1   **Title:** Not such silly sausages: Northern quolls exhibit aversion to toads after training with

2   toad sausages.

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Abstract

The invasion of toxic cane toads (*Rhinella marina*) is a major threat to northern

quolls (*Dasyurus hallucatus*) which are poisoned when they attack this novel prey item.

Quolls are now endangered as a consequence of the toad invasion. Conditioned taste aversion

can be used to train individual quolls to avoid toads, but we currently lack a training

technique that can be used at a landscape scale to buffer entire populations from toad impact.

Broad scale deployment requires a bait that can be used for training, but there is no guarantee

that such a bait will ultimately elicit aversion to toads. Here we test a manufactured bait—a

'toad sausage'—for its ability to elicit aversion to toads in northern quolls. To do this, we

exposed one group of quolls to a toad sausage and another to a control sausage and compared

the quolls' predatory responses when presented with a dead adult toad. Captive quolls that

consumed a single toad sausage showed substantially reduced interest in cane toads,

interacting with them for less than half the time of their untrained counterparts and showing

substantially reduced attack behaviour. We also quantified bait uptake in the field, by both

quolls and non-target species. These field trials showed that wild quolls were the most

frequent species attracted to the baits, and that approximately 61% of quolls consumed toad-

aversion baits when first encountered. Between 40-68% of these animals developed aversion

to further bait consumption. Our results suggest that toad-aversion sausages can be used to

train wild quolls to avoid cane toads. This opens the possibility for broad-scale quoll training

with toad aversion sausages: a technique that may allow wildlife managers to prevent quoll

extinctions at a landscape scale.

50   **Introduction**

51   Invasive species are a major threat to biodiversity (Reaser *et al.* 2007; Woinarski, Burbidge

52   & Harrison 2014). In Australia, species such as feral cats (*Felis catus*) (Legge *et al.* 2017),

53   domestic dogs (*Canis familiaris*) (Doherty *et al.* 2017), foxes (*Vulpes vulpes*) (Short & Smith

54   1994; Risbey *et al.* 2000) and cane toads (*Rhinella marina*) (Burnett 1997; Letnic, Webb &

55   Shine 2008; Jolly, Shine & Greenlees 2015) all have serious impacts on native species.

56   Controlling these species at a landscape scale, however, has proved extremely difficult

57   (Ziembicki *et al.* 2015). Because of this, increasing attention is being paid to mitigating the

58   impact of invasives, rather than supressing their populations (Simberloff *et al.* 2013).

59   Cane toads are a case in point. These invasive amphibians now occupy more than 1.5

60   million square kilometres of Australia, continue to spread (Urban *et al.* 2007), and have

61   proved difficult to control. The cane toads' defensive chemicals (bufadienalides and related

62   toxins) are highly cardioactive and are unlike toxins possessed by native Australian animals

63   (Hayes *et al.* 2009). As a result, many vertebrate predators, including varanid lizards, snakes,

64   and marsupial predators such as quolls, die after attacking or consuming toads (Covacevich

65   & Archer 1975; Webb, Shine & Christian 2005; Smith & Phillips 2006; Hayes *et al.* 2009;

66   Shine 2010). Some reptilian predator populations have adapted to the presence of toads by

67   evolving innate aversion to toads (Phillips & Shine 2005; Llewelyn *et al.* 2011). In the short

68   term, some marsupial predators rapidly learn to avoid toads as prey (Webb *et al.* 2008; Webb,

69   Pearson & Shine 2011). An obvious avenue for mitigating the impact of toads, then, is to

70   train predators to avoid toads (Webb *et al.* 2008).

71   Such training can be achieved through conditioned taste aversion (CTA).

72   Conditioned taste aversion is a powerful innate response found across all vertebrates; an

73   evolved defence mechanism against poisoning (Sinclair & Bird 1984; Conover 1995; Cohn &

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74   MacPhail 1996; Bernstein 1999; Mappes, Marples & Endler 2005; Page & Ryan 2005;

75   Glendinning 2007). With CTA, animals acquire an aversion to a referent food as a result of a

76   nauseating experience (Gustavson & Nicolaus 1987). Agriculturalists and wildlife managers

77   have used conditioned taste aversion to reduce wildlife damage to crops, industry, or

78   livestock (Gustavson *et al.* 1974; Ellins & Catalano 1980; Avery 1985; Provenza *et al.* 1990;

79   Ternent & Garshelis 1999; Smith *et al.* 2000). CTA has also been used successfully to reduce

80   predation on native or introduced wildlife (Nicolaus & Nellis 1987; Conover 1989; Nicolaus

81   *et al.* 1989; Semel & Nicolaus 1992; Avery *et al.* 1995; Bogliani & Fiorella 1998; Cox *et al.*

82   2004).

