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ABSTRACT

Efforts to euthanise stranded cetaceans remain highly variable in their outcomes, with few field tested operational procedures available. This study sought to validate the efficacy of using modern firearms technology to euthanise small (<6m length) stranded cetaceans. Post-mortem evidence was gathered from the standardised shooting of cetacean cadavers (n = 10), representing six species, using .30 caliber (7.62mm) firearms and blunt solid copper-alloy non-deforming projectiles, in southwestern Australia. The six species studied were Risso's dolphin, common dolphin, bottlenosed dolphin, pygmy sperm whale, Cuvier's beaked whale, and humpback whale. Post-mortem data revealed that 100% of bullet wound tracts fully penetrated the skulls of shot animals, with associated indirect skull fracturing, secondary bone missiles and brain parenchyma laceration. The results suggest that appropriate firearms technology is fully capable of inducing instantaneous fatal pathology to the central nervous system of these species. In comparison to alternative methods for the euthanasia of stranded cetaceans, the use of firearms is associated with superior animal welfare outcomes, public safety levels and accessibility. This paper provides a template for the safe, humane and repeatable use of this technique to euthanise <6m length stranded cetaceans.

KEYWORDS: AUSTRALASIA; STRANDINGS; STRESS; EUTHANASIA

INTRODUCTION

In cetacean stranding events, euthanasia is considered a desirable animal welfare outcome when animals are deemed non-viable for release. The novel size and physiology of cetaceans dictates that routine euthanasia techniques (AVMA, 2013) are rarely applicable. Methods for euthanising stranded cetaceans remain highly variable and poorly standardised (Barco *et al.*, 2012). With recent research showing increases in cetacean stranding incidence (e.g. Coughran *et al.*, 2013), increasing anthropogenic causes for stranding events (Barlow and Gisiner, 2006), the projected effects of climate change (Schumann *et al.*, 2013), and suggestions of declining marine mammal health worldwide (Gulland and Hall, 2007), reliable euthanasia methods for stranded cetaceans are increasingly required. Acceptable euthanasia methods must offer high safety levels for personnel and public health, be publicly acceptable and cost-effective (Harms *et al.*, 2014) but above all else, must be humane and offer the most rapid death possible (Øen and Knudsen, 2007).

Approaches to cetacean euthanasia have included the use of chemical injection (Harms *et al.*, 2014), explosives (Coughran *et al.*, 2012), exsanguination (Harms *et al.*, 2014) and firearms (Blackmore *et al.*, 1995). Despite extensive research into humane killing methods for whale hunting (Gales *et al.*, 2008; Kestin, 1995; Knudsen and Øen, 2003; O'Hara *et al.*, 1999; Øen and Knudsen, 2007), little of this knowledge has been applied to stranding scenarios. Animal welfare studies into livestock slaughter and marine mammal hunting have produced the most scientifically rigorous templates for assessing killing methods. The two key parameters identified for assessing the humaneness of any killing method are the duration and intensity of suffering induced before the animal becomes permanently insensible (Mellor and Littin, 2004; Newhook and Blackmore, 1982). While the intensity of suffering is a difficult parameter to quantify or objectively assess, duration of suffering is relatively simple to measure (Knudsen, 2005). A recent scientific focus on quantifying animal welfare outcomes has seen the parameter time to death (TTD) commonly adopted as a parameter for assessing wildlife killing techniques (e.g. Cowled *et al.*, 2008; Hampton *et al.*, 2014a; Gales *et al.*, 2008). Physical euthanasia methods are generally considered to be the only killing methods capable of providing instantaneous deaths (Grandin, 2006). As such, the proportion of animals for which TTD is zero, known as the instantaneous death rate (IDR) is commonly cited to benchmark physical killing methods (Hampton *et al.*, 2014a), in particular for marine mammals (Gales *et al.*, 2008). The International Whaling Commission (IWC) has used TTD and IDR to assess cetacean killing methods for more than thirty years (IWC, 1981; 2012).

