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DEVELOPMENTS IN THE QUANTITATIVE ASSESSMENT OF WELFARE OUTCOMES IN HUNTED MAMMALS SUBJECT TO SHOOTING

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ABSTRACT

Knowledge gaps surrounding animal welfare assessment in hunted terrestrial wild mammals and seals were highlighted in the reviews by Knudsen (2005) and EFSA (2007). Following these reviews, the present paper aims to report on developments in the quantitative assessment of welfare outcomes in wild mammals killed via rifle shooting, and modern explosive harpoon grenades used in the killing of whales. Time to death (TTD) and instantaneous death rate (IDR) are widely accepted ante-mortem variables for assessing the duration of suffering during the killing process. The addition of post-mortem assessments allows for validation of TTD and IDR, thus providing a more accurate appraisal of animal welfare during hunting. While this combined assessment for large cetaceans has been implemented since the 1980s in the Norwegian minke whale (*Balaenoptera acutorostrata*) hunt, we report that this approach has been implemented in studies of the Icelandic minke and fin whale (*Balaenoptera physalus*) hunts, as well as the Canadian and Norwegian commercial harp seal (*Pagophilus groenlandicus*) hunts. Additionally, this approach has been incorporated into welfare studies in terrestrial herbivore management programmes. Quantitative welfare assessment during hunts is capable of effectively evaluating the weapons used and judging modifiable variables such as projectile choice, optimal shooting procedure, as well as identifying areas for improvement in hunter training. In moving towards a standardised approach for welfare outcome assessment, an established framework can effectively allow all hunts to be contrasted and allow for identification of optimal strategies that minimise animal suffering.

Keywords: animal welfare outcomes, hunting, shooting, wildlife shooting programmes, time to death, instantaneous death rate, post-mortem examination, marine mammals, terrestrial mammal

INTRODUCTION

Shooting is a widely used wildlife management tool. It is applied in many contexts, such as: commercial and recreational hunting, subsistence hunting, and culling as a means of controlling overabundant species (Hampton, Arnemo et al., 2021). As for any method of slaughter, animal welfare in terms of protecting the animal from pain and suffering is a key ethical issue for hunting (Grandin, 2010; Hampton, 2017; Knudsen, 2005; Terlouw, Bourguet & Deiss, 2016).

Welfare assessment

Welfare assessment in any interaction with animals requires an understanding of what harms may be done, the severity of the harms, and an appraisal of the methods available for harm mitigation (Mellor & Littin, 2004). Welfare assessment in the context of hunting and slaughter should aim to identify the most effective methods by which the killing can be conducted (Grandin, 2010; Kestin, 1995; Øen, 2021). This follows a utilitarian precept where one aims to do the most good for the least amount of harm (Mellor & Littin, 2004). This consideration is often extended to animals given their capacity to feel pain and to suffer (Mellor & Littin, 2004).

In a hunting and slaughter context, the "harm-benefit" analysis necessitates minimising the duration of suffering such that the time to bring about insensibility to pain is reduced (Knudsen, 2005; Mellor & Littin, 2004; Terlouw et al., 2016). However, assessing welfare outcomes of hunted animals in general is more challenging than for slaughtered livestock due to multiple factors. To limit stress, slaughter of livestock is commonly conducted using two interventions. First, the animal is stunned to induce a loss of consciousness and second, the animal is bled to induce death. The induction of unconsciousness aims to ensure that the animal does not experience pain or fear during the slaughter process (Terlouw et al., 2016). Some authors prefer the term *insensibility* over *unconsciousness* (Daoust & Cattet, 2004; Verhoeven, Gerritzen, Hellebrekers & Kemp, 2015), however we use unconsciousness to refer to the imperception of painful stimuli. Furthermore, attention is paid to not only identifying best practices that reduce suffering during the killing process, but also towards reducing stress in the preceding stages, i.e., rearing and transport (European Commission, 2009; European Food Safety Authority [EFSA], 2007; Grandin, 2010; Shaw & Tume, 1992; Verhoeven et al., 2015). As the environment in which domestic animals exist is dependent on farmers and operators, the conditions for assessing welfare outcomes can be largely controlled (Grandin, 2006; Mellor & Littin, 2004).

Hunting, by contrast, most often takes place in uncontrolled conditions. Shooting can take place on unstable terrain or

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from moving platforms, over a larger distance, and in changing weather conditions (Aebischer, Wheatley & Rose, 2014; Bateson & Bradshaw, 1997; Cockram et al., 2011; Hampton et al., 2017; Lewis, Pinchin & Kestin, 1997; Mellor & Littin, 2004; Ryeng & Larsen, 2021). These factors may influence the efficacy of the hunt.