83   One of the Australian species most strongly impacted by cane toads is the northern

84   quoll, *Dasyurus hallucatus*. As toads have spread, they have caused numerous local

85   extinctions of this native marsupial predator (Burnett 1997; Oakwood & Foster 2008). CTA

86   training using small toads infused with the nausea inducing chemical thiabendazole (TBZ)

87   elicits aversion to live toads in northern quolls (O'Donnell, Webb & Shine 2010), suggesting

88   the technique has promise as a management tool for mitigating toad impact. Capacity to

89   elicit aversion is, however, only the first hurdle. To be effective as a management tool, CTA

90   needs to meet two additional conditions. First, CTA training needs to be deliverable to a large

91   number of individuals under field conditions. Second, prey aversion needs to occur in a large

92   enough proportion of the population, and be behaviourally persistent for long enough (within

93   and across generations), that population-level benefits are realised. In quolls, it is clear that

94   CTA training in captivity can be used to elicit toad aversion, and that this aversion improves

95   survival rates when animals are released into the field (O'Donnell, Webb & Shine 2010).

96   More importantly, parentage analyses demonstrated that some offspring of surviving 'toad

97   smart' females also survived and reproduced (Cremona *et al.* 2017), suggesting that training a

98   single generation could yield significant conservation benefits. The remaining challenge then

99   is to effectively deliver CTA training to a large number of individuals under field conditions.

100   In captivity, CTA training was achieved by feeding quolls a small non-lethal-sized

101   toad laced with the nausea-inducing chemical thiabendazole. Such a strategy is not feasible at

102   a large scale in a field setting. To achieve in situ training at scale requires use of a

103   manufactured training bait. Any bait, of course, needs to fulfil the criteria we have identified

104   above: elicits aversion to toads, has a high uptake rate; and effectively trains a high enough

105   proportion of the population that population persistence is assured. An additional

106   consideration is whether the bait is taken by non-target species. This is a major concern in

107   lethal baiting campaigns (Sinclair & Bird 1984; Avery *et al.* 1995; Fairbridge *et al.* 2003;

108   Glen & Dickman 2003; Claridge & Mills 2007; Jolley *et al.* 2012), but a smaller

109   consideration in non-lethal baiting such as we envisage here. Non-target uptake remains

110   important, however, because it can reduce target species' access to bait and so significantly

111   increase the cost and complexity of the baiting effort. Because of this, it is important to

112   understand non-target species uptake rates.

113   In this study we assess the value of a manufactured bait ('toad aversion sausages').

114   We ask whether quolls generalise their CTA from the bait to toads, whether the bait is taken

115   up by wild quolls (and non-target species), and whether it appears to elicit CTA under field

116   conditions.

117   **Methods**

118   *Cane toad sausages*

119   Cane toad sausages were made up of 15g of minced skinned adult cane toad legs, 1 whole

120   cane toad metamorph weighing <2g, and 0.06g of Thiabendazole (per sausage; dose rate less

121   than 300mg/kg adult quoll body weight, determined by the smallest – 200g – adult seen at

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122   our study site) packed into a synthetic sausage skin. In our captive trials, we used the same

123   sausage composition, to accurately reflect our field scenario. Thiabendazole is an

124   inexpensive, broad-spectrum anthelmintic and antifungal agent (Robinson, Stoerk & Graessle

125   1965). It is orally-effective and regarded as relatively safe, producing low mammalian

126   mortality: oral LD_{50} is 2.7g/kg body weight (Dilov *et al.* 1981). It is fast acting and peak

127   concentration occurs in the plasma one hour after consumption (Tocco *et al.* 1966).

128   Thiabendazole has produced strong aversions to treated foods in lab rats (Gill, Whiterow &

129   Cowan 2000; Massei & Cowan 2002), wolves (*Canis lupus*) (Gustavson, Gustavson &

130   Holzer 1983; Ziegler *et al.* 1983), and black bears (*Ursus americanus*) (Ternent & Garshelis

131   1999). Thiabendazole induces a robust CTA after a single oral dose (Nachman & Ashe 1973;

132   O'Donnell, Webb & Shine 2010) and is physically stable at ambient conditions in the bait

133   substrate (Gill, Whiterow & Cowan 2000; Massei, Lyon & Cowan 2003).

