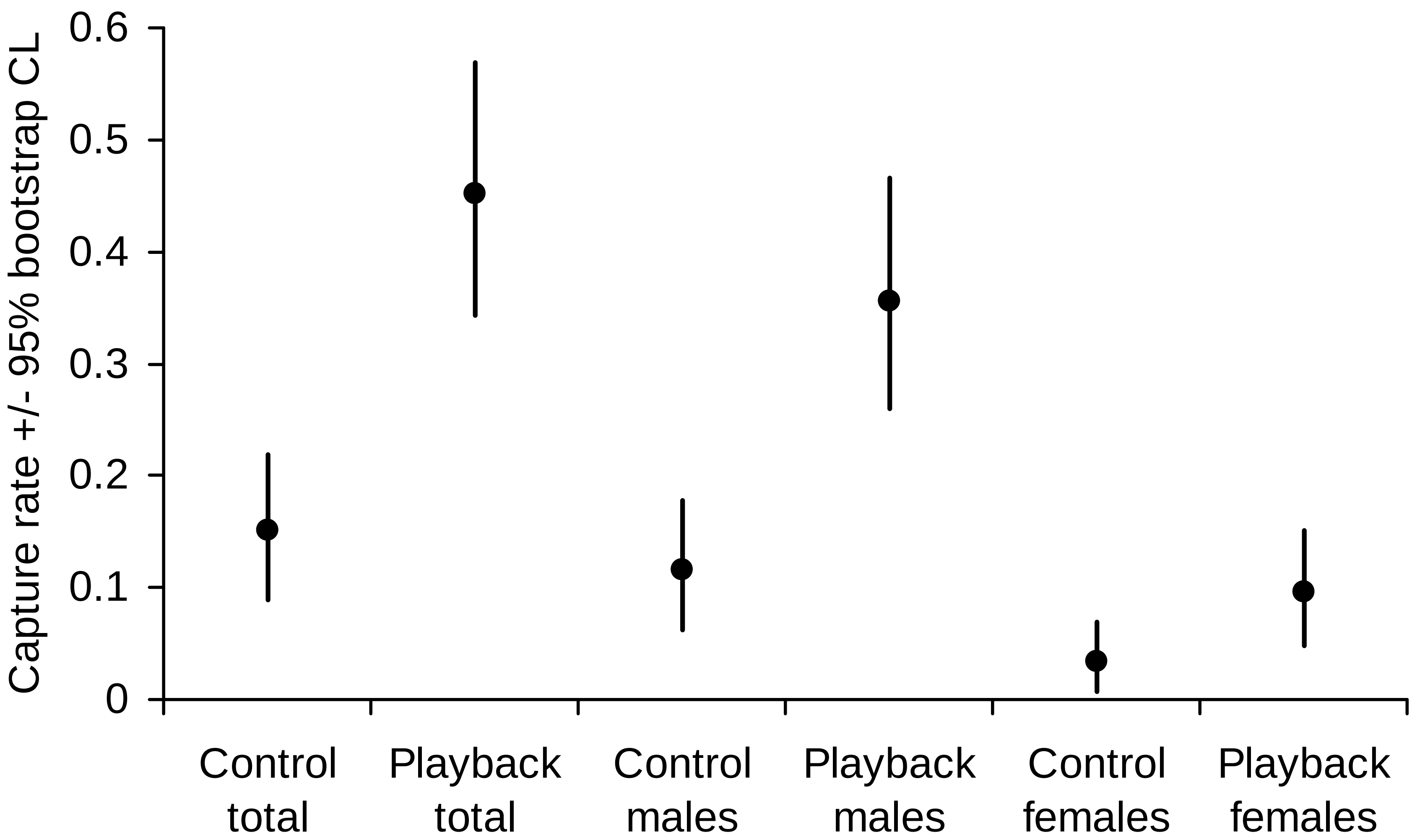
(Schwarzkopf and Alford 2006, 2007)

Trapping + Acoustic Trials

- **Traps deployed in pairs, separated by 50+ metres**
  - **1 in with playback, 1 without**
  - **Pairs at widely separated (1-20 km) sites**

(Schwarzkopf and Alford 2006, 2007)

Trapping trials, capture rates (toads/trap-night)



(Schwarzkopf and Alford 2006, 2007)

Cane toad control/damage mitigation

- Small scale/short term methods
  - Hand collection
    - Can work to some extent if carried out when vulnerable
      - Kimberly Toad Busters, 450,000 hours of volunteer effort by 1700 people, over 1,000,000 toads, have only slowed the invasion towards Western Australia
  - **Trapping**
    - **Effectiveness can be tripled using acoustic attractants**
    - **Can be highly effective, but only in relatively limited areas**
    - **If used in dry season at water, can temporarily clear larger areas, because water concentrates toads**
- **Combinations of trapping, hand collection can reduce impacts in small, protected areas**

Cane toad control/damage mitigation

- Prevention of anthropogenic movement
  - Western Australian government along highway
  - Northern Territory government for island shipping
  - Both use
    - Vehicle/cargo inspection stations
    - Sniffer dogs
    - Containment plans for outbreaks

Summary

- Cane toads have invaded Australia very successfully, and continue to do so, despite mean mortality rates of ca. 99.97% before reproduction
- Control efforts thus far have been ineffective
  - Even the massive KTB effort has only possibly slowed their advance
- In Australia, best strategy appears to be understanding their effects and minimizing them, while working towards long-term understanding of diseases/parasites that might aid in large-scale control
- Controlling anthropogenic spread is also critical

Acknowledgements

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