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A welfare assessment of methods used for harvesting, hunting and population control of kangaroos and wallabies

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Abstract

In Australia, several macropod species are subjected to commercial harvesting, recreational hunting and population management, using both lethal and non-lethal measures. Some techniques for killing macropods can cause prolonged and/or severe suffering, and of particular concern is the welfare of remaining pouch young or young-at-foot, when females with dependent young are killed. Non-lethal methods are more widely supported by the general public and include reproductive control and relocation. These methods, however, also have significant associated welfare challenges. This review outlines the welfare concerns for each current method, and concludes that an accurate head-shot by an experienced shooter is least likely to inflict suffering. However, this assumes best practice shooting, which may not be representative of field conditions. Furthermore, many aspects of macropod control and killing still require significant research. These include, but are not limited to: accurate statistics for pouch young and young-at-foot mortality and morbidity in Australian states; data on field-based compliance with National Codes of Practice; safe and remote administration of reproductive control measures; and the impact of using dogs and trapping in wallaby destruction and hunting.

Keywords: *animal welfare, culling, lethal control, macropod, non-lethal control, population management*

Introduction

In Australia, four kangaroo and three wallaby species are killed or subjected to population management for reasons such as commercial harvesting, protection of agricultural land and crops, recreational hunting, animal welfare and conservation (Tasmanian Department of Primary Industries, Parks, Water and Environment [TAS DPIPWE] 2006; Australian Capital Territory and Municipal Services [ACT TAMS] 2010; Queensland Department of Environment and Heritage Protection [QLD EHP] 2012; Department of Sustainability, Environment, Water, Population and Communities [SEWPaC] 2013). While accepted methods differ between states, lethal options include shooting with a firearm and poisoning (TAS DPIPWE 2006; SEWPaC 2008a), and non-lethal methods include fertility control (Herbert *et al* 2006) and relocation (Higginbottom & Page 2010). Some animal protection and welfare groups oppose lethal methods, arguing that such practices inflict pain and suffering (Voiceless 2013; Animal Liberation ACT 2014; Animals Australia 2014) and that compliance with the relevant National Codes of Practice (eg SEWPaC 2008a,b) is inadequately monitored or adhered to (Boom *et al* 2012). In situations where human activity affects animals, there is an ethical responsibility to ascertain whether suffering occurs as a direct or indirect result of these activities (Fraser & MacRae 2011). For clarity within this review, harvesting will refer to killing for commercial purposes; destruction will refer to killing for the protection of agricultural land and crops or population reduction, or the killing of joeys and young-at-foot; hunting will refer to killing by recreational shooters; and euthanasia will refer to killing for the purpose of ending the suffering of a sick or injured animal.

The aim of this review is to examine the welfare implications of current, legal methods for macropod harvesting, destruction, recreational hunting and population control within Australia. The literature will be evaluated with reference to welfare assessment frameworks by Kirkwood *et al* (1994), Mellor and Reid (1994) and Sharp and Saunders (2011) and focusing on the number of individual animals affected, the likelihood of exposure to harm, the nature and extent of harm and the capacity of the animal to suffer, with specific reference to cognitive development in pouch young. Harm is assessed against five recognised domains of suffering (adapted from Mellor & Reid 1994): i) starvation/dehydration/malnutrition; ii) exposure to extreme environmental temperatures; iii) injury and pain; iv) behavioural restriction; and v) anxiety, fear and distress. Methods are assessed for their effectiveness, and where methods are lethal, the duration of suffering until insensibility or death occurs.

Table 1 The estimated number of macropods killed for commercial harvesting and non-commercial purposes (destruction and hunting) in Australian states per year.

	Species	Combined harvest		Non-commercial purposes	
		Year	Number	Year	Number
Australian Capital Territory (ACT Environmental and Sustainable Directorate, personal communication)	1	n/a	0	2013	19,000
New South Wales (NSW OEH 2013, personal communication)	1–4	2012	336,001	2012	data unavailable
Northern Territory		n/a	0	n/a	data unavailable
Queensland (QLD EHP 2012)	1, 2, 4	2011	1,013,330	2012	31,545[†]
South Australia (SA DEWNR 2013)	2–4	2012	122,301	2012	26,951[‡]
Tasmania (Lenah Game Meats 2012; TAS DPIWPE unpublished; personal communication)	1, 5, 7	Annual estimate	30,000	2007	969,467[§]
Victoria (VIC DEPI unpublished)	1–3,5	n/a	0	1/7/12–30/6/13	54,536[‡]
Western Australia (WA DEC 2013; WA DPAW 2013; personal communication)	2,3	2012	126,980	n/a	data unavailable

Species codes: 1) eastern grey kangaroo (*Macropus giganteus*); 2) red kangaroo (*M. rufus*); 3) western grey kangaroo (*M. fuliginosus*); 4) common wallaroo (*M. robustus*); 5) red necked/Bennett's wallaby (*M. rufogriseus*); 6) swamp wallaby (*Wallabia bicolor*); 7) Tasmanian pademelon (*Thylogale billardierii*).
[†] From 1 January to 10 October 2012;
[‡] Estimate based on quota statistics as actual numbers are unknown or not available;
[§] Estimate based on partial returns;
n/a: Not applicable; Statistics do not include dependent young.

