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Review

Utilising aversive conditioning to manage the behaviour of K'gari (Fraser Island) dingoes (*Canis dingo*)

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Abstract. K'gari (Fraser Island) offers a rare opportunity for people to observe and encounter wild dingoes. Occasionally, however, such encounters can entail dingoes acting in a threatening or aggressive manner towards people, resulting in human injury and, in one tragic case, death. A suite of approaches aimed at minimising the risk to human safety posed by dingoes have been implemented on the island, including fencing, island-wide warning signage, and regulations against feeding. Despite such measures, negative encounters continue, and in cases where dingoes are deemed to pose an unacceptable risk, they are usually destroyed. In searching for non-lethal management alternatives, attempts have been made to modify undesirable dingo behaviour through aversive conditioning, but results to date have either been mixed or largely disappointing. Here we review a wide array of research that has utilised aversive stimuli in an effort to modify and manage the behaviour of wild animals, with a particular focus on related predators such as coyotes and wolves. We identified eight major categories of experimental research: conditioned taste aversion/avoidance (CTA), electric fencing, fladry, chemical repellents, fear-evoking stimuli, physical repellents, aversive collars/devices and hard release procedures. We then outline each of these categories in more detail, complete with pertinent examples of successes and failures as well as advantages and disadvantages. We conclude that some approaches offer promise within three main areas of incident mitigation experimentation: dingo exclusion (e.g. electric fencing), personal protection (mild chemical irritant sprays, sturdy umbrellas) and remedial aversive conditioning (e.g. shock collars). Other approaches, such as CTA and sublethal projectiles are not recommended. Like any approach, aversive conditioning is not a panacea, but it does offer promise in filling gaps in current management and as an alternative to lethal control.

Additional keywords: human–wildlife interaction, non-lethal management

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Introduction

Certain species of carnivores can, under some circumstances, pose a threat to human safety, including the three species of North American bear (*Ursus* spp.) (Herrero 1970, 2002; Herrero and Fleck 1990; Herrero and Higgins 1999, 2003; Herrero *et al.* 2011), grey wolves (*Canis lupus*) (Linnell *et al.* 2002; McNay 2002), coyotes (*Canis latrans*) (Carbyn 1989; Timm *et al.* 2004; White and Gehrt 2009) and cougars (*Puma bicolor*) (Beier 1991). The Australian dingo (*Canis dingo*) is no exception (Appleby *et al.* 2017*a*). In April 2001 this threat was starkly realised when two dingoes on K'gari (Fraser Island), a World Heritage wilderness area off the coast of Queensland, Australia, fatally mauled a young boy. This tragic incident highlighted the need for vigilant supervision of children (Beier 1991; EPA/QPWS 2006; Appleby 2015; Appleby *et al.* 2017*a*), a problem that has recently been flagged as a major correlate of attacks elsewhere in the world (Penteriani *et al.* 2016).

Since 2001, spates of ongoing negative human–dingo interactions (or incidents) on the island, have prompted calls for more effective management interventions. Several years beforehand, Corbett (1998) had begun to identify a suite of actions aimed at bolstering dingo research and management programs, including visitor education programs and erecting warning signage, monitoring interactions, dingo population assessments, radio-tracking dingoes, campground fencing and the lethal removal of dingoes deemed to be problem animals. Corbett (1998) also proposed investigating aversive conditioning, largely with a view to what he envisioned as '… educating dingoes to avoid certain areas' (p. 13). Almost two decades later, most of Corbett's (1998) recommendations have been widely implemented under the ongoing Fraser Island Dingo Management Strategy (EPA/QPWS 2001; DEHP 2013). These include ongoing, adaptive education and interpretive programs, appropriate campground and human-use area sanitisation and food storage practices, strong enforcement

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procedures to limit dingoes accessing anthropogenic food, ongoing reinforcement of the vigilant supervision of children and comprehensive dingo and incident-monitoring practices. While there has been some notable success in limiting dingo access to certain areas (e.g. through fencing) and what appears to be a reduction in human-sourced food items found in dingo scats from 46.9% in 1995 to 7.5% most recently (Behrendorff *et al.* 2016), occasional, serious incidents continue to occur.

A recent review of the most serious incidents recorded on the island highlighted the potential seasonality in incident dynamics, with peaks in March/April and July, corresponding with the dingo breeding and whelping seasons respectively (Appleby *et al.* 2017*a*). Most incidents were localised around the townships of Eurong and Happy Valley or the southern barge crossing site of Hook Point/Coolooloi (Appleby *et al.* 2017*a*). A strong sex bias was also observed, with 81% of incidents with a reported dingo sex involving males, and 78% of incidents involved juvenile or subadult dingoes (Appleby *et al.* 2017*a*). Some 67% of incidents also occurred while people were walking or running. Such patterns may offer an opportunity to focus management effort on key areas, times of year and what may constitute a relatively small number of young dingoes potentially attempting to engage in play behaviour while people walk or run on the beach (Appleby *et al.* 2017*a*).

Of all Corbett's (1998) recommendations, aversive conditioning remains an alluring, but elusive management approach, despite several attempts to date to explore potentially viable options. Aversive conditioning involves the use of stimuli that are painful, noxious or otherwise unpleasant to manipulate the behaviour of animals either through punishment (a reduction in behaviour) or avoidance learning (Dorrance and Gilbert 1977; Gillin *et al.* 1994; Mazur 2010). Soon after the fatality in 2001, rangers began using sublethal projectiles fired from shotguns and slingshots in an attempt to discourage unwanted dingo behaviours and dingo activity within human-use areas (Allen *et al.* 2012; EPA/QPWS, 2006). Although few formal records are available, anecdotal reports suggest that the results of these hazing practices were, at best, mixed, with some indication of the approach being more effective on younger, more naïve, dingoes than on older dingoes deemed to be 'habituated' (Allen *et al.* 2012). Allen *et al.* (2012) defined habituation as '… an animal learning to ignore a stimulus (e.g. person) originally seen as threatening through frequent exposure with neutral consequences' (p. 78). Debates about the role of habituation in negative human–wildlife interactions are ongoing (Appleby *et al.* 2017*a*). However, in the context of aversive conditioning, a decreasing response over time to a benign stimulus has important implications for the outcome of some experiments.

Corbett (2009) observed that, rather than hazing leading to dingoes avoiding a particular place, some dingoes had instead learned to move out of sight when a ranger, or ranger vehicle appeared, and likely returned to the area once the rangers had departed (see also Allen *et al.* 2012). Similar associative confounding has been noted for other species elsewhere (Herrero 2002; Shivik 2006). Because of such problems, hazing in this manner has been largely suspended and the practice has been rarely employed since 2010 (Allen *et al.* 2012; DEHP 2013). In the most recent comprehensive review of the dingo management strategy on the island, it was recommended that the approach be abandoned in lieu of scientific investigations into its utility, and that other potential approaches be investigated instead (Allen *et al.* 2012; DEHP 2013).

Several small-scale experimental investigations have also been undertaken. Tauchmann (1999) reported on an assessment of conditioned taste aversion/avoidance (CTA) trials. The study involved lacing food lures (party pies) with either lithium chloride (LiCl) or thiabendazole and placing them at three locations. A reduction in bait consumption was observed at one site only. Edgar *et al.* (2007) investigated the prospect of a commercially available ultrasonic device in deterring four captive dingoes, but found that the devices had no effect on dingo subjects. Appleby (2015) attempted to examine the responses of four Fraser Island dingoes to electric shock delivered via modified domestic dog shock collars. Only trials involving two dingoes provided reliable results, but these were encouraging in that dingoes receiving shocks immediately ceased exhibiting target behaviours (e.g. making physical contact with a person; approaching a child) and there were hints at a developing avoidance response in one individual and successful deterrence from closely approaching a child in another. However, as has been found in similar studies elsewhere (Hawley *et al.* 2009, 2013; Shivik *et al.* 2003), equipment problems led to unreliable collar functionality, ultimately limiting the utility of current designs.

Some objects people carry, such as sticks or walking poles, though better than no protection at all, may largely be ineffective as aversive stimuli, because dingoes rarely get hit (Appleby, pers. obs.). Among 160 serious dingo incident reports collected by Queensland Parks and Wildlife Service (QPWS) (Appleby *et al.* 2017*a*) there were seven cases found where people threatened by dingoes were listed as carrying sticks. Cases in which sticks both appeared to deter and not deter dingoes were found. Only one case mentioned a dingo actually being stuck with a stick, an adult male dingo, struck twice by a woman after it repeatedly lunged at her, after which it and two other dingoes left the scene. It is generally unclear how many people actually carry objects such as sticks and how often people carrying these objects have been in threatening interactions with dingoes, making efficacy difficult to assess.

Other activities people undertake in an effort to repel dingoes such as kicking sand, kicking or splashing water, and throwing objects at dingoes, also appear unlikely to repel dingoes in a meaningful way unless perhaps direct contact is regularly made (Appleby *et al.* 2017*b*). Clapping and yelling at dingoes may similarly be of little value; however, if used in combination with more immutably aversive stimuli, these could be useful as conditioned warning signals.

There is continuing interest in the pursuit of non-lethal dingo management approaches such as aversive conditioning on Fraser Island (Corbett 2009; Allen *et al.* 2012; DEHP 2013) and research from elsewhere suggests that a great deal of public support for non-lethal measures exists (Hunt 1984*a*; Gillin *et al.* 1994; Gilsdorf *et al.* 2002; Baker *et al.* 2005; Massei *et al.* 2010; Mazur 2010). However, given the mixed or disappointing results of previous attempts at aversive conditioning on Fraser Island mentioned earlier, it is fitting that a comprehensive methodological review be undertaken to determine whether there are approaches capable of offering meaningful benefit. To that end, we aimed at providing a synthesis of relevant explorations of aversive conditioning where similar conflict has driven, and continues to drive, the search for viable, non-lethal management solutions. We were particularly interested in studies involving closely related canid species and other carnivores. We identified eight major categories of aversive conditioning that have been used in various wildlife management contexts, and we briefly summarise each approach, including an assessment of potential advantages and disadvantages. We have also included a pertinent set of empirical investigations for each method. In this regard we selected studies that exemplify particular methodological or experimental strengths and weaknesses from a large array of empirical investigations that were examined in preparation of this review.

Methods

Background

K'gari (Fraser Island) is the world's largest sand island, located ~200 km north of Brisbane, Australia. It was inscribed onto the World Heritage List in 1992. The Butchulla people are the Traditional Owners of K'gari, and were awarded Native title by the Australian Federal Court in 2014. A mark–recapture study by Appleby and Jones (2011) determined that the island's dingo population comprised ~130 (range: 104–194) dingoes, but estimates vary, with one study suggesting a population of 162–257 individuals as of the 2012 whelping season (Allen *et al.* 2015). Approximately 400 000 people are thought to visit the island annually (Allen *et al.* 2015).