134   *Captive trials*

135   The uptake of toad aversion sausages by *D.hallucatus* and their subsequent response to toads

136   was observed in captive northern quolls previously collected from toad-free areas of Astell

137   Island, and then housed at the Territory Wildlife Park, Northern Territory. Animals (9 male

138   and 9 female) were randomly allocated treatment (*n*= 9) or control (*n*=9) sausage groups.

139   Treatment sausages were exactly as described previously. Control sausages were comprised

140   of store purchased beef sausages. These were selected as a control sausage as it was an item

141   that animals are also not familiar with to control for hunger differences and any possible

142   neophobic responses.

143   To measure individual responses to cane toads following ingestion of sausage, each

144   individual was presented with a dead adult cane toad the following evening. The dead adult

145   toad was secured in a wire cage, so that animals could see and smell the prey item but not

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146 access it. The experiment was run over 3 nights. Experiments began at sunset and ran for on

147 average 2 hours. The response was filmed using a GoPro Hero 3 White camera (GoPro Inc,

148 San Mateo, California, USA).

149 **Field trials**

150 *Study area*

151 The field study was conducted between May 2016- February 2017 at Mornington Wildlife

152 Sanctuary, a 300,000 ha property in the central Kimberley region of western Australia

153 managed for conservation by the Australian Wildlife Conservancy (17°01'S, 126°01'E; Fig.

154 1). The area is characterized by savanna woodland dissected by sandstone gorges of varying

155 topographic complexity. On average, this area receives 788 mm of rain annually, most of

156 which falls during the wet season from November to April.

157 We worked at four sites on the property; Site 1 (SJ) was at Sir John Gorge

158 (17°31.780S, 126°13.080E) along the Fitzroy River. Site 2 (KP) (17°31'43.032,

159 126°13'11.050) was approximately 2 km upstream from Site 1 in the same gorge. Site 3 (TC)

160 (17° 30' 37.213,126°14'4.092) was 5 km upstream from Site 2 in a narrow rocky gorge that

161 feeds into Sir John Gorge. Site 4 (RP) (17°35'12.119, 126°19'21.959) was a narrowly incised

162 sandstone gorge following a watercourse within rocky range country approximately 9 km

163 north-east of Site 1. Sites were selected based on the detection of quolls in the Australian

164 Wildlife Conservancy's fauna surveys (AWC unpub. data). At the time of the study, toads

165 were yet to arrive at our sites; they subsequently arrived by March 2017.

166 *CTA sausage field trials*

167 In this study, "site" is the location where an experiment took place. "Bait station" is a

168 location within a site where sausage bait was offered. A "session", is a time interval when

169 bait stations were active. A total of four sessions were conducted approximately five months

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170   apart. Sessions recorded up to four "bait events". Bait Events are defined as an occasion

171   when new bait was placed at a bait station and (if still existing) the old bait removed.

172   Each site contained 20 bait stations placed 50-80m apart in a linear transect along a

173   gorge wall where the presence of *D. hallucatus* was previously confirmed (AWC, unpub.

174   data). Bait stations consisted of one cane toad sausage placed under a single camera trap

175   (White flash and Infrared Reconyx Motion Activated, (HP800, U.S.A). Cameras were

176   secured to trees or rocky ledges approximately 1m from the ground and aligned to face

177   directly downwards (Diete *et al.* 2016). Cameras were set to take five consecutive

178   photographs for each trigger with no delay between triggers. Each cane toad sausage was

179   placed inside a ring of powdered insecticide (Coopex) to protect from ant spoilage. Each

180   session's bait stations were rebaited up to three times (for a maximum of 4 bait events within

181   any given session) whereby bait stations were rebaited with a fresh CTA bait and the old bait

182   removed (Table 1). A total of 513 individual cane toad sausages were deployed over the

183   period of study.

184   **Data analysis**

185   *Captive trials*

186   Videos were scored by the same observer who was blind to the quoll's treatment or control

187   group. Following Kelly and Phillips (2017) we separated the time that quolls spent

188   exhibiting various predatory behaviours into three categories: "Sniff", "Investigate" and

189   "Attack". Sniff was defined as when quolls were visibly twitching their nose in the direction

190   of the toad, "Investigating" behaviour was defined as the quoll being engaged with the cage

191   containing the toad, exhibiting scent marking or digging around the outside of cane toad

192   enclosure and "attack" behaviour was defined as quolls exhibited pawing or licking or biting

193   behaviour to toads cages. We summed all of these to measure the total time spent interacting

194   with a toad. We converted each of these variables to a proportion of time spent in each of

195   these activities, where the denominator was the total time that the animal was observable on