Ballistics and killing strategies

For the successful killing of wild mammals via rifle shooting, the power of the rifle and ammunition used, the properties of the bullet and ballistics are paramount factors to be considered (Daoust & Cattet, 2004; Kneubuehl, Coupland, Rothschild & Thali, 2011; Maiden, 2009; Ryeng & Larsen, 2021).

The path of the bullet through the air, the exterior ballistics, is affected by wind, gravity, and friction (Massaro, 2017). Wound ballistics is the study of the bullet's action in tissue (Kneubuehl et al., 2011). Important elements in determining the wounding capacity of a rifle bullet are its velocity and mass, its shape and design of core and jacket and its ability of expansion, as well as the physical characteristics of the target organ (Kneubuehl et al., 2011; Maiden, 2009). To kill an animal as quickly and painlessly as possible, as much energy as possible should be transferred from the bullet to the animal. The energy transferred is determined by the instantaneous energy of the bullet and its sectional density (Kneubuehl et al., 2011).

Bullet placement is a critical factor. A bullet strike to the upper portion of the central nervous system (CNS) is the only certain method of delivering an instantaneous death to a hunted animal (Maiden, 2009). Hence, instantaneous death can only be expected in species where the brain or upper spinal cord is the target area. Although not instantaneous, a rapid death can be induced through massive tissue damage or collapse of the circulatory system from severe disruption of vital organs and blood vessels in the thorax (Maiden, 2009). A shot to the thorax using an expanding bullet is regarded as "best practice" in most countries, and millions of mammals are killed this way annually worldwide (Stokke et al., 2018). Blood loss resulting in hypovolemic shock is the primary cause of death in these animals (Stokke et al., 2018), and there is never an instant loss of consciousness (Newgard, 1992). Additionally, aiming at the thorax provides a greater target area at which to shoot, increasing the hit probability than when targeting the head (Maiden, 2009).

In practice, the killing methods used in modern whaling utilise a combination of the strategies mentioned above. As for most terrestrial mammals, the target area for the projectile (the explosive harpoon grenade) is the thorax. However, unlike an expanding bullet, the grenade is designed to detonate in the centre of the thorax (Øen, 2021). As documented in studies of minke whales (*Balaenoptera acutorostrata*), the detonation results in blast-induced neurotrauma resulting in immediate or very rapid loss of consciousness and death (Knudsen & Øen, 2003). Although the detonation also causes severe damage to other vital organs, neurotrauma caused by the blast-generated pressure waves is considered to be the primary cause of the very rapid loss of consciousness (Knudsen & Øen, 2003).

Quantification of the duration of suffering

When evaluating animal welfare in hunts that utilise shooting, quantifying the duration of suffering is critically important for making comparisons within and between hunts (Hampton, Forsyth, Mackenzie & Stuart, 2015; Øen, 2021). An appropriate template for the assessment of welfare outcomes through benchmarked parameters comes from studies of duration of suffering in cetaceans (Hampton et al., 2015; Knudsen, 2005).

In the 1970s, criticism of whaling and whale killing methods were the cause of much discussion by the International Whaling Commission (IWC) (Knudsen, 2005; Øen, 2021). When aiming to assess welfare outcomes for whaling, the exact time to death might be difficult to observe for animals dying in or under water. To overcome this problem, an IWC workshop held in 1980 defined the following criteria of death in whales: the time taken for 1) the mouth to slacken, 2) the flippers to slacken, and 3) all movements to cease (International Whaling Commission [IWC], 1980; Knudsen, 2005; Øen, 2021). In the early 1980s, following this workshop and based upon the above "IWC criteria", research programmes to develop and improve hunting and killing methods for minke whales began in Norway (Øen, 2021).

These programmes utilised the ante-mortem variables time to death (TTD) and the instantaneous death rate (IDR) as well as the harpoon grenade entrance location and detonation site as a template for assessment of welfare outcomes of the killing methods. The TTD was defined as the time from a strike until the whale was declared dead according to the IWC criteria (Øen, 2021). The IDR equates to the proportion of animals where TTD is zero.

These programmes also confirmed that the IWC criteria, which in practice mean *immobility*, are not fully adequate. When TTD is determined solely on these criteria, a significant portion of whales may be recorded as being *sensible* or *alive* when they actually are *unconscious* or *dead* (Knudsen, 2005). Any motion following harpooning is interpreted as a sign of life, and these criteria give no account for unconscious uncoordinated movements triggered by reflexes. Hence, it was concluded that TTD based on the IWC criteria may be overestimated. If, however, the IWC criteria are used together with post-mortem examination, the reported TTD will be closer to the true TTD for the majority of whales. Post-mortem assessments therefore allow a more accurate validation of ante-mortem variables like TTD and IDR in whales (Knudsen, 2005; Knudsen & Øen, 2003; Øen, 2021).