Seriously negative human–dingo interactions (incidents) appear to be quite rare, with Appleby *et al.* (2017*a*) reporting an average of 10.7 (range: 3–22) Category E (the most serious) incidents per year between 2001 and 2015. However, despite considerable management effort directed at reducing serious incidents, reporting rates have remained relatively constant across the period (Allen *et al.* 2015; Appleby *et al.* 2017*a*). A single human fatality occurred on the island in April 2001 involving a young boy, but Appleby *et al.* (2017*a*) noted that serious incidents involving children continue to occasionally occur. Incident report sample sizes were too small to comprehensively analyse the relevance of proximity of the closest adults to children during interactions; however, Appleby *et al.* (2017*a*) suggested the possibility that poorer supervision on the part of adults may have contributed to more severe outcomes in at least some cases, recommending that adults remain within 5 m of children at all times if at all possible. They concluded that despite copious warnings about dingoes in the form of signage and other interpretive materials provided by the QPWS, some visitors may still not recognise the potential threat dingoes can pose, or are otherwise ignoring this threat.

In cases where a dingo is deemed to represent an unacceptable threat to human safety it is usually destroyed, with 110 dingoes destroyed for risk management purposes between 2001 and 2015 (Allen *et al.* 2015). The impact of lethal control on the dingo population is contentious, with Allen *et al.* (2015) concluding that it was unlikely to have any adverse impacts on breeding success or sustainability at the current rate, while O'Neill *et al.* (2017) contended that lethal control on the island leads to social disruption and instability, which in turn leads to negative human–dingo interactions, resulting in a perpetual cycle of conflict.

Literature review

Searches of major scientific literature databases (Scopus, Web of Science, Elsevier, Google Scholar) were conducted in order to locate pertinent literature. Databases maintained by associations producing specific journals were also searched (The Wildlife Society, The Berryman Institute). The primary search terms used were: 'aversive', 'aversive conditioning', 'hazing', 'nonlethal', 'non-lethal', 'nonlethal/non-lethal wildlife management', 'punishment', and 'negative reinforcement'. Specific terminology linked with a particular approach (e.g. 'conditioned taste aversion/avoidance') or aversive stimulus (e.g. 'LiCl') was also included. Subsequent literature was garnered from references provided within the bibliographies of retrieved documents.

Several other reviews of aversive conditioning and related approaches have been undertaken, largely within the context of livestock depredation management. Each contains valuable insights in relation to non-lethal management approaches, and summaries of 17 major reviews can be found in Table S1, available as supplementary material to this paper. Particular attention is drawn to Baker (2007), who reviewed coyote–human interaction conflict management, and van Bommel and Johnson (2014) as the only major review pertaining directly to dingoes that could be found (again, in the context of livestock depredation management).

Results

In total, 108 empirical studies were found during literature searches. An annotated bibliography of these studies is provided in Table 1. Most studies were drawn from North America (particularly the USA). We derived eight major categories where aversive stimuli were applied in an effort to modify the behaviour of certain animals: CTA, electric fencing, fladry, chemical repellents, fear-evoking stimuli, physical repellents, aversive collars/devices and hard release procedures. A special category of fear-evoking stimuli was predator containment/exclusion using conspecific urine/faeces. Some studies exhibited overlap in terms of these categories. Coyotes specifically featured in 29 studies, wolves in 14, domestic dogs in 9 and dingoes in 3. Four studies involved various predators including (potentially) canids and an additional 17 specifically featured bears. The remaining studies featuring other species contained interesting accounts of success/failure, novel approaches or uses of aversive stimuli or could be considered seminal or otherwise important in a given management context.

From the assembled literature, a selection was then chosen to exemplify major categories, particularly in terms of reported successes, failures, advantages and disadvantages, covered below.

Conditioned taste aversion/avoidance

Definition/description

Conditioned taste aversion or avoidance (CTA) involves an animal learning that a particular taste, or the ingestion of a particular substance, often in concert with any other salient

Table 1. A selective summary of 108 empirical studies involving the use of the aversive stimuli

A '?' indicates uncertainty about a figure. A '+' indicates that there are additional elements not included because of space restrictions

Study	Modification category	Aversive stimulus	Target species	Protected species/object	Location type	Sample size	Management context
Acorn and Dorrance (1994)	Electric fencing	Electric shock	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Andelt *et al.* (1997)	Fear-evoking stimuli	Pyrotechnics, light, human effigy	Herron	Commercial fish	Field	Unknown	Fish stock protection
Andelt *et al.* (1999)	Aversive collars	Electric shock	Coyote	Domestic sheep	Captive	5	Livestock protection
Appleby (2015)	Aversive collars	Electric shock	Dingo	Various items and humans	Field	4 (2 Useful)	H–W interaction management
Ausband *et al.* (2013)	Fear-evoking stimuli	Conspecific urine/faeces	Wolf	Livestock	Field	3 Packs	Predator containment/ exclusion
Baker *et al.* (2005)	CTA	Cinnamamide, capsaicin, ziram	European badger	Food pellets	Field	7	Crop protection
Baker *et al.* (2007)	CTA	Ziram and clove oil	European badger, foxes	Food pellets	Field	Unknown	Crop protection
Beckmann *et al.* (2004)	Hard release procedures	Pepper spray, rubber projectiles, cracker shells, dogs	Black bear	Various human-use areas	Field	62	H–W interactions Management
Bender (2003)	Fear-evoking stimuli	Ultrasound	Eastern grey kangaroo	Pastures	Laboratory/Field	31+	Grazing protection
Beringer *et al.* (2003)	Fear-evoking stimuli	Light, sound, human effigy	White-tailed deer	Commercial soybean plots	Field	Unknown	Crop protection
Biedenweg *et al.* (2011)	Fear-evoking stimuli	Sound (whip crack, foot stomp)	Kangaroo	Kangaroos and humans, pasture	Semi-captive	48	Vehicle strike/grazing protection
Blackshaw *et al.* (1990)	Fear-evoking stimuli	Light, sound, ultrasound	Domestic dog	Humans	Captive	29	H–W interaction management
Borgo *et al.* (2006)	Fear-evoking stimuli	Predator urine/fur	Southern flying squirrels	Red-cockaded woodpecker nest cavities	Captive	90	Reduce roost competition
Bourne and Dorrance (1982)	CTA	LiCl	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Breck *et al.* (2002)	Fear-evoking stimuli	Light, sound	Wolf	Livestock	Field	10?	Livestock protection
Burns (1983*b*)	CTA	LiCl	Coyote	Domestic lambs	Captive	20?	Livestock protection
Burns and Connolly (1980)	CTA	LiCl	Coyote	Jackrabbits	Captive	17?	Livestock protection
Cavalcanti *et al.* (2012)	Electric fencing	Electric shock	Jaguar	Domestic cattle	Field	Unknown	Livestock protection
Clapperton *et al.* (1996)	CTA	LiCl, NaCN	Brushtail possum	Various (particularly birds)	Captive	27	Bait shyness in control
Conover (1985)	Fear-evoking stimuli	Animated predator model	American crow	Tomatoes, cantaloupes	Field	Unknown	Crop protection
Conover (1990)	CTA	Emetine dihydrochloride	Racoons, opossum, striped skunk, rodents	Various (eggs)	Field	Unknown	Egg protection
Conover and Lyons (2003)	CTA	Pulegone	Various	Eggs	Field	Unknown	Egg protection
Conover *et al.* (1977)	CTA	LiCl	Coyote	Domestic chickens	Captive	5	Livestock protection
Cook and Mineka (1989)	Fear-evoking stimuli	Predator model (e.g. snake – video-taped display)	Rhesus monkey	n.a.	Laboratory	42?	n.a.
Cooper *et al.* (2005)	Aversive collars	Electric shock	Island fox	San Clemente loggerhead shrike	Field	~68/year	Predation prevention

Coppinger *et al.* (1988)	Fear-evoking stimuli	Livestock guarding dogs	Various predators	Livestock	Field	Unknown	Livestock protection
Cornell and Cornely (1979)	CTA	LiCl	Coyote	Campsites	Field	15?	H–W interaction management
Dale *et al.* (2013)	Aversive collars	Electric shock	Domestic dog	Kiwi	Captive	120	Predation prevention
D'Angelo *et al.* (2006)	Fear-evoking stimuli	Light	Deer	Deer and humans	Field	Unknown	Vehicle strike
Darrow and Shivik (2009)	Fear-evoking stimuli	Light, sound	Coyote	Domestic livestock	Captive	30	Livestock protection
Davidson-Nelson and Gehring (2010)	Fladry	Flagging	Wolves, coyote	Domestic livestock	Field	Unknown	Livestock protection
Davies and Rockwell (1986)	Electric fencing/ fear-evoking stimuli	Electric shock/audible alarm, airhorns	Polar bear	Humans, property	Field	Unknown	H–W interaction management
deCalesta and Cropsey (1978)	Electric fencing	Electric shock	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Dorrance and Bourne (1980)	Electric fencing	Electric shock	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Edgar *et al.* (2007)	Fear-evoking stimuli	Ultrasound	Dingo	Food	Captive	4	H–W interaction management
Ellins and Catalano (1980)	CTA	LiCl	Coyote	Domestic sheep, turkeys	Field	Unknown	Livestock protection
Ellins *et al.* (1977)	CTA	LiCl	Coyote	Domestic sheep	Field	Unknown	Livestock protection
(**Fedderwitz 2010**)	Fear-evoking stimuli/ aversive device	Ultrasound/electric shock	Wolf/African wild dog/dhole	Dummy device/dead animals	Captive	22+?	H–W interaction management
Gallagher and Prince (2003)	Electric fencing	Electric shock	White-tailed deer	Feed stations (corn)	Field	Unknown	Crop protection
Gates *et al.* (1978)	Electric fencing	Electric shock	Coyote	Domestic sheep	Captive	6	Livestock protection
Gehring *et al.* (2006)	Aversive collars/fla-dry/other	Electric shock/fladry/ livestock guarding dogs	Wolf	Domestic sheep, cattle	Field	10+?	Livestock protection
Gillin *et al.* (1994)	Physical repellents	Rubber, plastic bullets	Brown bear	Humans, campsite	Field	5	H–W interaction management
Gil.s.d.orf *et al.* (2004*a*)	Fear-evoking stimuli	Light, sound	White-tailed deer	Commercial corn	Field	12+	Crop protection
Gil.s.d.orf *et al.* (2004*b*)	Fear-evoking stimuli	Sound (whip crack, foot stomp)	Deer	Commercial corn	Field	Unknown	Crop protection
Greene (1982)	Fear-evoking stimuli	Airhorn	Black bear	Campsite	Field	1	H–W interaction management
Gustavson *et al.* (1974)	CTA	LiCl	Coyote	Domestic sheep and rabbits	Captive	7	Livestock protection
Gustavson *et al.* (1976)	CTA	LiCl	Coyote, wolf, cougar	Domestic sheep	Field	Unknown	Livestock protection
Gustavson *et al.* (1982)	CTA	LiCl	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Gustavson *et al.* (1983)	CTA	Thiabendazole	Dingo, New Guinea singing dog	Domestic sheep meat	Captive	19	Livestock protection
Hansen *et al.* (1997)	CTA	LiCl	Domestic dog	Domestic sheep	Captive	2	Livestock protection
Hawley *et al.* (2009)	Aversive collars	Electric shock	Wolf	Domestic livestock	Field	10	Livestock protection
Herrero and Higgins (1998)	Chemical repellents	Capsicum spray	Brown and black bears	Humans	Field	66	H–W interaction management
Hoover and Conover (1998)	CTA	Various	Coyote	Chicken eggs	Captive	40	Egg protection
Hoover and Conover (2000)	CTA	Pulegone	Coyote	Eggs	Captive	29	Egg protection
Horn (1983)	CTA	LiCl	Coyote	Domestic rabbits	Captive	14	Livestock protection