Assessment of welfare

Species and numbers of animals affected

Four species of kangaroo, red (*Macropus rufus*), eastern grey (*M. giganteus*), western grey (*M. fulliginosus*) and common wallaroo (*M. robustus*) and three wallabies, red-necked/Bennett's (*M. rufogriseus*), swamp (*Wallabia bicolor*) and Tasmanian pademelon (*Thylogale billardierii*) are affected by harvesting, destruction, and hunting across Australia, with each state differing as to the species targeted, numbers taken, and accepted purpose (Table 1). All affected species are listed by the International Union for the Conservation of Nature as of 'least concern' for the risk of extinction (IUCN 2013).

Shooting of macropods must be in accordance with the relevant federal code of practice: The National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Non-commercial Purposes or the National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Commercial Purposes (SEWPaC 2008a,b). Statistics on commercial harvesting are collated and made available by the participating states (Table 1). All states and territories were contacted for macropod destruction and hunting statistics; however, these are not routinely disclosed by most state authorities, and in some cases (eg New South Wales) are not collected at all. Destruction and hunting statistics provided by state authorities are detailed in Table 1. Statistics on macropod harvesting and destruction do not usually include the number of pouch young (joeys that live permanently or intermittently in the pouch) or young-at-foot (young animals that have emerged from the pouch but are still suckling) that are also killed, as there is no current requirement by state authorities or the National Codes of Practice for the reporting of joey destruction in commercial or non-commercial activities, and shooter compliance for pouch checking in accordance with the National Codes of Practice is unknown. Ben-Ami *et al* (2014) have estimated that as many as 800,000 pouch joeys and young-at-foot are destroyed per annum, in the mainland commercial sector alone. Statistics are discussed separately for commercial harvesting, destruction and recreational hunting.

Commercial harvesting

Five Australian states allow commercial harvesting of macropods: Queensland (QLD), New South Wales (NSW), South Australia (SA), Western Australia (WA), and Tasmania (TAS). Annual quotas average 15–16% of the population within harvest regions on the mainland (SEWPaC 2013) and at least 30,000 individuals in TAS (Lenah Game Meats 2012). Nationwide, this equated to almost 4 million macropods in 2012, however quotas are frequently not completely fulfilled. For example, in 2012, only 31% of the QLD quota and 22% of the NSW quota was fulfilled (SEWPaC 2013) (Table 1). Kangaroos that are injured, but not retrieved by commercial shooters, are not included in these statistics and the number of occurrences of this is unknown.

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Destruction

In all Australian states and territories macropods can be destroyed for damage mitigation purposes, for example, where they cause economic loss to primary industries (eg QLD EHP 2012). Not all state authorities collate or publish statistics on the number of macropods destroyed, and not all states require shooters to report the number of animals killed. WA, for example, operates under a seasonal permit structure with each local council designating a specific 'open season' during which shooting can occur (Western Australia Department of Parks and Wildlife [WA DPaW] 2013). Destruction activities may also be undertaken by commercial harvesters (WA DPaW, personal communication 2014), creating overlap between commercial and non-commercial activities and difficulties in accurately estimating the number of animals destroyed.

Similar to quotas set for commercial harvest, destruction quotas are often only partially fulfilled (Table 1). For instance, in QLD, the 2011 quota for kangaroos killed under destruction permits was approximately 203,000 animals, however less than 20% of this was fulfilled, equating to 30,000 animals (QLD EHP 2012) (Table 1). Some lethal control programmes are carried out directly by state government bodies for conservation purposes, such as in the Australian Capital Territory (ACT) where 1,000–2,500 kangaroos are destroyed for this reason each year (ACT CMD 2013).

Recreational hunting

QLD and TAS are the only states where macropods may be legally shot for recreational purposes (TAS DPIPWE 2003; QLD EHP 2012). In QLD, no person can simultaneously hold both a recreational and a commercial harvest licence, and each recreational licence has a maximum take of 50 animals per harvest period. In the first eight months of 2012, 1,350 macropods were killed under this permit in QLD. In TAS, figures solely on recreational hunting are unable to be quantified as recreational shooters often undertake destruction activities and therefore statistics on these two purposes are collated together (Table 1). Macropod populations across Australia are also subjected to illegal hunting, and the extent of this has never been quantified.