Firearms have been used for killing cetaceans (<6m length) in commercial and indigenous whale harvesting operations for decades (IWC, 1981; Øen and Knudsen, 2007). The studies of Ingling (1997) and Øen and Knudsen (2007) demonstrated that large calibre rifles are adequate for the rapid euthanasia of harpooned bowhead whales (*Balaena mysticetus*) and minke whales (*Balaenoptera acutorostrata*). However, the techniques described by Øen and Knudsen (2007) have not been widely utilised for euthanising stranded cetaceans (Barco *et al.*, 2012). One of the impediments to the employment of these methods is the inaccessibility of the large centre-fire calibers described (.577, Ingling, 1997; .375,

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.458, Øen and Knudsen, 2007) to wildlife management staff. For management techniques to receive widespread uptake, they must be accessible. In Australia, North America and New Zealand, .30 calibre (7.62mm) centre-fire firearms are used extensively for terrestrial wildlife management (Choquenot *et al.*, 1999; Hunt *et al.*, 2006; IWC, 2012; Thomas, 2013). Blackmore *et al.* (1995) identified the need for further ballistic research to develop or identify suitable projectiles for euthanising medium-size cetaceans.

Protocols for testing the ballistic properties of any particular firearm-projectile pairing have been well described (Thali *et al.*, 2002). The method of firing standardised shots into appropriate cadavers has been widely utilised in both humans (Kaplan *et al.*, 1998; Voiglio *et al.*, 2004) and animal species (Blackmore *et al.*, 1995; Daoust and Cattet, 2004; Grund *et al.*, 2010). This technique is more scientifically rigorous than the use of ballistic gel (Ingling, 1997; Zhang *et al.*, 2005) and allows relevant ballistic parameters to be repeatedly quantified without impacting on animal welfare (see Blackmore *et al.*, 1995). This paper attempts to scientifically validate the efficacy of .30 calibre firearms and appropriate projectiles as a euthanasia tool for moribund cetaceans <6m in length. We used cadaver studies to examine the cranial pathology induced by firearms euthanasia in a variety of smaller cetacean species commonly subjected to stranding. Following the approaches of Blackmore *et al.* (1995), Øen and Knudsen (2007) and Mörner *et al.* (2013), we combined a standardised shooting method with detailed post-mortem examinations. The research was a collaborative project between the Department of Parks and Wildlife (DPaW) and the Perth Zoo, and was conducted in the southwest of Western Australia during 2013.

MATERIALS AND METHODS

Animal specimens

Ten dead stranded cetaceans, representing six species: Risso's dolphin (*Grampus griseus*), Common dolphin (*Delphinus delphis*), Common bottlenosed dolphin (*Tursiops truncatus*), Pygmy sperm whale (*Kogia breviceps*), Cuvier's beaked whale (*Ziphius cavirostris*) and humpback whale (*Megaptera novaeangliae*), were accessed opportunistically between April and September 2013 in southwestern Australia. Past studies have identified cetaceans with a body length of 5–9m as an appropriate upper limit for the use of firearms for euthanasia (Barco *et al.*, 2012; Blackmore *et al.*, 1995; Greer. *et al.*, 2001; IWC, 2006). As such, only animals <6m in length were considered for inclusion in the study. Southwestern Australia was selected as a field site due to the high diversity of species available for experimentation, combined with a relatively high incidence of stranding events (Coughran *et al.*, 2013). A long term cetacean stranding record (Groom and Coughran, 2012) for Western Australia reports 37 cetacean species observed off the coast and 34 species in the stranding record. All animals were freshly dead, with evidence of post-mortem change indicating they had been dead for less than 12 hours.

Shooting methodology

All cadavers were shot in a standardised manner (see Fig.1a), using a single dorsal midline aim point, while in ventral recumbency, following the methodology of Blackmore *et al.* (1995). The aim point is described as 40–100mm caudal to the blowhole, at a 45° angle towards the middle of an imaginary line connecting the anterior edges of two flippers (Blackmore *et al.* 1995). Shots were fired 0.5–1.0m from the surface of the animal. All cadavers were shot on land, rather than in water, over sandy substrate. Three *Browning* hunting rifles, of calibre .300 *Winchester* Magnum (.300 WM; one cadaver), .300 *Winchester* Short Magnum (.300 WSM; six cadavers), and .308 *Winchester* (.308 WIN; three cadavers) were used (Fig. 1b; Table 1).

All rifles fired the same projectiles; 12g/180 grain *Woodleigh* hydrostatically stabilised blunt non-deforming solid bullets (Table 1; Fig. 1b). These projectiles are constructed from copper-alloy (see Thomas, 2013) and have been developed to allow deep tissue penetration in large, thick-boned game species. These projectiles were chosen on the basis that blunt-nosed non-deforming projectiles have previously been shown to successfully penetrate cetacean craniums (Øen and Knudsen, 2007) while shotgun solids,

Fig. 1. Standardised shooting methodology used in this study. (a) Standardised shooting technique for post-mortem ballistic testing on a neonate humpback whale (*Megaptera novaeangliae*) in ventral recumbency. (b) The non-traditional design of the .30 calibre blunt solid copper-alloy non-deforming *Woodleigh* hydrostatic projectiles used for standardised shooting. The shell casings are .300 *Winchester* Short Magnum (left) and .308 *Winchester* (right).