(*Continued*)

Table 1. (Continued)

Study	Modification category	Aversive stimulus	Target species	Protected species/object	Location type	Sample size	Management context
Hunt (1984*b*)	Chemical repellents/ fear-evoking stimuli	Capsaicin spray/various sounds+	Brown and black bears	Humans	Captive/Field	Unknown	H–W interaction management
Jackson *et al.* (2012)	Fear-evoking stimuli	Conspecific urine/faeces	African wild dog	Livestock	Field	18	Predator containment/ exclusion
Jelinski *et al.* (1983)	CTA	LiCl	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Juarbe-Diaz and Houpt (1996)	Aversive collars	Citronella spray collar/ electric shock	Domestic dog	n.a.	Captive	17	Barking prevention
Kimball *et al.* (2002)	CTA	LiCl	Domestic lambs	Various foods	Captive	32	Herbivory management
Kistler *et al.* (2013)	Electric fencing	Electric shock	Stone martens	Building	Field	Unknown	Building protection
Kloppers *et al.* (2005)	Fear-evoking stimuli	Humans, dogs	Elk	Humans, human-use areas	Field	24	Prevent/reverse habituation
Lance *et al.* (2010)	Fladry	Electric shock, flagging	Wolf	Food, domestic livestock	Captive/Field	45/Unknown	Livestock protection
Leigh and Chamberlain (2008)	Hard release procedures	Rubber buckshot, dogs	Louisiana black bear	Various human-use areas	Field	11	H–W interaction management
Linhart (1984)	Fear-evoking stimuli	Light, sound	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Linhart *et al.* (1976)	Aversive collars	Electric shock	Coyote	Rabbit	Captive	4	Livestock protection
Linhart *et al.* (1992)	Fear-evoking stimuli	Light, sound	Coyote	Domestic sheep	Field	Unknown	Livestock protection
Maguire *et al.* (2009)	CTA	Sodium carbonate	Various species (primarily red fox)	Hooded plover eggs (quail egg model)	Field	Unknown	Egg protection
Mason and Burns (1996)	Chemical repellent	Capsicum oleo resin	Coyote	Domestic lambs	Captive	5	Livestock protection
Mazur (2010)	Chemical repellents/ physical repellents	Pepper spray/various projectiles	Black bear	Humans	Field	~150	H–W interaction management
Miller (1983*a*)	Chemical repellents/ fear-evoking stimuli	Various chemical sprays/ sound	Brown and polar bears	Humans	Captive	4	H–W interaction management
Miller (1987)	Chemical repellents/ fear-evoking stimuli	Various chemical sprays/ sound	Polar bear	Baited areas, human	Field	Unknown	H–W interaction, nuisance behaviour
Moffat *et al.* (2003)	Aversive collars	Citronella spray/scentless spray	Domestic dog (various breeds)	n.a.	Captive	41	Barking prevention
Musiani and Visalberghi (2001)	Fladry	Fladry	Wolf	Cordoned areas and food	Captive	5	Livestock protection
Musiani *et al.* (2003)	Fladry	Fladry	Wolf	Food, Domestic cattle	Captive/Field	9/Unknown	Livestock protection
Nass and Theade (1988)	Electric fencing	Electric shock	Various predators	Domestic sheep	Field	Unknown	Livestock protection
Nolte *et al.* (2003)	Aversive collars	Electric shock	Black-tailed deer	Seedlings in pasture plots, apple slices	Captive	6	Food competition with livestock
Olsen and Lehner (1978)	CTA/Fear-evoking stimuli	Various	Coyote	Rabbit	Captive	8	Livestock protection
Osborn (2002)	Chemical repellents/ fear-evoking stimuli	Capsicum oleoresin spray/ various sounds+	African elephant	Crops	Field	18+	Crop protection
Phillips and Winchell (2011)	CTA	LiCl	Island fox	Baited cage traps	Field	Unknown	Unwanted captures
Rathore (1984)	CTA	LiCl	Domestic dog	Domestic sheep and rabbit meat	Captive	10	Livestock protection
Rauer *et al.* (2003*b*)	Physical repellents	Rubber bullets, cracker shells, warning shots, fireworks	Brown bear	Humans	Field	7+	H–W interaction management

Reidy *et al.* (2008)	Electric fencing	Electric shock	Feral pig, various	Food, bait stations, sorghum crops	Captive/Field	18/Unknown	Crop protection
Rogers (1984)	Chemical repellents	Capsaicin spray, CN tear gas	Black bear	Humans	Field	9	H–W interaction Management
Romin and Dalton (1992)	Fear-evoking stimuli	Ultrasound	Mule deer	Deer and humans	Field	Unknown	Vehicle strike
Rossler *et al.* (2012)	Aversive Collars	Electric shock	Wolf	Bait sites	Field	14	Livestock protection
Sargisson *et al.* (2012)	Aversive collars	Citronella spray	Domestic dog (various breeds)	n.a.	Captive	10	Barking prevention
Schultz *et al.* (2005)	Aversive collars	Electric shock	Wolf	Domestic cattle	Field	2	Livestock protection
Seamans and VerCauteren (2006)	Electric fencing	Electric shock	White-tailed deer	Cordoned areas and food	Semi-captive	Unknown	Crop protection
Shivik and Martin (2000)	Aversive collars	Electric shock	Wolf	Domestic calves	Captive	3	Livestock protection
Shivik *et al.* (2002)	Aversive collars	Electric shock	Wolf	Domestic calves	Captive	4?	Livestock protection
Shivik *et al.* (2003)	Fear-evoking stimuli/fladry/aversive collars	Light, sound/flagging/electric shock	Wolf	Supplied carcasses	Field	>10?	Livestock protection
Sillings *et al.* (1989)	Electric fencing	Electric shock	Black bear	Apiaries	Field	Unknown	Apiary protection
Smith *et al.* (2008)	Chemical repellents	Capsaicin spray	Black, brown, and polar bears	Humans	Field	83	H–W interaction management
Steiss *et al.* (2007)	Aversive collars	Electric shock/lemon spray	Domestic Dog	n.a.	Captive	24	Barking prevention
Stenhouse (1983)	Physical repellents/fear-evoking stimuli	Batons, plastic slugs/sound, flare, bang cartridges	Polar bear	Specific baited sites	Field	257	H–W interaction management
Stickley *et al.* (1995)	Fear-evoking stimuli	Human effigy	Cormorant	Commercial fish	Field	Unknown	Fish stock protection
Storer *et al.* (1938*b*)	Electric fencing	Electric shock	Brown bear, black bear	Food pens, apiaries	Field	Unknown	Apiary protection
Ternent and Garshelis (1999*b*)	CTA	Thiabendazole	Black bear	Meals-Ready-to-Eat (MREs)	Field	5?	H-W interaction management
Thompson (1979)	Electric fencing	Electric shock	Coyote	Cordoned areas	Captive	15	Livestock protection
van Bommel and Johnson (2012)	Fear-evoking stimuli	Livestock guarding dogs	Various predators (mostly wild dogs, foxes)	Livestock	Field	150 (Surveyed Producers)	Livestock protection
VerCauteren *et al.* (2003*a*)	Fear-evoking stimuli	Red laser	White-tailed deer	Humans, commercial crops	Field	Unknown	Various
VerCauteren *et al.* (2003*b*)	Fear-evoking stimuli	Light, sound, human effigy	Coyote	Domestic sheep	Field	Unknown	Livestock protection
VerCauteren *et al.* (2005)	Fear-evoking stimuli	Light, sound	Elk, mule deer	Alfala bails	Field	Unknown	Various
Wagner and Nolte (2001)	Chemical repellents/fear-evoking stimuli	Sulfurous compounds (amongst others)	Black-tailed deer	Western red cedar seedlings	Captive	~30	Herbivory management
Wells (2001)	Aversive collars	Citronella spray	Domestic dog (female Labrador)	n.a.	Captive	30	Barking prevention
Zarco-González and Monroy-Vilchis (2014)	Fear-evoking stimuli	Human effigy?, sound, scent?	Jaguar, puma	Domestic livestock	Field	Unknown	Livestock protection
Zemlicka and Mason (2000)	CTA	Renardine	Coyote	Ground meat	Captive	24	Livestock protection

odour or visual cues, is associated with a feeling of illness (e.g. nausea), thus tending to cause avoidance of consumption of that particular substance in the future (Conover 2002). Such associations can be artificially induced in animals through a variety of mechanisms, but usually involve some sort of chemical being mixed with the ingested substance that produces emesis and nausea (Dorrance and Gilbert 1977; Conover 2002).

Background/overview

Investigations of CTA in relation to wildlife management were first undertaken by Gustavson *et al.* (1974), who explored whether the emetic, lithium chloride (LiCl), could be used in baits made up of the flesh of selected prey animals or their carcasses and fed to coyote subjects in an effort to induce sickness and suppress attack responses when subjects were later presented with live prey animals. Their initial results, while not entirely definitive, appeared promising (Mason *et al.* 2001).

Example success

Two notable studies have reported the successful implementation of CTA in relation to preventing wildlife from obtaining anthropogenic food. Cornell and Cornely (1979) treated several food items (e.g. hot dogs) with LiCl and fed them to coyotes attempting to scavenge at a campground, concluding that following observed emesis and related illness, coyote activity was reduced at the campground. Avoidance appeared to last a reasonable amount of time, with coyote activity at the campground remaining low for at least two months, after which the study terminated, but there was no way to determine whether avoidance was directly the result of successful CTA. Treated coyotes were observed to be sick for several hours, and one lay in a campground while recovering. In a second study, Ternent and Garshelis (1999*a*) demonstrated CTA in black bears that had previously been accessing so-called meals-ready-to-eat (MREs) in a military reserve, with two of three bears exhibiting avoidance more than one year after treatment, while the third bear no longer showed avoidance. The results of Tauchmann (1999) suggested that some dingoes avoided eating baits following trials, but results were confounded because different chemicals were used simultaneously at the same location, making interpretations difficult.

Example failure

Most failures have been reported in relation to studies involving attempts to condition coyotes (or other predators) to avoid killing sheep simply from exposure to baited sheep meat (e.g. Conover *et al.* 1977; Burns and Connolly 1980; Bourne and Dorrance 1982; Burns 1983*b*). The majority of criticism appears to relate to what actually constituted an aversion and whether, and to what degree, an aversion to baits would generalise to live prey (Bekoff 1975; Conover *et al.* 1977; Griffiths *et al.* 1978; Burns and Connolly 1980; Bourne and Dorrance 1982; Burns 1983*a*). The latter in particular raises concerns about generalisations beyond a given bait type (e.g. type of food).