Welfare impact of lethal methods

Macropods are killed in Australia by shooting with a firearm, sometimes assisted by dogs; live-trapping followed by shooting; and poisons and barbiturates. When females are killed, dependent young may be destroyed by shooting, a manual blow to the head, or stunning followed by decapitation, depending on their stage of development. The likelihood of harm, and the domain of harm for each lethal method are summarised in Table 2(a) (see supplementary material to papers published in *Animal Welfare* on the UFAW website: http://www.ufaw.org.uk/supplementarymaterial.php), along with the effectiveness of the method, and duration of suffering until insensibility or death. Unless otherwise specified, all methods are discussed with reference to adult macropods.

Shooting

Shooting is the most common form of macropod population control for destruction purposes, and the only legal method of commercial harvesting (SEWPaC 2008a). Shooting permits are administered by each relevant state, however all shooters, including those involved in recreational hunting, are obligated to abide by the relevant federal codes for commercial and non-commercial shooting (SEWPaC 2008a,b). The two National Codes of Practice are similar and key aspects are:

1) Where doubt exists that a sudden and humane death can be achieved, as defined by instantaneous loss of consciousness and rapid death, shooting should not be attempted;

2) The shooter must ensure the target animal is dead before attempting to shoot another animal, even if an animal has escaped after being injured;

3) Female macropods with obvious dependent young should not be shot unless extenuating circumstances apply, such as when the animal is sick or injured;

4) Shooters must thoroughly search the pouch of any females which have been shot, and young that are found must be killed with the recommended method for the size of the joey. Where the mother of a dependent young-at-foot has been killed, the dependant should be shot. Each joey should be examined to confirm death;

5) While a commercial shooter and those using rifles must only aim so as to hit the target animal in the brain, non-commercial shooters using shotguns may also aim for the chest in order to hit the heart, although this must not be attempted from behind the animal;

6) Should a macropod need to be euthanased to alleviate suffering, this must be carried out via a shot to the brain, unless impractical or unsafe in which case a shot to the heart is an acceptable alternative. When neither option is possible, a heavy blow to the base of the skull is permissible;

7) The National Codes of Practice do not override state or territory legislation.

The National Codes of Practice guide shooters to administer a 'rapid and humane' death in order to minimise suffering of the target animal. To achieve this the shooter must be experienced, accurate, aiming for a head-shot, and be able to recognise a female with pouch young or young-at-foot, although it should be noted that small pouch young are generally not evident from outside of the pouch.

When a shooting attempt does not result in immediate death or permanent loss of consciousness, significant suffering may occur, and the likelihood of this is affected by shot location. To our knowledge, the effectiveness of head-shots on macropods has not been experimentally evaluated, however extrapolations can be made from species of similar cranial structure such as deer and antelope. In wild impala (*Aepyceros melampus*) more than 90% of head-shot animals were killed instantaneously (Lewis *et al* 1997) and in red deer (*Cervus elaphus*) head-shots were less likely to require follow-up shots than chest-shots (Bateson & Bradshaw 2000). This suggests that in kangaroos and wallabies, head-shots that penetrate the brain are most likely to result in death or instantaneous loss of consciousness, although this is contingent on accurate shot placement.

In the commercial harvesting industry, carcases must usually be head-shot for acceptance at meat processing sites (Royal Society for the Prevention of Cruelty to Animals [RSPCA] Australia 2002; Primary Industries and Regions South Australia [PIRSA] 2014). Reports on carcases submitted for processing estimate that 3–4% are killed by shots to other parts of the body (Ben-Ami *et al* 2014), although this would not reflect the percentage of animals killed by body-shots in the field as these are less likely to be transported to processing sites. It is nevertheless a reasonable assumption that commercial shooters, who are also required to undergo shooting accuracy tests, would primarily attempt head-shots to ensure that carcases and pelts are acceptable for sale.

In the non-commercial industry, shooters are not generally required to undergo accuracy testing except in the ACT (ACT TAMS 2010), and cannot sell carcases and pelts, therefore the proportion of animals killed by head-shot is unknown. Furthermore, non-commercial shooters using shotguns are permitted to kill using heart-shots according to the National Code of Practice (SEWPaC 2008b) as noted above, and this is likely to result in a slower death than a head-shot, as has been found in deer (Bateson & Bradshaw 2000).