Table 1

Ballistic properties of .30 caliber (7.62mm) firearms used in this study (Barnes, 2009).

Calibre	Projectile grain	Projectile weight (g)	Muzzle velocity (ms^{-1})	Muzzle energy (J)
.300 *Winchester* Magnum	180	12	959	5,385
.300 *Winchester* short Magnum	180	12	943	5,190
.308 *Winchester*	180	12	800	3,890

expanding projectiles and pointed-nosed projectiles have proven unreliable (Blackmore *et al.*, 1995; IWC, 2000). The sectional density (SD) of a projectile, the ratio of a projectile's mass to its cross-sectional area, is an important terminal ballistic parameter influencing tissue penetration (see Ordog *et al.*, 1984). In terminal ballistics, the SD of a firearm projectile is calculated as the weight of the projectile, in pounds (lb), divided by the square of the projectile's diameter, in fractions of an inch, (w/d^2). The SD of the projectiles used in this study was 0.286. All projectiles were factory loaded.

Post-mortem examination

After shooting, cadavers were subjected to veterinary post-mortem examination to record the nature of cranial pathology sustained. The locations of entry and exit wounds were recorded, the head was dissected from the body at the atlanto-occipital joint (Fig. 2a) and the skull and brain were subjected to detailed post-mortem examination (Fig. 2b). Gross pathology of the brain and surrounding organs attributable to bullet wound tract injuries were recorded following the principles of Hollerman *et al.* (1990) and Di Maio (1999). Morphometric parameters were recorded from each animal, including total body length, and maximum head diameter, including cranium and surrounding soft tissues (Table 2). Radiographic documentation of the entire head was employed for the six animals with maximum cranial diameter <400mm (Fig. 2b), being the only animals for which our equipment possessed sufficient power for radiographic resolution.

All summary statistics are presented as mean ± standard deviation (range, sample size).

RESULTS

As noted, all animals were freshly dead cetaceans under 6m in length. Six species were represented (Table 2). Mean total body length was 2.7 ± 1.1 (range 1.3–4.3, n = 10) meters. Mean maximum head diameter was 0.37 ± 0.15 (range 0.18–0.60, n = 10) meters. In all cases, bullet placement was sufficiently accurate to achieve penetration of the cranial cavity. All specimens were shot through the midline hindbrain with complete penetration of the dorsal and ventral surfaces of the skull (Fig. 2a, b). The permanent bullet wound tracts through the brain parenchyma were limited to a tract roughly the diameter of the projectile (Fig. 2b). There was widespread evidence of meningeal trauma in all cases. Intra-cranial in-driven bone fragments and extensive indirect skull fracturing were present in all cases (Fig. 2b). No projectiles or projectile fragments were recovered from any cranial tissues from any animals upon dissection, and evidence of intra-animal projectile fragmentation was not detected radiographically in any of the six animals x-rayed (Fig. 2b).

DISCUSSION

Wound ballistics

The field of science relating to the interaction between a projectile and a target is known as terminal ballistics. When the target struck is living tissue, the patterns observed constitute the field of study known as wound ballistics (Fackler, 1988). The killing power of a projectile is a function of the energy it carries and the behaviour of the projectile. There are three distinct mechanisms of ballistic injury: crushing of tissue producing a permanent tract; temporary cavitation; and hydrostatic shock (Caudell, 2013). The predominant mechanism of injury for any individual gunshot is highly dependent on the behaviour of the individual projectiles. Based upon their terminal ballistic behaviour, centre-fire projectiles can be divided into three