Advantages

CTA would generally not require the capture of animals in order to promote conditioning. Theoretically, it could reduce incidence of dingoes seeking food in camp grounds, although this would require a considerable degree of generalisation to be effective (see below).

Disadvantages

The association between particular anthropogenic food and the onset of illness is required for each food type if avoidance of that food is to develop. For example, Ternent and Garshelis (1999*a*) demonstrated that bears conditioned to avoid MREs did not generalise this response to other foods, even when these other foods were presented along with (but separate from) MREs in post-treatment trials. Dorrance and Gilbert (1977) suggested that, for black bears, CTA would likely be ineffective in producing aversion to tourist handouts and garbage, precisely because of the wide array of tastes and related cues associated with such food. This sort of caveat could logically be extended to many species in similar circumstances, including dingoes on Fraser Island. Also, if treatment results in prolonged malaise, this could be considered unacceptable to members of the public, and could place animals in jeopardising situations that they might otherwise not be in (e.g. they could be vulnerable to injury from people or other animals). If subjects are potentially dangerous animals, people being able to closely approach them, when normally this wouldn't be possible, might also put such people at risk, particularly if animals are irritable or feel threatened. Finally, there are certain food types that are both naturally and artificially available (e.g. fish) to dingoes. These would need to be excluded from treatment programs, because dingoes would be unlikely to discriminate between artificial sources and natural sources and so would likely come to avoid both.

Conclusion

Given the limitations and disadvantages identified above, CTA is unlikely to be appropriate for managing dingoes on Fraser Island.

Electric fencing

Definition/description

Electric fences usually consist of several electrically conductive wires strung between poles or posts secured to the ground. As the name suggests, electric fences feature a purposeful aversive stimulus in the form of electricity, usually delivered as a pulse at relatively high voltages (e.g. >5000 V) and varying amperages (see, for example, Linhart *et al.* 1982). There are considerable variations in relation to permanency, materials and energizers used to create the electrical stimulus.

Background/overview

Electric fences are amongst the most widespread attempts to utilise an aversive stimulus in controlling the behaviour of animals, including wild animals. An early example in wildlife management was an investigation into keeping bears from raiding apiaries (Storer *et al.* 1938*a*), but until relatively recently, had not been comprehensively explored as a means of a barrier in other applications and for other predators (Dorrance and Bourne 1980).

Example success

Recently, Smith and Gookin (unpubl. data) explored the utility of highly portable electric fencing for campers and hikers to prevent ingression of bears (and other animals) at campsites. They found that as long as food, garbage and related scents/odours were properly managed, bears were successfully deterred from campsites. A video (https://www.youtube.com/watch?v = Sv2G-aRDvyY) of some of the testing involving captive brown bears demonstrates the reluctance that bears appear to exhibit in relation to breaching small areas in which attractive food items were placed, protected by the temporary electric fencing. Smith (pers. comm.) suggests that pricing ranges from US$75 to US$250, depending on requirements, and that the systems are light enough to be highly portable. Davies and Rockwell (1986) reported similar success with reasonably inexpensive, semipermanent electric fencing in deterring polar bears from a research facility. They added that careful management of attractants and proper grounding of the system likely served to deter repeated intrusion attempts from bears, at least one of which was known to exhibit nuisance behaviour in the area.

Example failure

Thompson (1979), who tested 34 types of electric and non-electric fences on penned coyotes, concluded that electric fences were unlikely to serve as effective barriers to coyotes. One important variable that Thompson (1979) identified was the height of fences, with an apparent minimum threshold height of 168 cm, the point at which most coyotes would hit fences if attempting to jump over them. Thompson's (1979) poor results in relation to electric fencing largely appeared to relate to the difficulty of consistently delivering shock to coyotes attempting to cross fence lines (only 13 of 466 test occasions), with coyotes seemingly able to avoid the wires that delivered shock, and he suggested that shock alone may not be sufficient to deter coyotes with a history of killing sheep. However, given the ability Thompson (1979) noted for coyotes to avoid electrical wire, more appropriate wire spacing for a given species appears to be of relevance.

Advantages

Electric fences effectively exclude animals from human-use areas, and can usually be built cost effectively. Portable, personal fencing is relatively cheap and can be used anywhere that camping is allowed. In addition, conditioned avoidance is likely to be generalised to any similar-looking fence, particularly if salient visual stimuli are also used (e.g. fladry, see next section).

Disadvantages

The electrical stimulus can also affect people so ample warning, and possibly an intermediate barrier may be required to minimise exposure to human beings. Careful consideration needs to be given to designing fences to prevent digging under, or rapid movement through, wiring (Acorn and Dorrance 1994). Fences become ineffective if power is lost. Solar-battery systems will be required for semipermanent or permanent fences in remote areas. If built surrounding entire human-use areas, entry/exit points for people and vehicles will usually have to be included (individual tent sites are probably an exception). In turn, this may limit scalability.

Conclusion

Both semipermanent and temporary, personal electric fencing may have application on Fraser Island; the former, for example, in relation to established camping sites used regularly by commercial operators, and the latter for casual visitors.

Fladry and electrified (turbo) fladry

Definition/description

Fladry is a curious form of fencing or visual barrier constituting a wire (or similar) rope hung between stakes or posts secured to the ground, with material 'flags' or pennant-shaped objects suspended at regular intervals along the rope. In this sense it is often used in contexts where a temporary barrier might be required, such as a so-called 'night-pen' to protect livestock being moved around. Similar to electric fencing, electrified fladry involves the addition of an electrical stimulus delivered through the fladry materials. This pairing of electric shock with fladry is sometimes referred to as 'turbo fladry' (e.g. Bangs *et al.* 2006).

Background/overview

Fladry was originally used in eastern Europe and Russia to herd wolf packs into constricted areas using a funnel-shape arrangement, where they could then more easily be killed (Okarma and Jędrzejewski 1997; Musiani and Visalberghi 2001). Indeed, it is wild canids, and particularly wolves, that appear most troubled by fladry, the reasons for which are somewhat enigmatic. The apparent wariness and unsettled behaviour often displayed by wolves when close to fladry is reminiscent of aspects of neophobia (van Bommel and Johnson 2014), or the fear of something novel (but see Musiani and Visalberghi 2001).

Example success

Lance *et al.* (2010) carried out experiments of electrified fladry in penned and field trials involving wolves. From penned trials, they concluded that it was superior to ordinary fladry in protecting a food source, but noted that hunger was a strong motivator in wolves approaching fladry. The authors pointed out that as wolves began to investigate the systems (e.g. nipping and biting at flags), ordinary fladry soon failed, whereas electrified fladry '… reinforced the initial fear response' (Lance *et al.* 2010, p. 712). They concluded that the initial increase followed by a decrease in approaches observed in relation to electrified fladry were the result of conditioned avoidance. In the final phase of testing, wolves that had been previously presented with electrified fladry were presented with ordinary fladry in post-treatment trials, which eventually they breached, suggesting that avoidance responses would extinguish over time in the absence of shock.

Example failure

Davidson-Nelson and Gehring (2010) found that while electrified fladry was an effective, temporary barrier to wild wolves on protected pastures, it did not deter wild coyotes, suggesting that the aversive effects of fladry may be limited to wolves (see also Okarma and Jędrzejewski 1997). However, Davidson-Nelson and Gehring (2010) wondered whether the lack of effect on coyotes might be a limitation associated with the spacing of flags as well as species and individual differences in initial responses and subsequent habituation.

Advantages

Fladry may be more cost-effective and simpler to erect in comparison to other types of fencing, particularly where temporary, small-scale barriers are required. In conjunction with electrification, or in addition to electric fencing, flags or pennants may serve as a useful, secondary, visual stimulus.

Disadvantages

While fladry can be effective as a barrier, its effects appear to be relatively short-lived, with Musiani *et al.* (2003) observing a period of up to 60 days before wolves in field trials eventually crossed the barrier, appearing to do so through a learning process of exploratory interactions with various elements of the fladry equipment. In other words, whatever apprehension or fear fladry initially causes, this eventually dissipates over time and exposure. No published tests involving dingoes could be found.

Conclusion

Fladry may have application on Fraser Island, particularly in terms of visually enhancing electric fencing. However, before adoption in management programs, it requires further testing, both as a temporary aversive stimulus in its own right, and also as a secondary, visual stimulus in relation to enhancing associative properties of electric fences

Chemical repellents

Definition/description

Smith *et al.* (2000, p. 305) defined a repellent as anything designed to '… discourage an approaching or attacking animal from completing that approach'. Certain chemicals are irritating or painful (i.e. are in some way aversive) when in contact with mucosal tissues, the nasopharyngeal system, or nerve endings. As such, such chemicals are capable of producing a repellent effect, a good example being capsaicin (or related derivatives). A common delivery mode is via pressurised canisters or containers.

Background/overview

In an attempt to find potential repellents to brown bears and polar bears, commonly implicated in attacks, Miller (1983*b*) tested a variety of stimuli on captive bears of both species, including a variety of chemicals and chemical sprays. Miller (1983*b*) found that several chemical sprays had a repellent effect, particularly a commercially available spray marketed as a dog repellent (Halt! Animal Repellents, Inc.), which contained capsaicin. Later, Rogers (1984) tested the same product on free-ranging black bears and an initial focus of the research was to determine whether pain-inducing stimuli would make bears more aggressive or dangerous in realistic settings where encounters may occur. Rogers (1984) found that sprayed bears never acted aggressively, and when sprayed, usually immediately retreated a short distance, where they then rubbed their eyes with their paws.

Example success

Smith *et al.* (2008) amassed all available (83) records on the use of capsaicin spray (commonly referred to as bear spray) against bears in Alaska, USA. They found that in all cases (72 of 83) where bear spray was used defensively by a person, neither bears nor people were severely injured (i.e. people did not require hospitalisation). In 18% of cases involving aggressive bears, a resumption of the behaviour that prompted spraying occurred again, such that people had to respray bears, which eventually resulted in bears leaving. Wind, although having some effect on spray direction, did not appear to hamper the ability of users to make facial contact of spray with bears. In four cases, spray caused minor injury to people and they had to vacate the area. Smith *et al.* (2008) concluded that bear spray was an effective non-lethal measure in diffusing potentially dangerous encounters between all three North American bear species and humans, and encouraged widespread use for both human safety and bear conservation reasons.

Example failure

Smith (1998) warned against the use of chemical sprays as some form of topical deterrent to areas or objects, as bears he observed were actually attracted to the scent and displayed vigorous rubbing and body rolling in affected areas (see also Smith *et al.* 2008). The same could also be true for some other potential irritants, such as citronella.

Advantages

Chemical repellents that visitors could carry and use in appropriate cases (e.g. if threatened or attacked) offer a means of personal, defensive protection that is currently unavailable.

Disadvantages

Capsaicin-based and related sprays are restricted and are illegal to carry in many Australian states and territories, including Queensland (Western Australia is an exception), so appropriate alternatives would need to be found and tested (see below). Certain sprays can also affect people in the process of deployment (Herrero and Higgins 1998; Smith *et al.* 2008) so care and practice is required in terms of safe operation.