Shot accuracy is affected by the distance between shooter and animal. For night-stalked impala, close-range shots (< 40 m) result in more instantaneous deaths than long range (≥ 80 m) (Lewis *et al* 1997). Flight distance in kangaroos is dependent on species and approach method, but day-time flight distance, in response to approach on foot, may be as high as 75–93 m (Wolf & Croft 2010) or as low as 23–28 m (Roberts *et al* 2010). Both Wolf and Croft (2010) and Roberts *et al* (2010) noted that kangaroos were less flighty in response to a vehicle than to a human on foot. The National Codes of Practice specify much higher maximum distances (up to 200 m depending on the firearm and species), however to our knowledge no experimental data exist on the effectiveness and accuracy of head-shots across varying distances for macropods. A lowering of the maximum shot distance may improve instantaneous death rates, and experimental evaluation should be undertaken.

Hunting dogs

The pre-shooting environment may also affect the duration and magnitude of suffering, for example, if the animal is fleeing. In TAS, wallabies may be caught in live traps prior to shooting, and dogs may be used in daylight hours for flushing and retrieving (TAS DPIPWE 2003, 2010). Evidence across animal taxa suggest that exposure to predators or predator cues (eg scent) has significant and lasting stressful effects (Clinchy *et al* 2013). It is also probable that flight behaviour of wallabies in response to a dog would affect shooter accuracy, as has been found in deer (*Cervus elaphus; Capreolus capreolus*) (Deutz *et al* 2006). The effect of this is two-fold: the likelihood of achieving an instantaneous death is reduced, and the chase would trigger significant stress in the fleeing animal (Clinchy *et al* 2013). Furthermore, negative effects of dog presence on wildlife are not restricted to the target animal and may have broader implications on non-target species (Grignolio *et al* 2011).

While TAS law prescribes that hunting dogs must not be used to kill or injure wallabies and may only be used for flushing, locating and retrieval, we consider that this is unlikely to be achievable in the field. Analogies can be drawn with the Irish sport of hare-coursing where hares (*Lepus europaeus*) are released for dogs to chase (Reid *et al* 2007). Although, it is not the intention that the hare is killed by the dogs, this frequently occurs as a result of dogs mauling and biting the animal, or in the case of muzzled dogs, by causing the hare to stumble or fall. This suggests that owners may not have complete control over dogs engaged in hunting activities.

While wallaby-specific data are lacking on the physiological effects of hunting using predators, comparisons can be made from other species such as deer, as both taxonomic groups demonstrate an aversion to canids (Bateson & Bradshaw 1997; Parsons *et al* 2007) and are susceptible to stress-induced myopathy (Mentaberre *et al* 2010; Wiggins *et al* 2010). Wild red deer stalked by hunters with dogs experience extreme stress, which is evidenced by high concentrations of cortisol, depletion of carbohydrate resources, disruption of muscle tissue and elevated β-endorphin (Bateson & Bradshaw 1997). It was further suggested by Bateson and Bradshaw (1997) that deer that escape after a dog chase may succumb to stress myopathy because of the severe depletion of glycogen in the muscles. This is highly relevant to the use of dogs in wallaby destruction activities, and it is critical that the experiences of macropods prior to destruction are not overlooked when considering welfare.

The use of dogs in wallaby hunting may also conflict with the National Codes of Practice specification for rifle users that only stationary animals should be targeted in order to achieve an accurate head-shot, although this is not specified for non-commercial shooters using a shotgun (SEWPaC 2008a,b). Whilst mandatory muzzling of hunting dogs would not reduce distress in a fleeing wallaby, it could be a strategy for ensuring that wallaby deaths are not the result of dog attacks.

Trapping

In TAS, two wallaby species (*T. billardierii, M. rufogriseus*) may be trapped prior to shooting using either an Ivo Edwards/Stubby tent trap (both species) or a Mersey box trap (*T. billardierii* only) (TAS DPIPWE 2010). In other species, box traps have a low incidence of injury, are less stressful than other trap types, and when regularly monitored have a low to zero mortality rate (Iossa *et al* 2007), with skin abrasions and tooth damage being the most common injuries (Powell & Proulx 2003). Some foot-hold traps are able to restrain without injury (Short *et al* 2002). The two trap types used for wallabies are modified to reduce contact with wire (TAS DPIPWE 2010), and it is reasonable to assume this reduces injury risk. Prior to shooting,

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wallabies must be restrained by a holding device, which limits movement and likely improves shot accuracy and the chance of a humane death.

Welfare risks from trapping have species-specific challenges (Iossa *et al* 2007) and for this reason caution should be exercised in generalising from other species. It is recommended that several aspects of trapping be evaluated experimentally specifically for wallaby species. In particular, these could include: the compliance of trappers with the TAS government code of practice; injury and mortality rates; behavioural responses suggestive of distress; and the risk of exposure to environmental challenge.