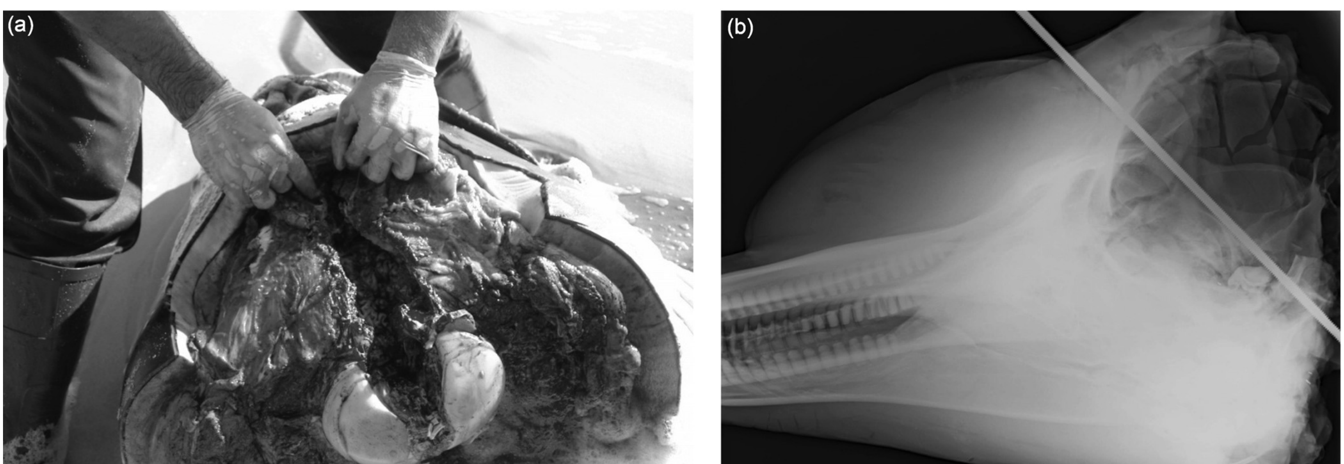

Fig. 2. Patterns of ballistic pathology evident at post-mortem examination. (a) Gross dissection of the permanent bullet wound tract from a neonate humpback whale (*Megaptera novaeangliae*) in ventral recumbency, dissected through the atlanto-occipital joint. (b) Contrast radiographic study using a .30 inch diameter threaded metallic rod passed through the permanent bullet wound tract in a bottlenosed dolphin (*Tursiops aduncus*) in ventral recumbency, dissected through the atlanto-occipital joint.

Table 2
Individual cadavers examined in this study.

Species	Length (m)	Head diameter (m)	Firearm calibre	Projectile	Aim point	Dorsal skull penetration	Ventral skull penetration	Projectile fragmentation	Indirect skull fractures
Risso's dolphin	2.7	0.36	.308 WIN	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
Common dolphin	1.8	0.18	.308 WIN	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
Bottlenose dolphin	1.3	0.18	.300 WSM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
	2.7	0.26	.300 WSM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
Pygmy sperm whale	2.5	0.41	.300 WSM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
	1.8	0.29	.300 WSM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
	1.9	0.31	.308 WIN	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
Cuvier's beaked whale	4.2	0.55	.300 WSM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
Humpback whale	4.2	0.51	.300 WM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	Yes
	4.3	0.60	.300 WSM	Hydrostatic 180 grain	Dorsal	Yes	Yes	No	No

groups; rapid expansion (RE), controlled expansion (CE) and non-deforming projectiles (Caudell *et al.*, 2012). Expanding projectiles (RE and CE) are designed to expand and/or fragment upon penetration, and are commonly used to hunt thin-skinned terrestrial mammal species. Non-deforming projectiles are designed to penetrate deep into the body after striking without fragmenting, and are used for very large, heavily boned or muscled mammal species. Projectile shape also has an important bearing on wound ballistic patterns, with blunt-nosed projectiles more effective at penetrating rigid structures and less prone to trajectory deviation than pointed-nose projectiles (Øen and Knudsen, 2007).

While crushing of tissues is an important process for RE and CE projectiles, non-deforming projectiles are more reliant on temporary cavitation and hydrostatic shock to induce death. The killing effect of hydrostatic shock is of particular relevance for high energy and non-deforming projectiles. The process of temporary cavitation is particularly important to the pathology induced in inelastic tissues, especially the cranium (Karger *et al.*, 1998; Zhang *et al.*, 2005). The structure of the cranium generates wound ballistic features not encountered with other parts of the anatomy (Karger *et al.*, 1998). The inelastic nature of the cranium ensures that the temporary wound cavity created by a high velocity projectile plays a much larger part in the creation of pathology than in more elastic tissues (Zhang *et al.*, 2005). The high intracranial pressures generated by the temporary cavitation process within the inelastic environment of the skull create indirect skull fractures, cortical contusions and perivascular haemorrhage (e.g. Øen and Knudsen, 2007). The generation of secondary bone projectiles from penetrating skull injuries is also an important mechanism underlying the killing potential of cranial gunshot wounds (Karger *et al.*, 1998). These principles are well established in human medicine (Quatrehomme and İşcan, 1999; Zhang *et al.*, 2005) but their application in wildlife shooting studies has lagged (Caudell, 2013).