Conclusion

Chemical repellents, particularly in the form of pressurised sprays offer potential in terms of personal and defensive protection for people encountering dingoes that could represent an imminent risk to human safety. However, given legal restrictions, an alternative to capsaicin-based sprays would need to be found and experimentally tested.

Fear-evoking stimuli

Definition/description

This approach encompasses a relatively large array of stimuli that promote or elicit fear. Conover (2002) regarded fear-provoking or -evoking stimuli as those objects that increase an animal's fear or wariness and include visual (e.g. predator models/effigies, strobing lights, lasers), auditory (e.g. alarm calls, sirens, loud bangs from pyrotechnics or gas exploders) and olfactory (e.g. predator urine) stimuli. So-called 'frightening devices', which are often limited to producing visual and auditory stimuli, are synonymous with fear evocation and the allied concept of neophobia.

Background/overview

Effigies, such as the humble 'scare-crow', have been utilised in an attempt to protect crops for centuries (Conover 2002), taking advantage of the fear that some species have of being close to human beings (e.g. because humans are a potential threat). Modern versions include rapidly inflating (via compressed air or other gas) human-like effigies that appear periodically (e.g. Stickley *et al.* 1995; Andelt *et al.* 1999; Conover 2002) or when activated by motion such as an animal moving nearby (e.g. VerCauteren *et al.* 2003*b*). In an attempt to deter coyote depredation (and that of other species) on livestock farms, early incarnations of light- and sound-based frightening devices suggested considerable promise (Linhart 1984).

Example success

Darrow and Shivik (2009) explored the differential effects of light and sound stimuli on captive coyotes, testing each sensory type of stimulus separately, and then in combination. The combined treatment was the only one in which habituation to stimuli was not observed. They also found that light was the more important of the two stimuli, with less habituation observed in light-only treatments than in sound-only treatments. However, and perhaps most interestingly, they also found something akin to an individual personality effect in their results, with individuals that they had classified as *bolder* more commonly exhibiting habituation to such stimuli, while those classified as *shy* never exhibited habituation to the stimuli and always showed avoidance. A final class, labelled as *persistent* coyotes, were initially repelled but did not avoid stimuli, landing them somewhere in the middle of bold and shy.

Example failure

Ultrasonic 'deterrents' generally appear to have little merit in actually deterring test subjects in a meaningful manner (Bomford and O'Brien 1990; Romin and Dalton 1992; Bender 2003; Edgar *et al.* 2007). An exception was Blackshaw *et al.* (1990), who observed partial success in deterring dogs exposed to various sound-producing stimuli, including ultrasound, at a distance of 1 m. Generally, there was no clear pattern in relation to the frequency (sonic or ultrasonic) or other characteristics (e.g. sound pressure level) of the units tested that produced favourable responses considered consistent with the stimuli being aversive. In the one case where a specific unit produced notable aversions in 9 of 14 (64.3%) dogs exposed, because the unit ranged in frequency of emissions between 17.5 and 55 kHz (i.e. between sonic and ultrasonic frequencies), it was unclear whether it was ultrasound that actually produced the favourable results.

Advantages

Potentially, a very large array of lights and sounds with considerable variation in relation to how they are presented (e.g. randomly modulating pitch, random strobing etc.) is available in developing fear-evoking devices. Much of the equipment required to generate the stimuli is also commonly available and is not likely to be overly expensive. The ability to randomly generate unpredictable combinations of lights and sounds may decrease the prospect of habituation and maintain startle or fear-evoking responses (but see Koehler *et al.* 1990; Avery 1997; Gilsdorf *et al.* 2002). Interestingly, Karp *et al.* (2014) found that signal non-linearity and unpredictability were a key to limiting habituation in conspecific responses to the alarm calls of other meerkats (*Suricata suricatta*), hinting at how habituation might be avoided in other contexts. Radio-activated systems can limit operation to only those occasions when instrumented (e.g. radio-collared) animals are relatively close to equipment (Breck *et al.* 2002).

Disadvantages

A common assessment of many fear-evoking or frightening devices is that they work for only short periods and responses are subject to habituation (Koehler *et al.* 1990; Andelt *et al.* 1997; Smith *et al.* 2000; Mason 2001; Conover 2002; Gilsdorf *et al.* 2002). Extremely loud noises or bright lights (e.g. lasers) can also cause permanent eyesight or hearing damage to both dingoes and people, so care is required in explorations of efficacy.

Conclusion

The sentry-like frightening devices often used in livestock protection applications are probably of limited value on Fraser Island. However, similar hand-held devices that utilise bright, strobe or pulsing lights and multiple, loud sounds emitted in an unpredictable manner might have merit in terms of personal repellents and should be investigated.

Physical repellents (e.g. sublethal projectiles)

Definition/description

In a similar vein to chemical spray repellents, there is a suite of physical or tactile stimuli available that may act as aversive stimuli in many contexts. These include sublethal projectiles (e.g. plastic/rubber bullets, bean bag rounds, paint balls) deployed from firearms, or clay balls/marbles deployed from slingshots.

Background/overview

Most early research using sub-lethal projectiles has involved the three North American bear species. Most of this research was published as internal government reports or was otherwise not accessible for review. An exception was a report by Stenhouse (1983), in which 257 free-living polar bears were attracted to field sites using food lures and exposed to various potentially aversive stimuli including rubber batons and plastic slugs. Stenhouse (1983) reported that rubber batons fired from an antiriot gun were 100% successful in repelling bears, while rubber batons fired from a pistol and plastic slugs failed to repel bears. Later research from Gillin *et al.* (1994) attempted to pair an otherwise benign stimulus (a bird call not from the area) with an imminent presentation of sub-lethal projectiles to free-living, female brown bears, with somewhat encouraging but ultimately mixed results, leading them to suggest that evidence relating to conditioning of the benign stimulus was inconclusive. Overall, they felt that the use of sub-lethal projectiles was of temporary benefit in managing bear behaviour, but they noted that if site (or place) avoidance was to occur, presentation of the aversive stimulus was required at each site (i.e. experiences at one site were not generalised to all such sites).

Example success/example failure

With the exception of Stenhouse (1983), all empirical examples that could be found, all involving bears, reported mixed results from the use of projectiles (Gillin *et al.* 1994; Rauer *et al.* 2003*a*; Beckmann *et al.* 2004; Leigh and Chamberlain 2008; Mazur 2010), so only one, relatively recent, example is detailed here. A comprehensive assessment comes from Mazur (2010), who employed a variety of aversive stimuli, including several sub-lethal projectiles, in attempting to modify the behaviour of black bears labelled as food-conditioned. Over a four-year period, she amassed a large dataset of trials involving 150 bears and over 1000 attempts at conditioning. For a subset of 36 food-conditioned bears, rubber slugs fired from a shotgun caused bears to run away on 92% of occasions, which was markedly more successful than other treatments. Mazur (2010) considered conditioning trials to have been most effective on bears that were not considered food-conditioned. Yet there was an indication that at least some bears deemed to be food-conditioned and persistent in terms of food seeking, did undergo beneficial behavioural modification. For instance, 25 of 36 bears were considered less persistent in terms of food-seeking activity (but still displayed unwanted behaviour). Of these, 16 were exposed to treatments for a year or more, and ceased entering human-use areas. A further two animals went from having their behaviour deemed to be unacceptable to acceptable by managers. And of 11 of 36 bears classified as the most persistent in exhibiting food-seeking and unwanted behaviours, one stopped visiting human-use areas altogether and four had their behaviour modified but required treatments each year. The remaining six bears were deemed to represent a danger and were killed or relocated, but it is possible that this number might have been higher without the aversive interventions. Mazur (2010) estimated that at approximately US$400 per bear annually, costs for lethal control and aversive conditioning were roughly comparable.

Advantages

Most physical stimuli such as rubber bullets are likely to be broadly aversive to most individuals encountered and habituation to these sorts of stimuli would probably be uncommon. In other words, such stimuli are likely to be immutably aversive. Proficient users could probably deploy stimuli over longer ranges than most other repellents, although safety considerations may be a limiting factor in this regard.

Disadvantages

The use of firearms is heavily restricted and will necessarily be limited to a few licenced carriers within the wildlife management or law enforcement agencies present on Fraser Island, limiting application. Perhaps the biggest limitation relates to the likelihood of animals developing an avoidance response only in regard to people (and associated stimuli such vehicles) that deploy such stimuli rather than the more ideal response of avoiding a particular place (e.g. a campground) where aversive events take place (Herrero 2002; Shivik *et al.* 2003; Corbett 2009; Mazur 2010; Appleby 2015). Finally, there is a risk of permanent injury or worse if an animal (or person) is hit by a projectile in certain places (e.g. an eye).

Conclusion

There may be some potential applications for the use of physical aversive stimuli in a limited number of circumstances, most likely presented by highly skilled practitioners. However, due to considerable limitations, alternative approaches should take experimental precedence as recommended in the Allen *et al.* (2012) review and this approach should generally be avoided.

Aversive collars

Definition/description

Aversive collars consist of an aversive stimulus (commonly shock or a potential irritant such as citronella or lemon spray) that is activated via a radio signal or once a threshold decibel is reached (i.e. from barking or similar vocalisations). Currently all available collars are derived from domestic applications which include so-called 'virtual fences' for containing domestic animals, usually through a short-range radio transmission wire being buried around a perimeter within which a collared animal must remain, or else for wider training applications in which the stimulus is activated via a hand-held remote control.

Background/overview

The earliest investigation of shock collars in relation to aversive conditioning in a wildlife management context also remains one of the most compelling. Linhart *et al.* (1976) tested a custom-built shock collar on the behaviour of four captive coyotes. The experiment consisted of coyotes being presented with black or white rabbits as a food source; however, if coyotes attempted to attack black rabbits, they would receive a shock, whereas no shock was presented if they attacked white rabbits. One coyote failed to learn the association between colour of the rabbit and shock and initially avoided all rabbits, but only for a short time. The remaining three coyotes acquired the association after only 3–5 shock presentations. They retained this response for 3–9 months after treatment without subsequent shock treatments. In a later experiment, Andelt *et al.* (1999) observed similar avoidance responses rapidly develop in two wild-caught coyotes in relation to lambs, even observing submissive behaviour being exhibited by one conditioned coyote directed at lambs in close proximity.

Example success

Rossler *et al.* (2012) remains the largest-scale trial of shock collars on free-ranging, wild wolves, with 10 collared subjects, and four control subjects, from a mixture of control and treatment packs, with encouraging results. They compared the time that collared and non-collared wolves spent near bait sites outfitted with radio systems that activated collars when they came into range. Results showed that collared wolves spent significantly less time near bait sites than did control wolves, for periods greater than 40 days. Interestingly, they also found that non-collared pack members in packs containing collared wolves also spent significantly less time at bait sites in comparison to control-only wolf packs, likely facilitated through some process of cultural transmission. Collared wolves were not observed to move outside of established home ranges following treatment. Rossler *et al.* (2012) concluded that collared wolves had undergone avoidance learning, coming to associate the general area of bait sites with the prospect of shock, thus learning to avoid such places. It is also possible that a similar avoidance response developed in some non-collared wolves within the same packs.