For shooting activities affecting kangaroo and wallaby populations, we conclude that accurate statistics are needed to determine the level of compliance with the National Codes of Practice for both commercial and non-commercial activities, and research should be undertaken to determine time to insensibility from head- and heart-shots, and the effect of the pre-shooting situation including dog use and trapping.

Destruction of pouch young

A further significant welfare challenge is presented if pouch young and/or young-at-foot are present with mothers that have been killed. Macropods remain dependent on their mothers while in the pouch and for some time after they emerge. When the mother is killed, pouch young will not survive without intervention due to fluid loss (Taggart *et al* 2002) and a limited ability to regulate their body temperature, which is particularly exacerbated in unfurred joeys before endothermy has developed (Rose *et al* 1998). Young-at-foot rely less heavily on milk for nutrition, however they are unlikely to survive without it unless available forage is high in quality and abundance and other environmental conditions, such as ambient temperature are favourable (Munn & Dawson 2006).

Recent research suggests that over a short period of ten days, *M. fuliginosus* joeys separated from their mother exhibit both behavioural and physiological changes (McLeod & Sharp 2014). Separated joeys experience more targeted aggression from other kangaroos, and increase their vocalisation rates, while physiological changes suggest the beginnings of starvation (McLeod & Sharp 2014). It is not known whether the macropod mother plays a large role in the development of appropriate behaviour in the joey, however social transmission of predator recognition does occur in macropods (Griffin & Evans 2003), and in other mammals the mother is an important model for developing behaviour such as foraging (Thornton & Clutton-Brock 2011). These factors suggest that mortality risk is high for joeys left without a mother. The National Codes of Practice address this possibility by recommending that dependent young-at-foot and pouch young of killed females should be destroyed immediately to avoid a prolonged and painful death (SEWPaC 2008a,b). The recommended method of destruction is shooting for young-at-foot and manually applied physical trauma for pouch young (SEWPaC 2008a,b).

Manually applied physical trauma

A wide variety of manual methods can be used to kill animals, including blunt trauma (blow to the head), cervical dislocation, and decapitation (American Veterinary Medical Association [AVMA] 2013). However, not all of these methods may be appropriate for the humane killing of macropods, particularly under field conditions. A recommended method in the National Codes of Practice for destruction of all pouch young is a blow to the base of the skull with sufficient force to destroy brain function (SEWPaC 2008a,b). Blunt trauma to the head is suggested (AVMA 2013) to be an effective way to kill small animals with thin craniums, as loss of consciousness is rapid when the procedure is carried out correctly and with enough force. However, proper training of personnel and proficiency monitoring must be undertaken to ensure correct application of the technique and the AVMA (2013) recommends that alternatives be sought.

Only one study has investigated the efficacy of manual blunt trauma in macropod joeys and it was found that a "single forceful blow to the base of the skull sufficient to destroy the functional capacity of the brain" caused immediate loss of consciousness without recovery in all instances (McLeod & Sharp 2014). When blunt trauma was assessed as a killing method in piglets, it was found that manual blunt trauma was less effective than 'controlled blunt trauma' using (non-penetrating) captive bolts, due to animal movement affecting placement of the strike, and a need for subsequent re-strikes before unconsciousness is achieved (Whiting *et al* 2011). Spring-loaded penetrating captive-bolt guns have been assessed for use in larger kangaroo joeys (*M. rufus, M. giganteus, M. fuliginosus*) measuring more than 15 cm from the head to the base of the tail (McLeod & Sharp 2014). Shooting was performed perpendicular to the skull on the midline, at the highest point of the head. The success rate of the penetrating captive bolt was low, only 65%, and some animals persistently retained signs of consciousness even after three successive applications (McLeod & Sharp 2014). It is possible that other types of penetrating captive-bolt guns might be more effective for the destruction of pouch joeys, but further research is needed to determine whether this is the case.

The National Codes of Practice stipulate that an alternative to blunt trauma for very small pouch young (ie those that fit in the palm of the hand) is stunning followed by decapitation. However, the stunning method is not stipulated by the code and decapitation alone may not cause instantaneous death even in small animals. Conscious and anaesthetised rats have post-decapitation brain-wave patterns indicative of pain for up to 30, and 15 s, respectively (Mikeska & Klemm 1975; Kongara *et al* 2014). Neither decapitation nor stunning provides acceptable welfare outcomes unless they achieve high rates of instantaneous death or loss of consciousness, with the major risk factor being untrained operators. There is no legal or National Codes of Practice requirement for macropod shooters to be trained in blunt-force destruction or decapitation, despite their obligation to perform these operations in the field. When these procedures are incorrectly performed and do not result in instant death or loss of consciousness, extreme pain and distress is a probable outcome.

