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Supplementary material

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

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Table S1. A summary of previous reviews relating to aversive conditioning and allied methodology in managing predators

Review Topic	Context	Summary	Reference
Livestock Guarding Animals	Livestock-Predator Management	•Predators reported to have killed 273000 sheep and 147000 cattle and calves in 2000 and 2001 respectively •Livestock guarding dogs used in America since the 1970's. Various breeds: Great Pyrenees, Akbash and Komnodor, most common and Anatolian Shepherd, Maremma, Shar Planintez and mixed breeds less common •About 28% of US sheep producers used guard dogs in 1999 •Sheep produces in Colorado who did not employ guard dogs lost 5.9 and 2.1 times the number of lambs to all predators compared to producers who did use dogs in 1986 and 1993 respectively •Some potential problems including dogs themselves harassing or abandoning sheep, being aggressive towards people or being prone to injury or premature death. Most producers appear content that advantages outweigh these relatively rare problems •Concluded that overall guard dogs are a cost-effective means of reducing livestock depredation •Provides advice on achieving the greatest success (e.g. procedures for raising with, and introducing pups to, flocks) •Reports that Llamas have been used to successfully reduce sheep losses. One potential advantage over guard dogs is that llamas eat the same feed as the sheep they protect •Donkeys are also used with success and are cheaper to purchase and maintain in comparison to dogs and llamas. Both donkeys and llamas tend to live longer than dogs, neither need special raising conditions (protective behaviour is inherent), are more compatible with lethal control practices targeting predators (e.g. trapping) •Dogs may be superior at deterring larger predators such as bears and mountain lions •Concludes that guard animals are more publically acceptable in comparison to some techniques (particularly lethal approaches) but their use is not a cure-all and other techniques are likely to be required by producers	Andelt (2004)

Review Topic	Context	Summary	Reference
Predator Odour Effects	Predator-Prey Relationships	•Division between primary defences (e.g. always present - crypsis, mimicry, defensive weapons) and secondary defences (what happens when a predator is actually detected) •Primary defences can also be behavioural (e.g. living in a social group or sleeping in a different place each night) •Lists a large array of studies exploring the responses to prey species (mostly comprising small mammals) to myriad predator stimuli, with a focus on odours •Predator avoidance is the best way to avoid predation •Odour effectiveness as repellents (deterrents) is mixed, although some categorically successful studies given •Suggest that failures occur because of a mismatch between predator odour and target prey, or a mismatch in context, along with sub-optimal substance concentrations, behavioural variation within prey species and ultimately, habituation •Concludes that further study will be required to produce commercially-viable deterrents	Apfelbach et al. (2005)
Non-lethal management	Livestock-Wolf Conflict	•Wolves killed 148 cattle, 356 sheep & 37 dogs from 1987 to Jan 2001 in MT/ID (USA) and surrounds •99 and 85 wolves have been relocated or killed respectively in response •Divided stimuli into aversive (e.g. CTA; electric shock) and disruptive (e.g. lights; sounds) •Suggest behaviour-contingent activation of disruptive stimuli could be important in developing long-term beneficial responses	Bangs and Shivik (2001)
Lethal and Non-lethal Management	Livestock-Wolf Conflict	•Recovered wolf populations in MT, ID and WY (USA), comprising 1020 wolves, killed 528 cattle, 1318 sheep, 83 dogs and other animals between 1987 •$55000 paid by private compensation fund •117 and 396 wolves have been relocated or killed respectively in response •Advocate integrated, proactive and reactive, lethal and non-lethal approaches •Key recommendations: Focus recovery in areas with low chance of conflict; radio-collar 20-30% of a population; capture and radio-collar conflict animals on-site; increase monitoring after depredations; loan monitoring equipment to ranchers etc.; use harassment to relocate wolves away from conflict sites; modify grazing strategies and husbandry to avoid conflict; supplementally feed wolves at dens or orphan pups; delay removals if circumstances permit; allow the public to participate in harassing wolves to instil fear; utilise scare devices, sub-lethal munitions, fladry, shepherds and shock collars where appropriate; compensate for losses; reduce public land grazing; temporarily hold problem wolves in captivity; relocation is of limited utility but may work; allow a more liberal destruction policy for members of the public; where necessary the government agencies should strategically destroy problem wolves	Bangs et al. (2006)