Appleby (2015) reported mixed but potentially beneficial results in modifying the behaviour of two Fraser Island dingoes.

All empirical assessments of citronella collars found related to attempts to suppress barking in domestic dogs, with mixed, but largely beneficial results in this regard (Juarbe-Diaz and Houpt 1996; Wells 2001; Moffat *et al.* 2003; Sargisson *et al.* 2012). Sargisson *et al.* (2012) did note that some dogs grew indifferent to the citronella stimulus, which they considered to indicate that it was only a mildly aversive stimulus.

Example failure

Shivik *et al.* (2003) presented the results of several experiments in which a variety of non-lethal management techniques were explored. Amongst these, shock collars were tested on 10 penned wolves in an attempt to examine if stimulation would prevent the consumption of a protected food source. They compared results of food consumed over several one-hour tests with a control group of wolves, and in contrast to other studies involving shock collars that had been largely successful, they found no significant difference in consumption levels between groups, although consumption did appear to be lower for collared wolves compared with control wolves. They concluded that shock collars were difficult to use with wolves, showed considerable variation in terms of the responses to stimulation exhibited by individuals, required a great deal of maintenance and suggested that, in conjunction with other logistical constraints, such challenges would complicate incorporation into wider management programs (see also Shivik 2006).

Advantages

Highly precise and contiguous presentation of the shock stimulus is possible in relation to target behaviour, as is precise adjustment of stimulus characteristics such as intensity and duration, which in turn addresses the need to establish stimulus sufficiency (Appleby 2015). Shock may be largely immutable as an aversive stimulus in most cases.

Disadvantages

Animals must be captured and outfitted with shock (or related aversive) collars. Collar performance has been mixed and unreliable in several studies involving wild canids (Shivik *et al.* 2003; Hawley *et al.* 2009, 2013; Appleby 2015). While responses to electrical stimulation may vary to some degree within and between individuals (Shivik *et al.* 2003), variation is more likely due to inconsistent collar performance (Hawley *et al.* 2009, 2013). Citronella might only be mildly aversive and thus, responses could be subject to habituation over time or muted in certain individuals (see Sargisson *et al.* 2012). At the time of writing, no commercially available collar systems ideally suited to wildlife management situations are available (but see Hawley *et al.* 2013 in regard to custom modifying a domestic dog shock collar in an effort to make it more suited to such applications). Polsky (2000) and Overall (2007*a*, 2007*b*) raised concerns about shock-induced aggression and other undesirable behavioural changes arising from the use of shock collars on domestic dogs, discussed later.

Conclusion

Shock collars have been investigated in several studies involving similar canids (coyotes and wolves) with largely positive results in relation to conditioning success and the development of avoidance responses. The results of Appleby's (2015) trials, while minimal, were also promising, and involved Fraser Island dingoes directly. Citronella collars do not appear to have been investigated in relation to an analogous wildlife management context, so more extensive, experimental investigations would be required in this regard. Aversive collars are probably best suited to very specific, challenging cases of conflict.

Hard release procedures

Definition/description

For some animals, capture and handling can represent a potentially aversive experience, which opens up the possibility of this being used specifically in relation to management. The deliberate enhancing of frightening, uncomfortable or otherwise unpleasant aspects of capture and handling processes, and particularly at the time of an animal's release, is sometimes referred to as hard release (Mazur 2010). A range of aversive stimuli can potentially be used at the point of release, but possible inclusions are loud sounds, bright strobe or flashing lights, and chemical/physical repellents.

Background/overview

It has been recognised for some time that capture and handling can be aversive to some animals that feature in conflict behaviour such as bears (Jonkel 1994; Chi *et al.* 1998; Clark *et al.* 2002). Two of the bear studies mentioned in the section on physical repellents actually involved hard release procedures (Beckmann *et al.* 2004; Leigh and Chamberlain 2008). The results of each were mixed, but in different ways, and here we have chosen to highlight the differing results in relation to place avoidance.

Example success

Leigh and Chamberlain (2008) wanted to ascertain whether bears labelled as a nuisance could be discouraged from exhibiting such behaviour through hard release procedures. They used two treatments: one involving rubber buckshot (fired from a shotgun) as an aversive stimulus, and the other using the same buckshot, but with the addition of dogs for harassment, applied when bears were released from culvert traps (similar in principle to a large cage trap, usually on a trailer for easy transport). Some bears were given more than one treatment. The authors reported that 10 bears (from a total of 11) returned to exhibiting nuisance behaviour within five months of exposure to treatments. In regard to experimental aims, the results were largely unsuccessful. However, only one bear returned to its place of capture, possibly indicating that place avoidance had occurred in most of the bears.

Example failure

Beckmann *et al.* (2004) measured the effectiveness of hard release procedures using various aversive stimuli in terms of the number of days following treatment that it took bears to return to urban patches where conflict was occurring. This was a more direct assessment of whether bears had learned to associate a hard release experience with a particular area, prompting place avoidance, for at least some reasonable period. Because many bears (44 of 62, ~71%) returned to such sites relatively soon after release (≤40 days), the authors concluded that effectiveness was ultimately limited. However, of potential note is that it did not appear that all bears were released in the same areas where they were captured, which may have confounded the learning process.

Advantages

Hard release procedures can be easily incorporated into existing capture and handling programs being undertaken in other management contexts (e.g. population studies – provided physical recapture is not a requirement). This could assist with identifying and targeting animals that are frequenting places where avoidance would be preferable.

Disadvantages

It may be difficult to avoid the stimuli associated with the management staff present at the point of release from overshadowing stimuli associated with the place, if place avoidance is the desired outcome. It could also make treatment animals very difficult to capture in the future.

Conclusion

For very challenging cases, hard release methods could be of use on Fraser Island in an effort to discourage dingo activity in particular areas (i.e. place avoidance) although aversive stimuli would likely need to be presented remotely (e.g. via remote-controlled shock collars) or in some other way that limits exposed dingoes from associating the experience with management staff, rather than the place of release.

Potential applications of aversive conditioning on Fraser Island

It is apparent from the literature that while there are few, unequivocal successes in relation to the use of aversive stimuli in successfully modifying the behaviour of wild animals, certain approaches warrant further investigation. Not all studies have involved species closely related to dingoes (e.g. wolves and coyotes as opposed to bears), so this needs to be considered in determining appropriate approaches worth trialling. However, similar types of conflict as seen on Fraser Island have led to empirical investigations that illustrate the challenges and opportunities of certain approaches, offering insights in how best to proceed. We determined that there are three major contexts within which empirical investigations of aversive conditioning, garnered from research elsewhere, could be useful in managing human–dingo conflict on Fraser Island. These were:

(1) excluding dingoes from accessing human-use areas such as camping grounds;
(2) diffusing encounters between dingoes and people in which people perceive a threat, or where dingoes actually display threatening or aggressive behaviour, but also in cases where discouraging close-quarter interactions in young or naïve dingoes may aid in preventing more serious conflict from emerging in the future; and
(3) modifying the behaviour of dingoes that chronically exhibit undesirable behaviour.

Opportunities and challenges for utilising aversive stimuli in managing dingoes in each of these contexts will be briefly discussed in the following sections.

Dingo exclusion

Much work has already been done in regard to exclusion on Fraser Island, with conventional fencing being erected around several major townships/resorts as well as some day-use areas and campgrounds (Corbett 2009; Allen *et al.* 2012). However, there remain a relatively large number of places where people visit or camp that are problematic or prohibitive to fence in this manner. An alternative option to conventional fencing is to explore variations of electric fencing, several of which appear very promising. For instance, there is currently a camping area where such an electric fence is being trialled, with preliminary reports suggesting that the approach is effectively excluding dingoes from the electrified fenced area (Novak, pers. comm.).

We recommend that any site utilising electrified fencing be closely monitored for dingo activity in an effort to both record general activity levels, but also to allow observations of any attempts by dingoes to breach fencing and their responses to the shock stimulus in this regard. Trail cameras capable of day and night (infrared) video recording positioned around the fence line are the best means of collecting such information, but opportunistic interviews with people who were present during such events could also be useful. If possible, several independent control sites should also be established (i.e. a similar fence is erected but not electrified) for comparative purposes. Alternatively, control (or pretreatment) periods for any future sites should be undertaken (i.e. a fence is erected but not activated for a period of ~2–4 weeks) before establishing a treatment period (i.e. the fence is activated for a similar period). A similarly timed post-treatment period would be of use in establishing the degree of conditioning that might have occurred, or whether dingoes can tell the difference between active and inactive fences. Randomised periods of active and inactive fence operation could also be experimentally effective in this regard. This approach should be replicated at as many sites as practicable, but a minimum of six sites is recommended.

An additional treatment or treatment level should be considered, by implementing fladry at some (again, with consideration of adequate replication) or all sites, before the electrification treatment, as fladry may initially cause an apprehension to approach in dingoes. It may also provide an additional, salient visual stimulus to dingoes that they come to associate with shock in the future if they approach and make contact with the fence. It could also discourage attempts to dig under electric fence wire. Post-treatment assessments should also be undertaken to examine the longevity of any effects. Fladry should initially be constructed following the recommendations of Young *et al.* (2015), who suggested that flags should be attached to wire via circular rings or else knotted below the attachment point, and constructed from a heavy material such as marine vinyl. In addition, Musiani and Visalberghi (2001) suggested that flags should be spaced ≤50 cm apart, bright in colour (consider red), and strung on wire between 25 and 75 cm (e.g. 50 cm) off the ground. We note though that dogs see certain colours poorly so this too may be a worthwhile experimental variable (C. Wynne pers. comm.). Given that most testing has been done on wolves, and the subsequent size differences with dingoes, some modification in design might be required.

In a similar vein, trials should be conducted to examine whether portable electric fences can adequately exclude dingoes from individual camp or tent sites, as Smith and Gookin (unpubl. data) found in relation to bears. It is recommended that, initially, testing be undertaken by management or research personnel, rather than the general public. Pilot test sites should actually be attended so that they are both a realistic analogue to actual campsites, but also in case dingoes that manage to breach fences become trapped, so that the system can be turned off, allowing escape. Some consideration should be given to the presence/absence and availability of attractants (e.g. food lures) as a variable to emulate 'ideal' and 'less-than-ideal' camp sites. Again, fladry could be included as a secondary stimulus. If initial results are encouraging, recommendations could be made to visitors planning on camping in otherwise unfenced areas to utilise such portable electric fencing, and rates of usage and outcomes should be monitored via direct observation and user surveys. Similarly, control-treatment–post-treatment experiments involving electrified individual storage items such as portable food coolers or bait buckets that might serve as an attractant to dingoes (QPWS, unpubl. data) should be undertaken.