196   camera. These response variables were not normally distributed, and could not be made to

197   conform to normality through transformation. Because of this we used bootstrapping to

198   obtain confidence intervals for the mean time engaged in each behaviour, and to test the null

199   hypothesis that there was no difference between treatments in mean time spent in each

200   activity. The perception that animals exhibit a lower propensity towards attacking a prey item

201   following ingestion and subsequent malaise during CTA training is non-controversial

202   (Gustavson *et al.* 1974; Gustavson *et al.* 1976; Gustavson 1982; Gustavson & Basche 1983;

203   Gustavson, Gustavson & Holzer 1983; Ziegler *et al.* 1983; Gustavson & Nicolaus 1987;

204   Nicolaus 1987; Nicolaus & Nellis 1987; Nicolaus *et al.* 1989; Schneider & Pinnow 1994;

205   Smith *et al.* 2000; Riley & Freeman 2004; Sevelinges *et al.* 2009; O'Donnell, Webb & Shine

206   2010; Thornton & Raihani 2010; Thornton & Clutton-Brock 2011). More relevant to this

207   study is the outcomes of previous trails by O'Donnell, Webb and Shine (2010) and Kelly and

208   Phillips (2017) where quolls exhibited less interest in prey items after consuming a toad

209   metamorph laced with thiabendazole. Based on these previous results, we had a strong *a*

210   *priori* expectation that animals could either be unaffected or only become less interested in

211   toads after ingestion of cane toad sausages. Thus, we employed a one-tailed test, with the

212   alternative hypothesis that the mean time spent investigating and attacking toads will be

213   lower in the treatment group.   This analysis was performed using R (R Core Team, 2016).

214   *Field trials*

215   Images from bait stations were collated and tagged by pass, session, site, bait-event, species

216   and activity. A 'pass' was defined as when a new species entered the frame or when images

217   that were at least 5 minutes between when the previous detection of the same species passed.

218   This reduced any likelihood of individuals of the same species being overlooked during

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219   analysis. "Activity" was hierarchical, with the highest activity being 'Bait taken'; this was

220   defined as either photographic evidence of animal eating bait or bait being taken from the bait

221   station. 'Bait investigated' was defined as when bait was sniffed but not consumed or taken.

222   'Bait area investigated with no bait available' was defined as when no bait was available at a

223   bait station, but the animal was still visiting or investigating the bait station.

224   We analysed data using two levels of observation to determine 1) which species were

225   attracted to bait, and 2) which species took bait. A frequency distribution (n times each

226   species was recorded) was calculated and the proportion of bait takers in each species was

227   estimated. Passes in which we were unable to identify the species were pooled and removed

228   from further analysis. Additionally, if a species total number of visits was less than 10 we

229   removed that species from the analysis. Additionally *Varanus tristis, V. panoptes, V. mitchelli*

230   and *V. mertensi* were pooled into '*Varanus* other species' due to small sample sizes.

231   We identified individual *D. hallucatus* that visited bait stations by their unique spot patterns

232   (Hohnen *et al.* 2013) to determine visitation rate and bait uptake of individuals. To do this we

233   employed Wild ID (Version 1.0, January 2011) (Bolger *et al.* 2011) to extract distinctive

234   image features in animals spot patterns, the program calculates a matching score that

235   characterizes the goodness of fit between two images. These matching scores were then used

236   to rank and select matches to each focal image. We also conducted manual checks with all

237   photographs and compared them to those already identified to determine whether a new

238   individual had been recorded. Quolls were identified to individual within each session, and

239   we treat each session (separated by a minimum of four months) as independent with regard to

240   quoll ID and behaviour. This decision was made for logistical reasons (difficulty of

241   identifying individuals using spot ID), but is supported by exploratory analysis of first pass

242   uptake rates showing that these do not vary systematically with session (see Results). It is

243   likely, therefore, that any training is forgotten within the 4-5 month window between

244   sessions.

245   **Results**

246   *Captive trials*

247   Of the treatment animals, seven (77%) consumed all or part of a cane toad sausage and eight

248   (88%) control animals consumed beef sausages. Treatment had no significant effect on

249   whether the initial sausage was consumed, ($\chi^2 = 0.0$, df = 1, $p = 1$). In our video trials, quolls

250   spent an average of only 0.6% of the total time on camera interacting with the toad. Control

251   animals, however, spent more than twice as much time interacting with the toad than

252   treatment animals (control = 0.95%; treatment = 0.42%, bootstrap p-value = 0.022). When

253   we break this down by specific types of interaction, control animals spend approximately

254   sixty times longer investigating (control = 0.15%; treatment = 0.00024%, bootstrap p-value =

255   0.051); twice as much time sniffing (control = 0.70%; treatment = 0.35%, bootstrap p-value =

256   0.044); and twenty times more time attacking (control = 0.03%; treatment = 0.0015%,

257   bootstrap p-value = 0.036) toads when compared with the control (Figure 2).