This combined approach could also apply to welfare assessment in other mammal hunts. Post-mortem examination of animals following killing to record the extent of tissue damage, projectile placement, and wound tracts can provide valuable insights into the efficacy of methods used to render the animal unconscious or dead (Knudsen, 2005; Ryeng & Larsen, 2021). However, judging welfare outcomes based solely on post-mortem examination should also be treated with caution; without direct observation of TTD the exact duration of suffering cannot be quantified. Retrospective assessment of TTD in terrestrial mammals by assessing such things as bullet tracts has been rejected as an acceptable approach (Hampton et al., 2015; Hampton, Eccles et al., 2021; Urquhart & McKendrick, 2006). Instead, the use of ante-mortem observations (e.g., TTD and IDR) in conjunction with post-mortem examination (e.g., gross pathology, bullet wound tracts, extent of tissue damage) has been considered to allow for effective quantification of welfare outcomes.

Recording the exact moment of unconsciousness or death observed in different hunts still relies on differing criteria. This may be related to differences in projectile placement between the hunted species and the ability for the observer to physically assess the animal's state of consciousness after shooting. While whaling utilises the IWC criteria, a standardised approach for assessing the exact moment of death does not exist for other mammal species (Knudsen, 2005). For physical killing methods, time to insensibility is the ideal measure for estimating duration of suffering (Newhook & Blackmore, 1982). In practise, this would mean irreversible unconsciousness. Like in whaling, immobility may be considered as appropriate for the recording of TTD provided that post-mortem examinations are performed. For hunts where observation permits, the inclusion of multiple signs, such as behavioural cues (e.g., loss of posture, degree of body relaxation, apnoea, convulsions), brain stem reflexes, and more, should ideally be applied (EFSA 2007; Ryeng & Larsen, 2021; Verhoeven et al., 2015). In any case, the inclusion of post-mortem pathological examination into welfare outcome reporting allows for validation of variables such as TTD and IDR.

Aim of the present paper

The use of both ante- and post-mortem observations has been used in studies quantifying welfare outcomes for whaling practices in Norway since the 1980s and would be applicable across a wide range of animal hunts (Hampton, 2017; Knudsen, 2005; Mellor & Littin, 2004; Øen, 2021). However, a comparative lack of studies using a similarly quantitative approach to assess welfare outcomes in hunted terrestrial wildlife was identified by Knudsen (2005). Furthermore, consistent reporting on animal welfare outcomes for hunted seals was noted as a considerable knowledge gap by EFSA (2007).

Following these reviews, the present paper aims to report on the development of quantitative assessments of welfare outcomes in wild mammals killed via rifle shooting, and modern explosive harpoon grenades used in the killing of whales. Of primary interest are studies that utilise combined ante- and post-mortem observations.

DEVELOPMENTS IN WELFARE ASSESSMENT

Marine mammals

Whales

Norwegian studies on TTD for minke whales involve specific reporting forms that have been used consistently by independent observers since their implementation in 1981 (Øen, 2021). This standardised approach has led to the refinement of hunting techniques. The most recent iteration of the harpoon grenade, "Whale Grenade-99", was the culmination of years of research and field trials by Øen (2021).

Sequential improvements to hunting techniques and equipment has now resulted in IDRs of up to 82% for minke whales in Norway (Table 1). Although praised for increasing IDRs in minke whale hunts, Norwegian whaling operations have been criticised for failing to significantly reduce TTD for whales not rendered instantaneously unconscious or dead (Butterworth, Sadler, Knowles & Kestin, 2004). In field trials conducted in 2011–2012, the mean TTD for survivors was considerably reduced, from 11 min in previous trials, to 1 min. An emphasis on correct shooting procedure and improved training of whalers is thought to have led to this improvement (North Atlantic Marine Mammal Commission [NAMMCO], 2015; Øen, 2021).

The Whale Grenade-99 has been implemented in the Greenlandic and Icelandic hunts for minke whales, modified for the hunt of fin whales (*Balaenoptera physalus*) in Iceland and Greenland, and for bowhead (*Balaena mysticetus*) and humpback whales (*Megaptera novaeangliae*) in Greenland (NAMMCO, 2015).