Briefly, the results of Robley *et al.* (2015) showed promise in potentially excluding dingoes from areas using chemicals derived from or mimicking dominant dingo urine. Theoretically, this could be used to emulate the scent-marking exhibited during territorial maintenance in what Robley *et al.* (2015, p. 11) called a 'keep out, no trespassing' message to other dingoes. These principles have been successfully demonstrated in other species. For example, Jackson *et al.* (2012) used translocated scent stations (naturally voided scats and urine) from a radio-tracked pack to effectively contain African wild dogs (*Lycaon pictus*) that had roamed near to or beyond the boundary of a protected area. Similarly, Ausband *et al.* (2013) found that translocated scent stations (naturally voided scats and urine) successfully manipulated the movements of wolves in one year (2010), but not the following year (2011). They suggested several reasons for a lack of aversion in 2011, including the possibility that additional cues normally associated with territorial maintenance (e.g. howling) may have led to habituation. However, Shivik *et al.* (2011) found that in coyotes, conspecific urine served as an attractant, with coyotes spending more time in treatment compared to controlled sites.

It is unclear whether bio-fences would be widely applicable on Fraser Island because, usually, relatively small areas such as camp grounds within existing territorial boundaries require exclusion. How readily scent boundaries in such areas would evoke territorially related avoidance is therefore unclear. However, if it did evoke avoidance, the approach is likely to be cheaper than fencing so could be of use in some circumstances, such as excluding dingoes from, for example, Orchid Beach, the only major township left unfenced on the island.

Personal protection

For those rare cases where an encounter involves a dingo or dingoes that could represent an imminent risk to human safety, there is a need for approaches that allow people involved to protect themselves in a safe, appropriate and effective manner using aversive stimuli. However, there is also a case for the general public using such aversive stimuli in another context. Discouraging younger or more naive dingoes from engaging in close-quarter interactions with people, by exposing them to aversive experiences as such behaviour begins to emerge, may also help to prevent more intractable or serious conflict situations involving those animals arising in the future (Mazur 2010).

One collective set of options for managing close-quarter encounters can be grouped into what might be regarded as personal repellents. There are a wide variety of stimuli that could potentially act as repellents. For example, Hunt (1984*a*) showed that an umbrella rapidly opened in front of charging bears was sufficient to cause them to halt or retreat. However, further provocation during testing caused these bears to recharge or display curiosity (Hunt 1984*a*). An open, sturdy umbrella may also serve as a useful shield against a dingo making a very close approach, or exhibiting potentially aggressive behaviour, reducing the prospect of a more serious incident occurring. This is similar to the current recommendation by QPWS to carry a stick for self-defence purposes, but may also have some increased utility in this regard. Umbrellas could even be 'enhanced' with other potentially aversive light and sound stimuli. However, as it is unclear how dingoes presented with an umbrella, enhanced or not, would actually react, experimental trials would be required before making any recommendations to the public.

A note here that novel stimuli, or previously encountered stimuli used in a novel way can also produce escape and avoidance responses, but if experience with such stimuli is only mildly aversive, responses will rapidly diminish, as has been observed with many fear-evoking stimuli (Koehler *et al.* 1990; Smith *et al.* 2000; Conover 2002; Gilsdorf *et al.* 2002; Shivik *et al.* 2003; Shivik 2006).

On the other hand, if painful or irritating effects of particular stimuli persist over prolonged periods, this may interfere with the normal, natural behaviours of animals in some cases (e.g. coyotes exposed to LiCl baits: Cornell and Cornely 1979). In some circumstances, a moderate degree of persistence of an aversive effect could be of direct benefit in terms of increasing human safety, as it might allow people the time required to retreat from an aggressive animal (Smith *et al.* 2008). It is therefore important to contextually determine the 'sufficiency' of a stimulus (Appleby 2015). This can be generally regarded as one that effectively and consistently produces a desirable result (e.g. immediate cessation of target behaviour such as an aggressive charge) on repeated occasions across most individuals exposed to the stimulus, but that does not continue to produce aversive effects long after exposure.

Given the restrictions involved with the use of capsaicin-based sprays and sub-lethal projectiles (particularly those fired from firearms) there is a need to find effective, alternative repellents specifically for dingo management on Fraser Island. Appleby *et al.* (2017*b*) recently began this process by examining the immediate responses of several dingoes on Fraser Island exposed to three stimuli: a whistle, an emergency air horn and a motorised water pistol. Neither the whistle nor the air horn appeared to be aversive to most dingoes, but the water pistol produced responses consistent with the stimulus being aversive in many cases. However, some dingoes responded very little to any of the stimuli, including the water pistol, and there were hints of habituation to the water pistol stimulus taking place in one subject towards the conclusion of the study. Thus, while the water pistol initially produced repulsion in many cases, this may have been related to neophobia, and water alone may not be sufficient in consistently repelling dingoes exposed on repeated occasions. A potential alternative is a commercially available spray advertised as a dog repellent called SprayShield® (PetSafe), which is listed as containing 1% citronella. No published accounts on the effectiveness of this product as a repellent could be found at the time of writing, so experimental testing is required in order to properly determine efficacy in wildlife settings.

Research such as that of Darrow and Shivik (2009) suggests that light may be an important potentially aversive stimulus to dingoes, or light stimuli in combination with loud sounds, which together may reduce the prospect of habituation (but see Koehler *et al.* 1990; Avery 1997; Gilsdorf *et al.* 2002). We are not aware of any studies involving the testing of hand-held light and sound devices in repelling wild animals, and we reiterate that many of the studies that have been undertaken in examining the effects of such stimuli in other contexts report only short-term benefits in modifying animal behaviour. It is possible though that if such a device could be made to resemble something that was more immutably aversive (e.g. if SprayShield® were found to be as effective as some bear sprays appear to be), or if all the stimuli were contiguously used on occasion, beneficial conditioning might occur. In turn, this might reduce the prospect of habituation to the less aversive stimuli, which is often regarded as the biggest limitation of so-called 'frightening devices' utilising light and sound stimuli (Koehler *et al.* 1990; Shivik and Martin 2000; Conover 2002; Gilsdorf *et al.* 2002; Shivik *et al.* 2003; Shivik 2006). Variability and unpredictability in relation to visual and audiogenic stimulus characteristics (e.g. non-sequential strobe lights, rapid changes in pitch of sounds, random loud sounds) may also reduce the prospect of habituation (Koehler *et al.* 1990; Gilsdorf *et al.* 2002). Suitable test devices will likely need to be custom made.

Remedial aversive conditioning

It is possible that any successful implementation of the previously broached aversive exclusion and repellent measures would go a long way to mitigating much of the ongoing conflict on Fraser Island. However, there still might be cases where dingoes develop behaviour that represents an unacceptable and unavoidable risk to human safety. In the absence of any alternatives, such animals will almost certainly be destroyed. Rather than removing these animals permanently through lethal control, an option is to capture and then house them temporarily in a containment facility, where they could undergo intensive aversive conditioning and assessment procedures (Appleby 2015). This would mirror a similar program involving black bears in North America nicknamed 'bear school' (Jonkel 1994: C-22).

There are several other distinct advantages to temporarily containing high-risk animals. The first and most obvious is that it removes any risk posed by such animals to the general public. The second is that aversive conditioning procedures can be undertaken systematically and precisely. Behaviour that is undesirable can be properly defined and then strategically targeted for modification in a stepwise manner, allowing proper conditioning to occur before moving on to the next target behaviour. Aversive conditioning and behavioural assessment procedures could be developed and evaluated in consultation with behavioural experts and animal welfare organisations such as the Royal Society for the Prevention of Cruelty to Animals and the Humane Society (see further below). In cases where behaviour has not been modified to an acceptable degree, decisions about the fate of the animal can then be made – importantly, without the need for haste often required when animals presenting a risk are free-living. In cases where animals are deemed to no longer represent an immediate risk, they could be released (potentially using hard release procedures), having been outfitted with monitoring equipment, and possibly temporary shock collars, so that their whereabouts and behaviour can be assessed and, where necessary, interventions, including the prospect of recapture, can be undertaken after release.

Ethical and welfare considerations

Any aversive conditioning procedure carries with it the potential to impact negatively on the welfare or wellbeing of individuals involved. This is such an important area of discussion that it warrants its own review. As such, we will only touch on some key aspects here, in hope of promoting further discussion and consideration.

The very intention of aversive conditioning is to pair either sets of stimuli or stimuli and behaviour in such a way as to reduce the exhibition of behaviour on the part of animals deemed to be of management concern. As such, this involves deliberately exposing animals to stimuli that cause pain or discomfort or otherwise results in fear, escape and avoidance responses. Note that this potentially involves a very large number of stimuli and stimulus complexes, and is not limited to stimuli that are perhaps more readily equated with pain or discomfort, such as electric shock. Arguably, almost any circumstance that produces punishment must in some way be unpleasant for the animals involved, otherwise the behaviour could continue. This includes stimuli that animals naturally encounter during their lives, such as chemical and physical antipredator strategies of potential prey. Predators that survive negative encounters with potential prey animals undoubtedly learn from such experiences, to such a degree that there is a significant adaptive component to this learning process, whereby, for example, highly visible markings of certain potential prey species serve as an unmistakable warning to would-be predators. Nature is replete with examples, from insects such as ants and wasps, amphibians such as toads, to mammals such as the skunk and the echidna. Some species even co-opt the warning signals (e.g. aposematic colouration) of noxious species despite not being noxious themselves, a phenomenon known as Batesian mimicry.

Modern aversive conditioning is therefore, at its best, simply an extension of these adaptive and learning processes. The goal is to target particular, undesirable behaviours in order to reduce or extinguish their exhibition, while having a limited impact on the general wellbeing or naturalistic behaviour of animals involved. In much the same way that a predator might come to avoid a noxious prey item, aversive conditioning should aim to encourage avoidance of particular behaviours on the part of predators, such as closely approaching humans, while not subverting or modifying normal foraging or other behaviours.

Note that for such a lesson to be quickly and effectively learned, there should be no competing or contradictory information available to the animals. An example would be if interacting with some humans might represent an opportunity to obtain food, while avoiding others (e.g. rangers) means avoiding negative consequences for such behaviour. In other words, behaviour that leads to an animal successfully accessing anthropogenic food is going to be reinforced, which directly competes with the aim of having these animals generalise that close association with humans is neither rewarding nor, in fact, likely to lead to negative outcomes and should therefore be avoided. This kind of discrimination would inevitably undermine the success of any aversive conditioning program and therefore has considerable welfare implications, particularly as it is likely to necessitate a much larger number of exposures to negative or benign encounters with people to extinguish interaction behaviour compared with a situation with no positive reinforcement. For instance, Mech (2017) found that it took ~90 occasions of presenting a handful of dirt to a wolf exposed to previous hand feeding to extinguish food solicitation and related interaction behaviour.

We agree entirely with Lewis *et al.* (2017, p. 4) when they argue that 'For managing apex predators, this requires innovative use of the least invasive techniques and translating them into specific actions within conservation efforts', and Fox and Bekoff (2011, p. 129), who similarly stated that 'We must ensure that we do everything we can to minimize pain and suffering and cause the least amount of harm'. This is in line with the ethical responsibilities outlined in the National Health and Medical Research Council's (NHMRC 2013, p. 51) Australian code for the care and use of animals for scientific purposes, which includes the statement 'Steps must be taken at all times to safeguard the wellbeing of animals by avoiding or minimising harm, including pain and distress, to the animals'. The code also makes provision for experiments in which animals will experience pain and distress that will not be alleviated with two major recommendations (NHMRC 2013, p. 53):

(1) the planned endpoint of the project must be as early as feasible to avoid or minimise pain and distress to the animals,
(2) the animals must be monitored and assessed so that the planned endpoints are detected, and actions must be taken in accordance with the AEC approval for the project.