258   *Field trials*

259   *Target and non-target uptake*

260   A total of 26 species were captured on camera traps visiting bait stations. For eleven of these

261   species, there were sufficient data to compare their response to bait uptake. The most

262   frequent visitors to the bait stations were quolls, with $n = 345$ passes (Figure 3). Almost all

263   bait removal was executed by quolls that took 65 baits of the 90 baits removed. Other species

264   took far fewer: *Zyzomys argurus,* 9; *Ctenotus spp.*, 2; *Pseudantechinus ningbing*, 2; *Varanus*

265   *glauerti*, 2; and *Varanus glebopalma*, 2.

266   *Target uptake and training rates*

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267   First pass uptake responses to the bait did not vary systematically across sessions (χ^2=1.7,

268   df=4, p=0.79; Fig. 4). We thus treated individuals as independent across sessions with regard

269   to behaviour.

270   Following identification of individual quolls within sessions, it became apparent that

271   bait stations were visited by a total of 70 "individual" quolls over the period of the study. Of

272   these individuals, and considering only their first bait encounter, the bait was taken by 28

273   individuals and rejected (bait investigated but not taken) by 18 individuals. Thus the total

274   bait uptake rate at first encounter was 61% (SE=7.2%). A further 24 individuals only visited

275   bait stations when there was no bait available.

276   Across all passes, a total of 31 quolls consumed a bait. Ten of these animals ultimately

277   consumed baits on more than one occasion within a session (32%, SE=8.3%). Clearly, these

278   individuals were not effectively trained, failing to even exhibit aversion to the bait. We have

279   two ways of estimating the conversion rate (from untrained to trained, given bait

280   consumption). Placing an upper bound, we could consider all individuals that took a bait but

281   were not observed to take a second bait (20 of 31 = 68%) as trained. For a lower bound, we

282   could take the conservative approach and consider only those known to have consumed a bait

283   and then seen to approach and reject a bait as trained (7 of 17 = 41%). Thus, somewhere

284   between 41 and 68% of animals consuming a bait appear to have been trained.

285   **Discussion**

286   Our captive trials clearly indicate that training a quoll using a thiabendazole-laced toad

287   sausage changes their behaviour towards toads. Although our sample sizes were modest and

288   not all of our treatment animals fully consumed the bait, it is clear that sausage-trained

289   animals spent substantially less time interacting with a toad —between one half to one

290   sixtieth of the time as control animals. This behavioural shift is reflected across all prey

291   acquisition behaviours: investigating, sniffing, and attacking. Quolls clearly generalise their

292   acquired aversion from the bait to a real toad.

293   The field trials show that the toad sausages are attractive to quolls. Although 26

294   species encountered the baits, quolls were the most frequent visitors to the bait at our study

295   sites, and were far and away the most likely species to consume the bait. Thus, non-target

296   uptake is relatively modest, compared with the high level of uptake of baits by non-target

297   animals observed in other lethal-baiting studies (Cowled *et al.* 2006; Dundas, Adams &

298   Fleming 2014) It is more difficult to estimate the rate of successful training in the field, but it

299   is likely that between 41-68% of animals consuming a bait in the field have been successfully

300   trained. The apparent independence of quoll behaviour to bait uptake across sessions also

301   suggests that, in the absence of further reinforcing stimulus (i.e., cane toads), CTA training

302   potentially only elicits aversion for a limited time (<4 months).

303   The TBZ dose of <300mg/kg animal body weight in our cane toad sausages was

304   relatively low compared to earlier work (400mg/kg in (Jolly et al.unpublished data;

305   O'Donnell, Webb & Shine 2010; Cremona *et al.* 2017; Kelly & Phillips 2017) but was set

306   low by regulators (Australian Pesticides and Veterinary Medicines Authority- (APVMA)) to

307   allow for potential multiple bait uptake, sub-adult target, and non-target species. Given the

308   LD_{50} of TBZ is more than nine times higher than our dose rate; the delivered dose is very

309   conservative. Our results suggest, however, that it is still effective. Regulators (APVMA)

310   also limited the number of treatment baits available at a site at any one time to 30 baits per

311   hectare. It is clear from our study that, at this density of baits, many quolls are simply not

312   encountering the bait; arriving at the bait station after baits have been taken; this in a

313   relatively low density quoll population, and despite multiple bait events at each site. Thus, to

314   effectively bait a large proportion of the quolls at a site (particularly a high density site), a

315   greater density of baits will be required.