In the present study, extensive cranial trauma was observed in all cadavers, with full penetration of the dorsal and ventral skull in all cases. Despite the absence of projectile fragmentation or expansion, the temporary cavitation effect of the high energy projectiles induced widespread indirect skull fractures, in-driven bone fragments and meningeal trauma. The use of specialised, blunt-nosed projectiles that are designed to withstand fragmentation, deformation or trajectory deviation (see Thomas, 2013) resulted in 'through-and-through' permanent wound tracts in all cases. The findings of this study provide strong evidence that insensibility and death would have been instantaneous in all cases. The results of this study suggest that rifle calibres smaller than those recommended in the past for the shooting of larger cetaceans (Ingling, 1997; Øen and Knudsen, 2007) can be effective if used with specialised projectiles for euthanising smaller cetaceans.

Results from other cetacean shooting studies

The IWC actively encourages member nations to provide it with records from all whale killing events, including details on TTD and IDR (Brakes and Donoghue, 2006), as determined according to the criteria of Knudsen (2005), and recognised by the IWC. The results are made publicly available on the IWC's website every year, and include methods and outcomes but provide limited detailed information when compared to a peer-reviewed case study. We searched all reports for case studies involving the use of .30 calibre firearms to euthanise stranded cetaceans and found 218 cases, comprising five species and three different .30 calibers (Table 3). Firearms used were .30–06, .308 and .303 calibers, and projectiles were 150 grain soft-point bullets. While firearm calibres and projectile design differed from our post-mortem study, all cases utilised an identical shooting method. All cases were recorded from New Zealand, where several recent mass stranding events necessitated the euthanasia of large numbers of cetaceans in an identical manner. Three animals were reported for which TTD was not

Table 3
Instantaneous death rates (IDRs) for .30 calibre (7.62mm) firearm euthanasia cases reported in published literature.

Year	Country	Species	*n*	Calibre	Projectile grain	Projectile design	Aim point	IDR (%)	Reference
2005	New Zealand	Long-finned pilot whale	41	.30–06	150	Soft point	Dorsal	100	IWC (2006)
2010–11	New Zealand	Long-finned pilot whale	48	.30–06	150	Soft point	Dorsal	100	IWC (2011)
2010–11	New Zealand	Long-finned pilot whale	48	.303	150	Soft point	Dorsal	100	IWC (2011)
2010–11	New Zealand	Dwarf minke whale	1	.30–06	150	Soft point	Dorsal	100	IWC (2011)
2010–11	New Zealand	Pygmy sperm whale	1	.303	150	Soft point	Dorsal	100	IWC (2011)
2011–12	New Zealand	Long-finned pilot whale	63	.30–06	150	Soft point	Dorsal	96.8	IWC (2012)
2011–12	New Zealand	Pygmy sperm whale	8	.30–06	150	Soft point	Dorsal	100	IWC (2012)
2011–12	New Zealand	Pygmy sperm whale	4	.303	150	Soft point	Dorsal	100	IWC (2012)
2011–12	New Zealand	Pygmy sperm whale	2	.308	150	Soft point	Dorsal	100	IWC (2012)
2011–12	New Zealand	Strap-toothed whale	1	.308	150	Soft point	Dorsal	100	IWC (2012)
2011–13	New Zealand	Humpback whale	1	.308	150	Soft point	Dorsal	0	IWC (2012)
Total			**218**					**Mean: 98.6**	

zero: two long-finned pilot whales, *Globicephala melas* and one humpback whale, *Megaptera novaeangliae* (IWC, 2012). The mean IDR for the 218 cases was 98.6% (Table 3).

Instantaneous death rate (or equivalent terminology) is considered the key parameter by which the welfare outcomes of many killing methods are benchmarked, including livestock slaughter methods (Grandin, 2006) and commercial whale harvesting techniques (Gales *et al.*, 2008). The calculated IDR of 98.6% from all published .30 calibre firearm cetacean euthanasia attempts reviewed is extremely high in comparison to other reported physical killing methods (e.g. Lewis *et al.*, 1997) including the stunning of domesticated livestock in controlled abattoir conditions (Grandin, 2006; Newhook and Blackmore, 1982). While the .30 calibre firearms used in New Zealand differ slightly from those used for cadaver studies, the result suggests that the professional shooting of smaller (<6m length) stranded cetaceans is one of the most humane killing methods documented.