Review Topic	Context	Summary	Reference
Lethal and Non-lethal Management	Human-Coyote Interactions	•Fatal mauling of a three-year-old girl prompted the development of coyote management programs to increase public safety •Defined seven stages of progressive interaction-related behaviour in coyotes: 1. an increase in night time observations of coyotes on streets and in yards; 2. an increase in coyotes attacking/killing pets and approaching humans; through to 7. coyotes acting in an aggressive manner to human adults during daytime hours •Fair level of success for hazing and aversive conditioning in stages 1 and 2 when employed consistently •Effects lasted for several months, or sometimes even years •Success of hazing for coyotes exhibiting behaviour in stages beyond 3 was temporary •Partially effective hazing/aversive conditioning approaches were: humans waving their arms and yelling at coyotes; loud noises (e.g. starter pistols; air horns); motion-activated lights and sprinklers; sub-lethal projectiles; trapping •Argues that lethal trapping works well to "...extinguish bold behaviours within the population, especially if the alpha male and/or female are taken." (p. 390) •Advocates broad public education programs (including on effective hazing), regulations to ban and enforce feeding, the development of behavioural monitoring programs and population reduction when required	Baker (2007)
Sonic Deterrents	Animal Damage Control	•Audible sound >130dB and infrasound/ultrasound >141dB cause pain and sometimes sickness in vertebrates, but is difficult to achieve except for explosive bangs •Some suggestion that biosonic devices (e.g. alarm or distress calls) could repel animals, with distress calls showing promise in captive and field trials, and further, that such calls may not be subject to the same rate of habituation that some artificial sounds might be. Concluded that the approach has potential •Sonic devices that invoke fear (e.g. bangers, crackers, sirens) may be limited to short-term control. Best results are from randomised presentation intervals, a range of sounds are used, sound sources are not static, distress calls are included and sounds are reinforced with real danger (e.g. shooting) •Generally, ultrasound has been found to have little beneficial impact and utility in management applications	Bomford and O'brien (1990)

Review Topic	Context	Summary	Reference
Conditioned Taste Aversion (Conditioned Food Aversions Based on Deception)	Animal Damage Control	•Begins by arguing that difficulty in reducing animal damage can stem from not being able to directly apply the repellent to animal or plants requiring protection •Objects that mimic the animals or plants (models) can be laced with chemicals that produce sickness, the aim being to get the affected individuals to avoid models in reverse form of Batesian mimicry •When 'mimics' poorly represent models, results tend to be negative, but hypothesised when they are indistinguishable, following exposure to treated mimics, provided costs (of sickness) outweigh the nutritional benefits of eating a model, then models will be avoided •In order for mimics and models to be indistinguishable, they must look and smell the same or very similar, and in reference to the latter, the chemical emetic must be undetectable •Argues that solitary foragers causing damage are the best candidates •Concludes that whilst it holds promise, and 20 years of research, use of the approach remains uncommon	Conover (1995)
Lethal and Non-lethal Management	Wildlife Management	•A comprehensive compendium of all relevant research on human-wildlife conflict up to that time •Four chapters devoted to each of the following topics: lethal control; fear-provoking stimuli; chemical repellents; exclusion •States that the main problem with fear-provoking stimuli is habituation, and this is inevitable unless the stimuli are capable of killing animals. Best used for short-term problems (e.g. birds eating seeds in newly planted fields •Habituation can be delayed several ways: use devices that mimic predators in some way; animate devices; use stimuli sparingly •Divides chemical repellents into area and contact repellents, with fear-provoking chemicals more successful as area repellents and some odour/taste and fear-provoking chemicals good contact repellents •Also makes mention of CTA in a similar context to Conover (1995) •Suggests that electric fencing may not be effective on some animals (e.g. deer) because may be prepared to get shocked. States that barrier fencing is generally one of the best ways to eliminate problems with wildlife •Concludes that there are no panaceas in wildlife management and advocates an integrated approach, utilising some specific examples which combine lethal and non-lethal strategies to achieve aims	Conover (2002)
Frightening Methods/Stimuli	Wildlife Damage Management	•Public surveys show an overwhelming support for nonlethal management methods, but there is acceptance for lethal methods when no alternatives exist •Comprehensive summary of auditory and visual physiology in vertebrates •Habituation is the major limitation with frightening devices, and random or animal-activated devices with multiple stimuli may reduce or delay the prospect of habituation •Devices deployed before or at the first sign of damage could be more effective than when damage is already underway •Many devices are ineffective and all devices must be tested to determine efficacy •Devices used in integrated management that incorporate multiple stimuli are the most effective at reducing damage	Gilsdorf et al. (2002)