Table 1. Adapted from NAMMCO (2015). Time to death (TTD) expressed as mean, median and maximum survival time (ST) in minutes, and instantaneous death rate (IDR) in percent collected from Norwegian minke whale hunts. Year of trial and number of whales assessed (n) stated with subsequent iteration of primary weapon.

				TTD			
Year	**n**	**Primary Weapon**	**Explosive**	**Mean**	**Median**	**Max ST**	**IDR**
1981–1983	353	Cold Harpoon	-	11	11	62	17
1984–1986	257	Raufoss Harpoon Grenade	22 g Penthrite	6	8	57	45
1993–1999	2,687	Raufoss Harpoon Grenade	22 g Penthrite	4	7	90	60
2000–2002	1,667	Whale Grenade-99	30 g Penthrite	2	10	90	80
2011–2012	271	Whale Grenade-99	30 g Penthrite	1	6	20	82

With the established ante- and post-mortem assessment protocols in place for the hunting of minke whales in Norway, the standardised approach has so far only been applied to minke and fin whale hunts in Iceland (NAMMCO, 2015).

Collection of TTD data from 13 Icelandic minke whales during the 2014 and 2015 hunting showed an IDR of 69%, which is lower than the IDR registered in the Norwegian hunt (82%) (NAMMCO, 2015). A NAMMCO expert group on assessing TTD in large whale hunts meeting did not find that they could draw any firm and strong conclusions regarding killing efficiency due to the very limited set of data from the two seasons. Data on Icelandic fin whale hunts surpass the Norwegian IDR of 82%, with an observed 84% of animals killed instantaneously (NAMMCO, 2015). By comparison, for cattle slaughterhouses to pass welfare audits in the United States, 95% of animals must be stunned instantaneously, with an "excellent" standard awarded if this rises to 99% (Grandin, 2010).

It must be noted that modern whaling is not restricted to the North Atlantic nations; Japan has for many decades been an important whaling nation. TTD data has been systematically collected during Japan's research programmes in the Antarctic (JARPA) and North Pacific (JARPN) whaling operations. Reporting of TTD in these programmes utilises the IWC criteria, and makes comments on gross pathology in line with the Norwegian assessments of shooting angle, location of shot, and damage to vital organs (Ishikawa, 2010; Ishikawa & Shigemune, 2005). Following Knudsen & Øen (2003), Japanese whaling assessments additionally interpret penthrite detonations close to the central nervous system as indicators of instant death (Ishikawa & Shigemune, 2005). NAMMCO expert groups on assessing TTD in large whale hunts (NAMMCO, 2010, 2015) have made recommendations that detailed post-mortem assessments are made more widely available, as there are significant discrepancies between Japanese and Norwegian IDRs (Ishikawa, 2010). This is potentially due to shooting angle; Japanese offshore operations tend to actively pursue animals, resulting in a narrower angle relative to the body's longitudinal axis (Ishikawa & Shigemune, 2005). This therefore means that critical damage to the CNS is less likely, and further examination of wound tracts and shooting angle have been called for (NAMMCO, 2010, 2015).

Seals

As was stated by EFSA (2007), limited information is available evaluating the killing methods employed in various seal hunts around the world. Furthermore, EFSA underlined the need for studies that include ante-mortem observations to assess the animal welfare outcomes in seal hunts, and that evaluations of welfare in seal hunts should present a "continuity of evidence". This continuity of evidence refers to sequential observations of the animal being killed, the application of tests (e.g., blink test, skull palpation or some other confirmation of irreversible unconsciousness or death), followed by bleeding out to ensure death occurs.

Daoust & Caraguel (2012) conducted a study during the Canadian commercial harp seal (*Pagophilus groenlandicus*) rifle hunt. In reference to the EFSA report regarding continuity of evidence in observations, the killing process was followed completely in 278 seals from step one to step three of the standardised three-step killing process: stunning, checking by palpation of the skull to determine the degree of damage, and exsanguination. To evaluate the animal welfare outcomes, post-mortem examinations and time measurements were reported in the study, yet these were recorded between step one and two (stunning and palpation). Fourteen animals (5.0%) of the 278 seals were considered to have had a poor welfare outcome, as the average interval between stunning and palpation in these seals was significantly longer than in the remaining seals. These animals were not killed instantaneously, nor were they shot again before retrieval. At least 12 of these animals were retrieved with a gaff from the vessel. Seven were shot on the ice and in the water, respectively. Given that palpation does not accurately reflect TTD measurements, it is unclear whether differences arise from genuinely lower welfare outcomes, or from the difference in time taken to retrieve an animal to perform the second step. As pointed out by the authors, these animals may or may not have been fully conscious throughout this interval.