We conclude that, based on current evidence by McLeod and Sharp (2014), a correctly positioned blow to the head has the potential to cause rapid and reliable loss of sensibility. However, as for many parts of the code, it is critical that more research be undertaken to the effectiveness and speed of field destruction techniques as well as the levels of compliance with the National Codes of Practice.

Poisons

Historically, poisons have been used to kill macropods in many pastoral areas of Australia (Cowan & Tyndale-Biscoe 1997). However, this practice no longer occurs in mainland Australia (APVMA 2008) and is associated with substantial animal welfare problems, in particular the risk of a prolonged period of pain and suffering prior to death, depending on the poison used (McIlroy 1982; Littin *et al* 2009). TAS is the only state or territory to allow macropods to be killed with poison, specifically sodium monofluroacetate (1080) (TAS DPIPWE 2006). Marsupial response to 1080 has been studied most comprehensively in possums (*Trichosurus vulpecula*), and is known to cause symptoms, such as hunching, retching, vomiting, ataxia, tremors, convulsions and abnormal lying behaviour, taking approximately 9–14 h from symptom onset to death with most animals remaining conscious until death, or just prior to it (Littin *et al* 2009). 1080 toxicity in macropods is less understood, but is known to cause lethargy, hunched postures and convulsions (McIlroy 1982). There are significant species differences in 1080 response times (McIlroy 1982). Time from dosing until death for *M. eugenii, M. rufogriseus, M. giganteus, T. billardierii*, have been determined as 12–81 h, 9–39 h, 21–62 h, and 8–131 hours, respectively. Symptom onset was at 17–24 h in *M. rufogriseus* and 13–24 h in *M. giganteus*, but was not well established in *M. eugenii* and *T. billardierii* (McIlroy 1982). The co-administration of analgesics, such as copper indomethacin may reduce some symptoms of 1080 toxicity (eg retching) and lessen the duration of suffering, as has been found in red foxes (*Vulpes vulpes*) (Marks *et al* 2009).

While 1080 is the only poison registered for use in Australia for macropod control, alternative poisons may deliver more acceptable welfare outcomes, pending further research on methods of delivery, choice of toxins and/or bait material (Eason *et al* 2010) and the monitoring of non-target specificity (Glen *et al* 2007). One potential alternative is encapsulated cyanide (Feratox, Connovation, Auckland, New Zealand). Under laboratory conditions, cyanide had a very high acceptance rate (90–95%) by *M. eugenii* and *M. rufogriseus* and a 100% mortality rate after ingestion (Eason *et al* 2010). Symptoms of cyanide toxicity include excess salivation, ataxia, dyspnoea, hyperpnoea, limb movement, forelimb paddling, hind-limb flexion and tail flailing (Eason *et al* 2010). The primary advantage of cyanide over 1080 is the major reduction in time from symptom onset to unconsciousness, which is less than 22 min for cyanide (Eason *et al* 2010) compared with around 15 h for 1080 (McIlroy 1982). This also means that carcases remain in close proximity to bait stations, which would allow pouch checking, body collection, and accurate mortality data. Cyanide decays in the body after death, but fresh carcases pose some risk of secondary poisoning to scavengers (Morriss *et al* 2003). In the environment, cyanide decays after approximately one month, but the risk to non-target animals extends past eight months because of the slow decay rate of the bait bags inside which this cyanide product is placed (Thomas & Ross 2007).

We conclude that destruction of macropods using 1080 is not a humane method of control based on both the symptoms displayed, and the length of time between symptom onset and loss of consciousness or death. It is therefore recommended that alternatives for macropod control in Tasmania continue to be sought.

Welfare impact of non-lethal methods

Lethal methods of wildlife management generate opposition on animal welfare and ethical grounds and consequently non-lethal alternatives have been explored (eg Nave *et al* 2002a; Herbert *et al* 2006; Coulson *et al* 2008). Reproductive control and relocation are the most commonly proposed alternatives to killing macropods (Table 2[b]; http://www.ufaw.org.uk/supplementarymaterial.php).