Review Topic	Context	Summary	Reference
Frightening Methods/Stimuli	Animal Damage Control	•Frightening methods are best used in situations where, for example, crop protection is only required for short periods of time (days to weeks) •Habituation to frightening stimuli appears to be the biggest limitation •Combinations of visual and acoustic stimuli can enhance effects and habituation can be delayed by varying presentation spatially and/or temporally •Threating objects (e.g. scarecrows) offer only limited scope for protection, but may be enhanced with other inventions being used simultaneously •In a similar vein, predator-resembling effigies may work for brief periods but require accompanying reinforcement/punishment in order to maintain effectiveness. Lifelike mimics are best and those incorporating motion may delay habituation •Some devices are advertised as effective repellents, but have little scientifically verified evidence to defend claims. In one case, action was taken against the manufacturers and distributors of devices purporting to utilise some form of electromagnetic aversive stimulus in an effort to stop sales based upon unsubstantiated claims	Koehler et al. (1990)
Lethal and Non-lethal Management	Predator Management (Particularly Coyotes)	•Argues that whilst lethal control can be effective in managing conflict, it is becoming increasingly criticised •Methods utilising aversive stimuli discussed along with other non-lethal management approaches •Suggests that electric fencing is likely more effective than conventional fencing; the effectiveness of fladry was unknown but likely to be useful in only specific circumstances; fear-evoking devices (light and sound emitting) can work temporarily but may be subject to habituation, and are relatively expensive and unsuitable for areas close to human habitation; there are no commercially available repellents that demonstrably work; CTA has been successful in some circumstances but its effectiveness in reducing livestock depredation is equivocal •Concludes that few viable, non-lethal alternatives are available at present, but an integrated approach involving lethal and non-lethal methods is likely to be more successful. At present, selective removal via lethal control remains the most ecologically and economically sound approach	Mason (2001)
Chemical Repellents/Aversive Strategies	Wildlife Management (Particularly Predators)	•States that chemical repellents and other aversive strategies are central to non-lethal wildlife management •Strategies are reliant upon pain, learning and fear and no single approach is universally successful •Strategies that combine approaches and are tailored to specific problems have the greatest promise •Special mention given to behaviourally-contingent auditory and visual stimulus devices, coupled with electric shock or vibration collars in promoting avoidance •Concludes that a combination of approaches, including lethal control is required in managing predators	Mason et al. (2001)