316   In addition to the high visitation rate of individual quolls to bait stations, some

317   individual quolls took baits on multiple occasions. Of the 70 "individual" quolls that visited

318   bait stations throughout study period, ten individuals consumed a cane toad sausage on more

319   than one occasion within a session. Why did these individuals manifestly fail to train? One

320   possibility is the low dose rate, 0.06g of TBZ in each sausage was calculated to provide

321   300mg/kg to the smallest adult quoll at our site; a 200g female. Long-term trapping at the

322   site (AWC, unpub. data) suggests that adult quolls in this population can reach more than

323   815g in weight. Thus, large animals could receive less than one quarter of the dose ingested

324   by small animals. As a consequence, we could expect larger animals (typically males) to be

325   harder to train with a fixed-dose bait. Another possibility is that these individuals were

326   unhealthy for other reasons (e.g., males in the process of annual die-off) and so were willing

327   to risk poisoning in order to acquire food, although such a mechanism would presumably

328   cause changes in uptake rate across sessions, so seems unlikely.

329   Our results also hint strongly that individuals lose their acquired aversion over the 4-5

330   month window between our baiting sessions. There was no evidence that first pass rates of

331   bait uptake declined over time across sessions. Whether this aversion would decline in the

332   presence of ongoing stimulus (i.e., continuous baiting, or the presence of toads) is unknown,

333   but long-term mark-recapture studies of CTA-trained quolls released into toad-infested

334   landscapes suggest that aversion can be long-held in the presence of reinforcing stimulus

335   (Cremona *et al.* 2017). Nonetheless, our finding should sound a note of caution with regard

336   to deployment of CTA. Training prior to toad arrival will need to be delicately timed: too

337   early, and trained animals may lose their aversion before toads arrive. This need for

338   precision timing is complicated by inevitable uncertainty with regard to where the toad

339   invasion front is, and when it will arrive at the site (with spread rate also being contingent on

340   the unpredictable timing of the wet season in northern Australia). Thus, any baiting

341   campaign will need to dedicate effort to predicting the date of toad arrival at the site.

342   Overall, however, our study is encouraging with regard to the use of toad sausages as

343   a vehicle for large-scale CTA training of quolls. Our results suggest that quolls will consume

344   cane toad sausages in the field and will, as a consequence, be less inclined to attack cane

345   toads. This opens the possibility for broad scale application of CTA as a management

346   technique for mitigating the impact of toads on quolls.

347   While many questions remain about optimal bait design, delivery, and timing, it is

348   clear that CTA training using toad sausages is likely a viable tool for land managers seeking

349   to protect quoll populations. Given that quoll populations in the Kimberley will likely be

350   completely overrun by toads within the next five years, this is a tool that is urgently needed.

351   More generally, however, our work joins a growing list of studies demonstrating that the

352   impact of invasive species can be mitigated not only by controlling the invasive species, but

353   also – or instead - by manipulating its mechanism of impact.

354   **Authors' Contributions**

355   All persons who meet authorship criteria are listed as authors, and all authors certify that they

356   have participated sufficiently in the work to take public responsibility for the content,

357   including participation in the concept, design, analysis, writing, or revision of the manuscript.

358   **Acknowledgements**

363   collation and individual identification of quolls. Additionally we wish to thank our volunteers

364   who participated with field trials.

369   **Data accessibility**

370   Data and scripts are available upon request.

371   **Compliance with Ethical Standards**

372   The study was conducted within Mornington Wildlife Sanctuary in accordance with Wildlife

373   Conservation Regulation 17 (Permit number: SFO10584). The area is jointly managed by

374   traditional land-owners and the Australian Wildlife Conservancy. The research was approved

375   by the University of Melbourne Animal Ethics Committee (Protocol: 1413369.2) and the

376   University of Technology Sydney Animal Care and Ethics Committee (Protocol: 2012-432A)

377   and Department of Parks and Wildlife Animal Ethics Committee (Protocol: DPaW AEC

378   2016_50 and Protocol 2013_37). Additionally this study was conducted in accordance with

379   the approved outline submitted to the AVPMA by the investigating team (Permit to allow the

380   possession and supply for research use of an unregistered Agvet chemical product. Permit

381   number: PER92262).