Reproductive control

Options for fertility control of kangaroos and wallabies include surgical sterilisation (Tribe *et al* 2014), hormonal manipulation (Hinds & Tyndale-Biscoe 1994; Nave *et al* 2002a) and immuno-contraception (Asquith *et al* 2006; Kitchener *et al* 2009). Surgical sterilisation requires general anaesthesia and carries a risk of peri- or post-operative complications (Mosley & Gunkel 2007; Bauquier & Golder 2010). Removal of the gonads can also affect behaviour (eg suppression of male sexual and agonistic behaviour), which may in turn destabilise group hierarchies and result in abnormal social interaction (ACT TAMS 2010; Tribe *et al* 2014). In *M. giganteus*, vasectomy and orchidectomy of sub-adult males reduces both aggression and sexual behaviour; in adults these effects were noted after orchidectomy only (Tribe *et al* 2014), suggesting that vasectomisation of adult males results in social behaviour that is most reflective of 'normal' behaviour. Surgical sterilisation reduces population growth but is costly to implement and has significant welfare concerns (Tribe *et al* 2014). The mortality risk of a recent project combining surgical and hormonal control methods for *M. giganteus* was between 5 and 11%, with primary causes being dart-related injuries, hyperthermia/myopathy, and death after anaesthetic recovery (Tribe *et al* 2014).

Contraceptive measures have temporary effects and involve either hormonal or immunological control. Hormonal control methods using implanted levonorgestrol (a progestin) or deslorelin (a gonadotrophin-releasing hormone [GnRH] agonist) have been trialled in *M. giganteus* (Nave *et al* 2002a; Poiani *et al* 2002; Herbert *et al* 2006; Coulson *et al* 2008;

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Wilson *et al* 2013) and *M. eugenii* (Nave *et al* 2000; Herbert *et al* 2004a,b; Hynes *et al* 2007). Deslorelin implants are ineffective in male *M. eugenii* (Herbert *et al* 2004b), but prevent reproduction in female *M. giganteus* for up to 24 months depending on dosage (Herbert *et al* 2006), with no observable effects on behaviour or welfare (Woodward *et al* 2006). Levonorgestrol implants successfully inhibit long-term female fertility in both *M. giganteus* and *M. eugenii* (Nave *et al* 2000; Coulson *et al* 2008), but efficacy declines over time (Nave *et al* 2002b; Coulson *et al* 2008). Levonorgestrol does not affect parturition or reactivation of blastocytes in diapause (Nave *et al* 2002a). Similar to deslorelin, no major effects on behaviour have been observed, although Poiani *et al* (2002) found that male kangaroos associate more with untreated females compared to those with implants. Welfare concerns of hormonal control primarily arise from the method of application. Implant sizes range between 12.5 × 2.3 mm (length × width) for a 5 mg deslorelin implant (Herbert *et al* 2006) to 2.4 × 44 mm for a 70 mg levonorgestrel implant (Nave *et al* 2000) and require surgical implantation. They cannot, therefore, be administered remotely and require capture, and restraint or sedation, which carry risks, as discussed for surgical sterilisation.

Immunological control differs from hormonal control in both mechanism and application. Immunological control interrupts reproduction by vaccinating against specific hormones or proteins needed for successful conception. In macropod species, sperm antigen and zonae pellucidae (ZP) vaccines have been trialled (Kitchener *et al* 2002, 2009; Asquith *et al* 2006). In male *M. eugenii*, sperm antigen was effective in reducing reproduction (Asquith *et al* 2006), however five applications were required over 13 weeks, which is prohibitive for the treatment of wild populations. In contrast, ZP vaccines were found to suppress reproduction in female *M. giganteus* for more than one year after a single vaccination (Kitchener *et al* 2009). Application of these vaccines is usually via hand-held injection and therefore there are some risks associated with capture and restraint. Remote application using dart guns has been achieved in other mammals (Willis *et al* 1994; Fayrer-Hosken *et al* 2000; Curtis *et al* 2007), however this can result in the formation of abscesses and granulomas at the injection site (Curtis *et al* 2007). Oral delivery of immunocontraceptives in macropods is yet to be attempted, however in mice and rabbits it was found that the gastrointestinal environment degraded the active ingredients before absorption could occur (Martin *et al* 2006). If oral delivery was successfully achieved in kangaroos and wallabies, this would eliminate the injury and mortality risks associated with other application methods.

Little is known about potential welfare issues arising from immunocontraception use in macropods. In elks (*Cervus elaphus*), ZP vaccines lengthened the normal breeding season, which could potentially disrupt both social dynamics and energetic expenditure in elk herds (Heilmann *et al* 1998). In contrast, GnRH vaccines in captive boar (*Sus scrofa*) had no effect on activity, social ranking or blood parameters, although treated females increased in bodyweight (Massei *et al* 2008). For a comprehensive review of side-effects in wildlife contraceptive treatments, see Gray and Cameron (2010).