Comparison with other euthanasia methods

In the field of small animal veterinary medicine, injectable chemical euthanasia is widely regarded as the preferred euthanasia method (AVMA, 2013). This preference, combined with high public acceptance of the technique and its 'aesthetically pleasing' nature, has led to the approach being preferred for cetacean euthanasia in some jurisdictions (Barco *et al.*, 2012; Harms *et al.*, 2014). There are important considerations when dealing with wild, rather than domesticated species, with chemical euthanasia methods requiring manual handling and restraint of animals that is likely stressful for non-domesticated species. In addition, the inherent difficulty in accessing the vasculature of cetaceans, as well as their sheer size, dictates that chemical euthanasia methods cannot generate instantaneous deaths and are invariably associated with prolonged TTD (Dunn, 2006; Kolesnikovas *et al.*, 2012; March, 2012). Harms *et al.* (2014) reported TTD ranging from minutes to hours for a recently developed chemical euthanasia approach. There is a compelling argument that the shortest TTD should be the overwhelming priority for euthanasia methods, over concerns such as public acceptance or aesthetics (Coughran *et al.*, 2012; Øen and Knudsen, 2007). In addition, methods involving protracted TTD are impractical for mass stranding scenarios (e.g. IWC, 2006). There are also increasing concerns surrounding the eco-toxicological risks associated with the use of chemical methods (Barco *et al.*, 2012). In particular, the high environmental pollution risks associated with the use of barbiturates have been acknowledged (Barco *et al.*, 2012; Harms *et al.*, 2014; Otten, 2001; Peschka *et al.*, 2006) and exemplified by a recent secondary toxicity or 'relay toxicity' case study (Bischoff *et al.*, 2011). Through the use of lead-free ammunition (Caudell *et al.*, 2012; Thomas, 2013), the method presented here poses negligible risk of eco-toxicity.

Physical methods, and particularly firearms, are used as the preferred euthanasia methods for many large mammal species (e.g. Blackmore *et al.*, 1995; Longair *et al.*, 1991), due to their capacity to deliver instantaneous killing, low levels of environmental contamination and their accessibility to non-veterinarians. Despite these benefits, perceptions of poor aesthetics, public acceptance and safety have seen the professional use of firearms decline in recent decades, particularly in charismatic species (e.g. Barco *et al.*, 2012; Herbert, 2004; Nimmo and Miller, 2007). The shooting method described in this study offers a high level of operator and public safety through the use of professional staff, appropriate equipment and adherence to a standard operating procedure (Hampton *et al.*, 2014b). However, there are possible limitations of the described technique including the difficulty of animal positioning on steep or rocky substrate, the availability of the specialised projectiles required and the importance of the shooter being familiar with anatomical landmarks.

Wider acceptance and use of firearms as a humane tool in wildlife management has been hindered by a lack of understanding of wound ballistics (Caudell, 2013), a scarcity of studies providing scientific validation of firearms efficacy (e.g. Parker *et al*., 2006; Hampton *et al.*, 2014a) and a lack of scientific rigor in shooting studies (Daoust *et al.*, 2014). The shooting approach presented here is a highly humane method for euthanising cetaceans of <6m using widely accessible equipment. We encourage further cadaver studies into the use of firearms to euthanise cetaceans in the medium size range (6–9m), for which firearm use is currently considered contentious (Blackmore *et al.*, 1995; Greer *et al.*, 2001; IWC, 2006).

CONCLUSIONS

The post-mortem evidence presented in this study demonstrate that shooting is a highly reliable and humane method for euthanising moribund small sized cetaceans (<6m). Post-mortem results demonstrate consistent skull penetration and cerebral trauma in all cases, while ante-mortem data collected by the IWC indicates a very high IDR. The method was found to be effective in all species examined and was associated with low operator and eco-toxicity risks. The calibres of firearms examined are readily available worldwide and have common applications in wildlife management for the shooting of many terrestrial species. The firearms method presented here shares the advantages of being accessible to non-veterinarians and of not requiring specialised equipment, beyond projectiles. The cadaver examination approach, originally described by Blackmore *et al.* (1995), is recommended in determination of optimum caliber-projectile combinations for the euthanasia of other species where methods remain contentious. Humaneness, rather than concerns over aesthetics or public acceptance, should be the first criteria for any euthanasia method. The use of appropriate firearms for euthanising smaller cetaceans is associated with superior outcomes for animal welfare, public health and accessibility when compared to alternative approaches. Physical euthanasia methods are currently under-represented in wildlife management but can often provide more humane and expeditious alternatives to other killing methods.

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