382

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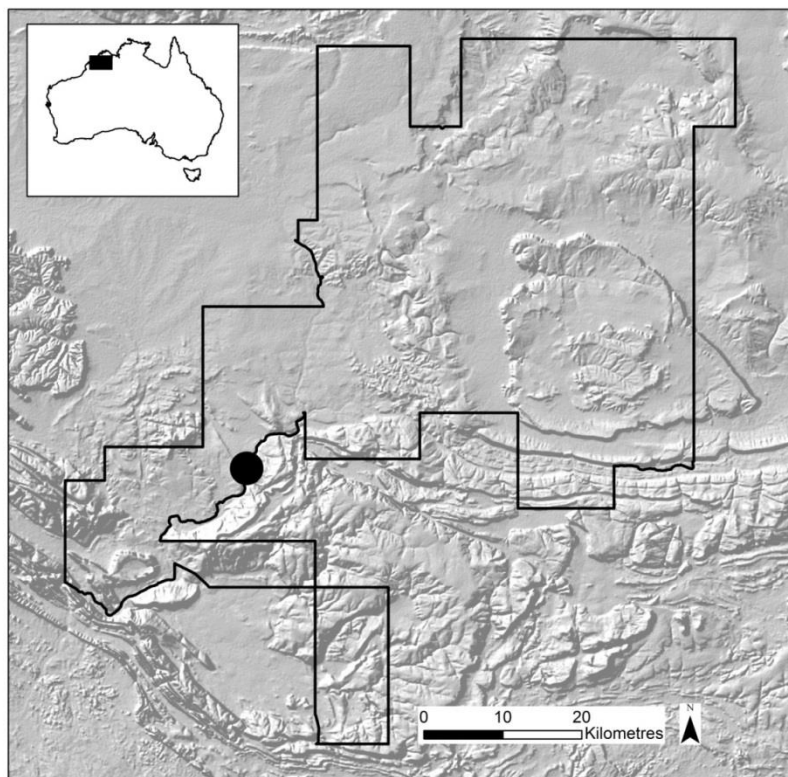589   Australia. *Therya,* **6,** 169-225.