We conclude that reproductive control of macropods may be a feasible alternative to destruction if an immediate reduction in population is not required, and if the following conditions could be met: remote administration; long-term suppression of reproduction; no adverse health effects; and no adverse behavioural or social effects.

Relocation

Relocation, defined as "any intentional movement by humans of an animal or a population of animals from one location to another" (Fischer & Lindenmayer 2000) is used as a conservation strategy to protect species at risk, or with limited range and ability to disperse. At the population level, macropod relocations have been moderately successful, with more than 60% of populations surviving for at least five years post-relocation (Clayton *et al* 2014). At the individual level, the capture, handling and transportation of macropods can result in death or injury (Higginbottom & Page 2010; Tribe *et al* 2014) with a risk of stress myopathy, in which skeletal and cardiac muscle rapidly degenerates, and paralysis or death can occur within hours (Paterson 2007; Wiggins *et al* 2010). In one *M. giganteus* relocation, three of 13 individuals died from physical injuries during capture (Dickinson 2004a,b as reported in Higginbottom & Page 2010). Conversely, a capture protocol using chemical immobilisation via dart gun with Zoletil 100® (Virbac Australia Pty Ltd, Australia) and diazepam (Pamlin, Parnell Laboratories Pty Ltd, Alexandria, NSW, Australia) was used for 123 *M. giganteus*, with no injuries or deaths (Roberts *et al* 2010) suggesting that these risks can be reduced.

The greatest difficulty in relocation is the identification of appropriate, predator-free release sites, especially in areas of encroaching residential development (Higginbottom & Page 2010; Clayton *et al* 2014), or where conflict between macropods and agriculture is widespread. Animals that do not adjust to new surroundings are likely to experience significant suffering (Table 2[b]; http://www.ufaw.org.uk /supplementarymaterial.php). Furthermore, there may be significant impacts on other fauna and flora at the site because of disease transmission (Cunningham 1996) or food availability, and the expertise and equipment necessary to perform the task safely can be a prohibitive expense in large-scale operations. Therefore, relocation is only likely to be a useful macropod management tool under specific circumstances, and potential welfare issues should not be underestimated.

Capacity for macropods to suffer

There are three prerequisites to animal suffering (Mellor & Diesch 2006). Firstly, the animal must have the neural structure to allow sentience. Secondly, they must be conscious and aware, and thirdly, their experience must be aversive (Mellor & Diesch 2006). The capacity of adult macropods to suffer is undisputed, however recent studies suggest that early pouch young are not sufficiently developed to feel pain (Diesch *et al* 2007, 2010). Diesch *et al* (2010) used electroencephalographs to measure brain activity in response to pain in lightly anaesthetised *M. eugenii*. Brain response to noxious stimuli became evident at 127 days of age, indicating that younger joeys could not experience pain. Two developmental milestones — eye opening and pelage covering — were proposed as bio-markers for this transition point. Behavioural signs of conscious awareness were apparent at 160–180 days (Diesch *et al* 2007). While these studies are convincing, an absence of experimental effect does not necessarily equate to an absence of suffering, and for the purposes of ensuring a humane death, there are no welfare disadvantages to assuming macropods of all ages have the capacity to suffer. With regard to the suffering of 'pest animals' in response to management, three key principles can be applied (Stafleu *et al* 2000 in Sharp & Saunders 2011). Firstly, if there is doubt as to whether an animal will suffer, it should be assumed that it will do so. Secondly, one should assume a worst case scenario, and thirdly, all dimensions of suffering should be considered equal. We conclude that killing of all macropods should be conducted in a way that ensures a quick and humane death characterised by minimal, or no, suffering,

Animal welfare implications and conclusion

For the killing of free-ranging macropods, an accurate head-shot is likely to inflict the least amount of pain and suffering in comparison with other control methods such as 1080 poisoning or relocation. However, it is premature to state that the current practice is always, or even usually, humane because the proportion of animals killed by accurate head-shots is unknown, and concerns exist for the welfare of pouch young and young-at-foot. Shooting of females with dependent young should be avoided wherever possible, and a blow to the head of sentient pouch young and young-at-foot is likely to be more humane than decapitation. Non-lethal methods, such as fertility control and relocation, are alternatives when dealing with abundant or endangered populations, respectively, but also have adverse welfare implications associated with the capture, treatment and release of the animals. Improvement in the following areas should be prioritised:

- The compilation of accurate annual statistics and quotas of macropods killed with inclusion of pouch young, and young-at-foot;
- Field-based assessments of competency and compliance with the National Codes of Practice for both commercial and non-commercial shooters;
- Safe and effective remote administration of reproductive control measures;
- Alternatives to the use of 1080 poison; and
- The impact of hunting dogs and trapping in wallaby control measures.

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