In the context of aversive conditioning experiments, we take these two recommendations to mean that any approved experiments should be conducted as quickly and efficiently as possible, such that a clear result, either way, is achieved in as short as possible a time frame, and that at all possible times during the experiment, animals involved should be monitored and assessed to ensure their wellbeing is not being compromised. Monitoring would likely entail a mixture of direct observation and behavioural assessment, and where possible and appropriate, the use of animal-borne devices to convey information about movement patterns and activity periods, and to facilitate direct observation.

Further, the code recommends that in relation to specific procedures, they must 'cause the least harm, including pain and distress, to the animals' (NHMRC 2013, p. 59). This allows, for example, aversive conditioning procedures to be ranked in relation to potential harm, such that two aversive conditioning procedures that aim to produce the same result (e.g. avoidance responses) can be weighed in terms of the potential harm they may cause. In such cases, obviously the procedure likely to cause the least harm, but have the highest degree of success at behavioural modification, should always be chosen. It also dictates that proposed experiments/approaches should be evaluated and appropriately employed in relation to their assumed aversiveness, an example being that, because the use of an umbrella may be considered less aversive than Sprayshield®, umbrellas should be trialled first and more widely, with the latter being trialled only in cases where either umbrellas are found to be insufficiently effective or for more intractable cases of problem behaviour. It also means that if less aversive procedures are found to be effective, suggestions such as remedial aversive conditioning may not be required, and if required, only in the worst-case scenarios.

The NHMRC (2008) also produces a more specific set of recommendations relating to behaviour modification. This document provides a risk matrix that includes two key areas:

(1) assessment of the frequency and pain associated with a procedure, and
(2) assessment of the consequence of this pain and distress for the animal.

Aversive conditioning procedures are most likely to fall into the 'frequent' category for (1), where an animal is highly likely to repeatedly experience pain and distress as a direct result of the procedure. This is the highest category rating. However, well planned and executed experiments should also fall into either the 'marginal' (temporary pain and/or distress occurs, but is alleviated in a short time) or 'negligible' (minor discomfort occurs for a short time) categories for (2).

Proposed procedures that fall more into the 'critical' (permanent impairment and/or serious pain or distress occurs as a result of the procedure) or 'catastrophic' (the procedure causes severe pain or distress that cannot be alleviated, which is grounds for euthanasing animals without delay) categories for (2) should obviously be avoided to the greatest degree possible.

Note that this potentially includes several procedures mentioned in this review, such as certain versions of CTA, which have been experimentally shown to cause relatively long periods of pain and distress to animals that have ingested emetic chemicals. Sub-lethal projectiles also have the potential to cause long-term damage and impairment. In the same vein, careful consideration would also obviously need to be given to the details of hard release and remedial aversive conditioning procedures, as previously mentioned. The risks involved in the use of sub-lethal projectiles warrants that only highly trained and skilled professionals be involved in delivering such stimuli. In fact, this recommendation should be extended to any aversive conditioning program that has the potential to fall into the 'critical' or 'catastrophic' risk categories outlined above. Programs most likely to fall within the 'marginal' or 'negligible' categories should still be overseen by trained professionals, but may offer opportunities to involve the general public in larger trials of certain defensive stimuli, if pilot studies are successful and provided appropriate information on safety and animal welfare are made available.

The specific case of shock collars

While any application of aversive conditioning might invite controversy, shock collars may be particularly controversial. The use of electric shock carries with it a stigma, not undeserved, perhaps because of historical uses of electric shock in highly invasive human and other animal experiments. It is therefore understandable that any proposed use of electric shock be both carefully considered and ethically defensible. As previously mentioned, there may be less controversial forms of aversive or defensive stimuli that warrant precedence in relation to testing in all but the most intractable cases. However, as Appleby (2015, p. 154) argued, modern '… shock collars allow for precise and controllable exposure to the intensity and duration of aversive stimuli'. In turn, this means that the use of shock as an aversive stimulus delivered via modern shock collars is actually well placed to meet the criteria demanded by the NHMRC (2013) code, and the 'sufficiency' argument raised above.

However, because of the controversy that shock collars evoke (Appleby 2015), several studies involving domestic dogs have specifically investigated aspects of their impacts on welfare and wellbeing. Results are mixed. A study by Steiss *et al.* (2007) found no significant changes in plasma cortisol (often used as a physiological measure of stress), adrenocorticotropic hormone (ATCH) or activity levels between three groups of eight dogs exposed to either shock, lemon spray or dummy collars. They did detect a non-significant, but initially marked change (169%) in acute plasma cortisol levels for dogs exposed to aversive stimuli, but this appeared to dissipate relatively quickly.

Conversely, Schilder and van der Borg (2004) found that amongst 32 dogs exposed to a total of 107 shocks, behavioural indications were that shocks were painful and had become associated with the presence of a trainer/owner. They concluded that the welfare of dogs exposed to shocks was at stake. Beerda *et al.* (1998) examined saliva cortisol and behavioural changes in dogs exposed to a variety of assumed aversive stimuli including shock. They found that random and unpredictable exposure to shock (and certain other stimuli such as loud noises) tended to produce elevations in saliva cortisol levels and a very low posture in exposed dogs.

The latter experiment hints at a potentially important qualifier in the use of aversive stimuli such as shock in relation to causing deleterious effects: that unpredictable, and therefore, inescapable or unavoidable exposure to painful experiences leads to physiological and behavioural indicators of distress in dogs. This was further demonstrated by Schalke *et al.* (2007), who examined salivary cortisol and heart rate as a measure of stress amongst three groups of dogs shocked via shock collars in different contexts – (1) when they made contact with a prey item (a rabbit dummy), (2) when they failed to return to a trainer after being trained to do so when recalled, and (3) randomly – Group 1 showed no significant increase in saliva cortisol levels, whist the other two groups did. They concluded that dogs that were clearly able to associate their behaviour with the possibility of a shock (i.e. touching a prey item led to a shock) were able to predict and control exposure to the stressor. Similarly, Christiansen *et al.* (2001) found that shock collars effectively suppressed very close approaches to sheep consistent with attack behaviour in collared dogs, but that apart from the initial reaction to shock, dogs did not show overt signs of stress or anxiety in other contexts.

Thus, it may not simply be shock, in particular, as opposed to other aversive stimuli, that evokes stress responses in dogs, but the lack of predictability about aversive events and a subsequent inability to escape or avoid such events. In turn, carefully providing salient links between behaviour, or predictor stimuli, and aversive events is critical to minimising stress and other related impacts on wellbeing when undertaking aversive conditioning, regardless of the aversive stimulus being utilised.

However, the use of shock collars as a means of attempting to modify the behaviour of domestic dogs remains ardently opposed by some professionals and affiliated organisations, including the Australian Veterinary Association (AVA 2014, p. 118), who released a policy against the use of shock collars: 'unless it can be scientifically shown that their use does not cause long-term physical or psychological harm to dogs'. Overall (2007*a*, 2007*b*) gave a comprehensive summary of concerns about the use of shock collars and provided compelling arguments for how and why other approaches are usually far more appropriate for treating behavioural concerns in domestic dogs. Overall's (2007*a*, 2007*b*) arguments were bolstered, for example, by a report mentioned previously from Polsky (2000), which found that five cases of aggression directed towards humans by domestic dogs may have been prompted by shocks experienced as part of a boundary containment system. Redirected or other forms of aggression were not observed by Appleby (2015) or in other reports of shock collar usage involving wild canids, but this remains a notable concern necessary of consideration.

Shivik *et al.* (2002) and Schultz *et al.* (2005) also noted moderate tissue damage localised to the area of some wolves' necks exposed to shock collar probes. Hawley *et al.* (2013) found that a revised design involving the use of rounded probes that made contact with the top of the neck (rather than the more usual bottom of the neck) and a reduction in any sharp edges of the collar material itself alleviated some tissue damage. Appleby (unpubl. data) did not observe tissue damage in any shock-collared dingoes examined. Again, though, this is a potential cause for concern and may warrant further collar revision (for example, incorporating retractable probes that only make contact with skin immediately before a shock is delivered). This would also likely serve as a salient secondary stimulus and promote rapid acquisition of escape and avoidance responses.

Understandably, both the AVA (2014) and Overall (2007*a*, 2007*b*) are in favour of using positive reinforcement training methods wherever possible. However, methods relying upon positive reinforcement are not likely to be appropriate in modifying the behaviour of wild animals, such as dingoes on Fraser Island, because access to food or other reinforcers is likely to confound and compound incident mitigation. Interestingly, the AVA (2014) does not rule out the use of other behavioural modification collars (e.g. citronella collars) in specific circumstances. It is not immediately clear why exposure to citronella should be any less aversive or more acceptable compared with shock, and, in terms of lingering aversive qualities, may arguably be more aversive.

However, we echo the conclusion of the AVA (2014) and Christiansen *et al.* (2001) that any proposed use of aversive collars in wildlife management should be reserved for very specific and appropriate cases, and that any trials be conducted by trained and experienced professionals in animal behaviour. Further, we call for the development of a code of practice for the use of aversive conditioning approaches such as shock collars in wildlife management contexts, as a guide for both researchers and Animal Ethics Committees.

Conclusion

No single approach that utilises aversive stimuli in an attempt to modify or moderate the behaviour of potentially dangerous wild animals represents a panacea for conflict resolution. Nor does aversive conditioning more generally. As encounters are capable of occurring across the entire island, and at all times of the day and night, it is also entirely unrealistic to assume that any management authority could prevent all negative encounters from occurring, and neither should it be expected to (Wolfe 2008). Therefore, some degree of risk is always likely to exist in wilderness areas and personal preparedness and responsibility, including adherence to all management regulations and recommendations, remains the best defence in this regard.

We have identified several potential opportunities for aversive stimuli to be incorporated into exclusionary, personal protective and dingo remedial behavioural contexts on Fraser Island, all of which require further, rigorous experimentation. In order to ensure that the wellbeing of dingoes is not compromised, experiments will require approval and oversight of an Animal Ethics Committee. Certain proposed procedures (e.g. remedial aversive conditioning) are also likely to require input and guidance from an expert panel if such measures are ever deemed appropriate and necessary. Even when the outcome of any experiments is encouraging, and leads to an adoption of the approach within the broader management strategy, the best chance of success in reducing conflict is to strategically use such approaches in conjunction with other, critical management approaches. In this sense, management of the 'human' element of wildlife–human interactions is as, if not more, important in successfully reducing the prospect of incidents occurring. Provided suitable aversive stimuli and conditioning procedures can be found, they offer an opportunity to fill some gaps in the current management strategy, and could represent a vital alternative to lethal control.

Conflicts of interest

The authors confirm that they have no conflicts of interest in relation to this paper.

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