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591 **Figures**

Figure 1: Location of the study area within Australian Wildlife Conservancy's Mornington Wildlife Sanctuary, in the central Kimberley, Western Australia.
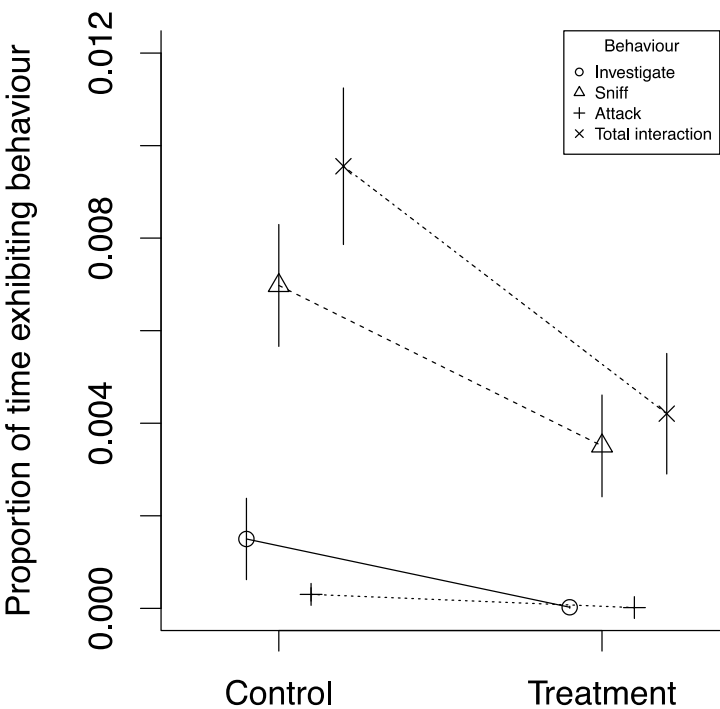
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Figure 2: Mean proportion of active time that quolls spent directed towards toads. Behaviours are split into categories and across control and treatment groups. Error bars represent bootstrap standard errors.
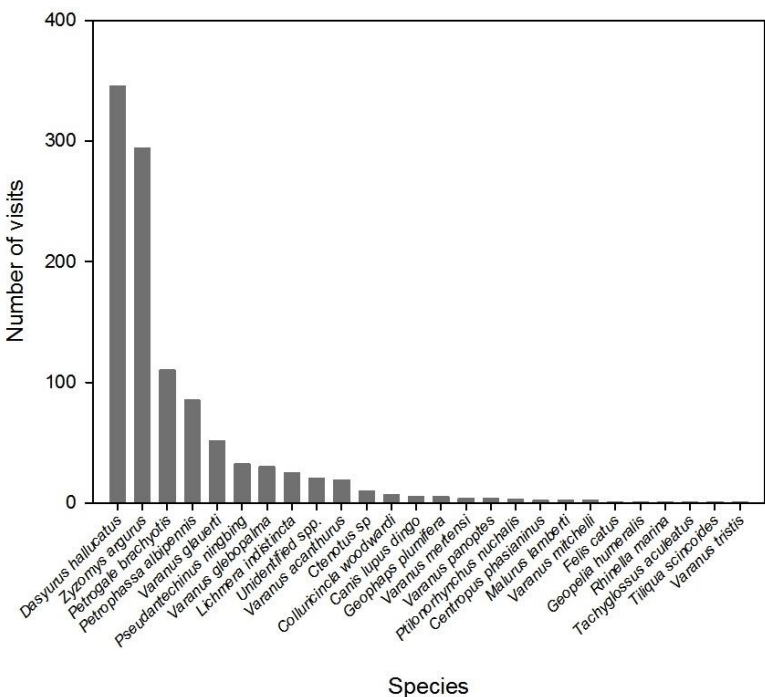
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Figure 3: Frequency of visits to CTA bait stations by each species. Unidentified species group comprises unidentified rodents, birds, and frogs.
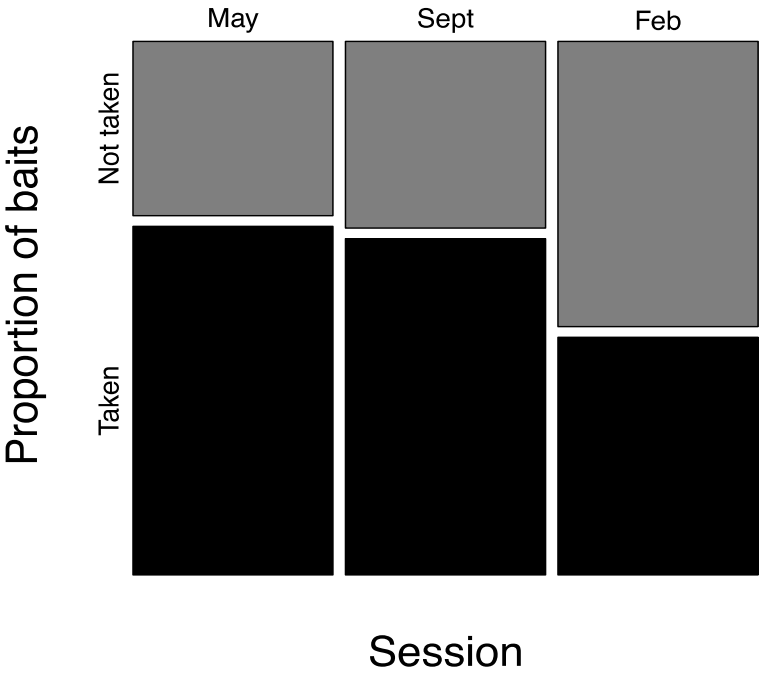
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Figure 4: First pass behavioural responses of northern quolls to the bait each session. "Sept" includes the one November session also.

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599 **Tables**

Site Name	Session Year	Session Month	No. Bait Events (BE)	BE 1-date	BE 2-date	BE 3-date	BE 4-date	No. of bait stations
KP	2016	Nov	1	31/10/16	1/11/16	2/11/16	*	20
RP	2017	Feb	1	3/2/2017	*	*	*	20
RP	2016	May	3	10/5/16	13/5/16	21/5/16	*	20
RP	2016	Sept	3	15/9/16	16/9/16	17/9/16	*	20
SJ	2017	Feb	1	3/2/2017	*	*	*	20
SJ	2016	May	3	10/5/16	13/5/16	21/5/16	*	20
SJ	2016	Sept	4	15/9/16	16/9/16	17/9/16	19/9/16	20
TC	2017	Feb	1	3/2/2017	*	*	*	33
TC	2016	May	3	10/5/16	13/5/16	21/5/16	*	20
TC	2016	Sept	3	15/9/16	16/9/16	17/9/16	*	20

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Table 1: CTA sessions and bait events, * denotes empty cells. Bait events occurred at the same time within each site. KP was baited only once in November to expand the sample size and CTA train quolls prior to cane toad arrival.

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