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Chemical Repellents/Aversive Strategies	Livestock-Predator Management	•Suggests there is a growing interest in developing efficacious non-lethal wildlife management approaches •Reports that scientists at the National Wildlife Research Centre (NWRC) are combing new technology with behavioural principles to develop innovative approaches to preventing damage by predators •Suggest that behaviourally-contingent stimuli help reduce habituation •Aversive stimulus devices such as shock collars also set up to activate depending on behaviour are being developed as well as automatically attaching collar systems •Conclude that whilst no single approach fits all management situations, the combination of new technology, coupled with appropriate considerations of animal behaviour, may allow for the development of cost-effective solutions to reduce conflict	Shivik and Martin (2000)
Non-lethal management	Predator Management (With a View to Conservation)	•Conservation of some carnivores is threatened because of losses due to conflict •Divides stimuli into disruptive (fladry; frightening devices) and aversive (shock collars; sub-lethal munitions), and suggests both sets of stimuli are useful in reducing conflict •Methods that allow for coexistence between livestock and predators are required •Provides a table broken down into approach, associated costs, duration of effectiveness, species involved and references •Suggests that most techniques have been subject to minimal testing •Biological theory coupled with innovative, cost-effective technology could "...go a long way toward promoting human-carnivore coexistence" (p. 257) •Further research including taking an interdisciplinary approach offers promise	Shivik (2006)
Aversive Conditioning, Deterrents and Repellents	Livestock-Predator Management	•Isolated aversive conditioning to specifically be related to CTA, concluding that results have been inconsistent and inconclusive •Repellents and deterrents comprise the remainder of aversive and related stimuli •They concluded that chemical repellents are not very effective on coyotes, but are more so on wolverines and bears in some cases [note that in each case cited, delivery of the chemicals varied somewhat which may have had some bearing on results] •Projectile repellents work with bears but application is limited •Auditory and visual devices work well but the effects are fleeting •Final conclusion was that such approaches "...showed little promise..." in relation to managing conflict involving livestock	Smith et al. (2000b)

Review Topic	Context	Summary	Reference
Livestock Guarding Animals	Livestock-Predator Management	•Livestock guarding dogs are the most common guard animal used •States that the most common predator involved in depredation is the coyote, so most interest in guard animals that can protect against coyotes •Other species such as bears, felids, wolves and wolverines are known to engage in depredation •Provided a comprehensive list of benefits of guard dogs (e.g. reduced depredation, reduced labour and access to areas previously unavailable) and problems (e.g. harassment of sheep, failure to guard sheep and interference with other working dogs) •Suggested that the use of donkeys and llamas as guard animals is less promising because enclosed pastures are required for best results •Other approaches such as bonding sheep to cattle has potential but more research is required •Noted some depredation displacement may occur if neighbouring properties do not employ guard animals •Concluded that livestock guarding animals are an effective approach to reducing livestock depredation and require evaluation in areas with high losses, compared to other approaches such as changing production systems	Smith et al. (2000a)
Non-lethal Management	Livestock-Dingo Management	•Lethal control has major drawbacks including having little effect on predation rates •Fences (conventional and electric) can work to keep livestock from wandering and dingoes entering pastures •Repellents disrupt immediate behaviour and rarely have a long-lasting effect •Deterrents should condition avoidance of a behaviour over a longer term •Visual/acoustic repellents have had some success but response are subject to habituation •Chemical repellents do not generally appear effective in the context of livestock depredation management •Disruptive harassment (usually a person standing guard over livestock with a non-lethal firearm) is unlikely to be widely used in Australia •CTA, whilst able to condition food avoidance, might not condition prey avoidance and currently the approach cannot be used successfully in managing livestock depredation •Fladry has yielded some success, but wariness is probably due to neophobia and subject to habituation. Not enough is currently known about efficacy to apply it at a large scale •Shock collars sow some promise at small scales, but collars need to be tailored to longer-term use and currently their use is impractical in protecting large areas/numbers of livestock •Various stock management approaches (e.g. night confinement) reduce depredation but require intensive effort •Dingo population control (through fertility control) could be feasible but more research is required •Livestock guarding animals, particularly dogs, have shown demonstrable efficacy even at large scales, and show the greatest promise reducing livestock depredation in Australia	van Bommel & Johnson (2014)

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