Again, Daoust & Caraguel (2012) do not present an accurate assessment of TTD as palpation is not equivalent with the moment of unconsciousness or death. Nevertheless, if palpation confirms the complete destruction of the skull, this indicates a very rapid or immediate loss of CNS function following shooting (EFSA, 2007). Should palpation of the skull fail to do this, then the following step – a secondary strike with a hakapik or a club – will ensure unconsciousness in the animal is achieved. While limiting the comparisons possible by using this method of welfare assessment, timing to the moment of palpation does allow some indication of the duration of suffering. Furthermore, when animals are shot in the water, it is difficult to assess TTD based on clinical examination.

Daoust et al. (2013) tested the efficacy of the .17 HMR (Hornady Magnum Rimfire) rifle cartridge on young grey seals *(Halichoerus grypus*) shot at close range. The criterion used to determine the success of the .17 HMR rifle cartridge was *immediate death* or death *within a few seconds*. The state of consciousness of the seal immediately after the shot was assessed by a veterinarian, based on at least two of the following criteria: degree of relaxation of the body, (including presence or absence of respiratory movements), presence or absence of a corneal reflex, and degree of fragmentation of the calvarium by palpation through skin and blubber. All 12 animals studied under controlled conditions, and 40 of 45 (88.9%) animals studied under field conditions died immediately or within a few seconds from a single shot. Post-mortem assessment of carcasses confirmed the extent of skull fracturing, with radiography detailing wound ballistics and bullet fragmentation characteristics. Although reporting death as being *immediate* or *within a few seconds* is not comparable with exact time intervals, the validation of instantaneous death through post-mortem does allow a degree of comparison to be made with other hunts that utilise IDR as an ante-mortem variable.

Recently, the first peer-reviewed study to assess the animal welfare outcomes in any Norwegian seal hunt based on ante- and post-mortem examinations, was published (Ryeng & Larsen, 2021). The study aimed to investigate the relative effectiveness of two expanding bullet designs in young harp seals shot using a .223 calibre rifle. TTD and IDR were the main variables. The moment of irreversible unconsciousness or death was identified based on the following signs: immediate collapse; total body relaxation; absence of the corneal and righting reflexes; apnoea; no recovery of rhythmic respiration or any breathing movements of the chest or nostrils and occurrence of uncontrolled tonic or clonic spasms, referred to as post-mortem reflex movements. In the case of young harp seals, the relatively short shooting distance, on average about 30 m, makes the shot animal quickly accessible for examination of its state of consciousness.

The study by Ryeng & Larsen (2021) was conducted as an open, controlled, and randomised parallel group designed field trial during the regular hunt. Young, weaned harp seals of both sexes were pre-randomised (1:1) into one explosively expanding 55 grain (fragmenting) (Varmint) and one rapidly expanding 64 grain (mushrooming) (Bonded) bullet type group, with 75 animals in each. The observed IDR was 84% in both bullet groups. However, correcting for Weather Condition Index, the IDR for the Varmint bullet was significantly higher compared to the Bonded. The mean TTD was 53 s and 74 s in the Varmint and Bonded group, respectively, but the difference did not reach significance. The detected differences in IDR and TTD indicated a higher effectiveness of the Varmint bullet relative to the Bonded. This was supported by a higher total cranial damage score and bleeding intensity produced by the Varmint bullet. Furthermore, the Varmint bullet produced more pronounced post-mortem reflex movements, making the effect of the shot more visible as well as lowering the frequency of perforating shots (i.e., bullets passing through the animal). This acts to reduce the risk of accidental injuries to neighbouring seals. These findings strongly indicated that the explosively expanding Varmint bullet may improve animal welfare in the hunt of young harp seals.

In a case study presented in Hampton, Arnemo et al. (2021), the issue of rifle calibre and shooting distance is discussed concerning adult harp seals in Canada. During a hunt in 2016, an independent observer collected data from 96 seals that were shot at using .223 calibre rifles, firing 50 grain hollow-point or 62 grain soft-point ammunition. Seals were shot from a single sealing vessel at distances ranging from 15 to 200 m (*M*: 110 m). The proportion of animals hit and rendered instantaneously dead was 30%, and 21% were struck-and-lost. Post-mortem examinations confirmed that 73% of killed seals were shot in the cranium. If struck-and lost animals are included, the results suggest that the majority of animals were not rendered immediately insensible using these shooting procedures. Therefore, it was concluded that the choice of projectile was not adequate to achieve optimal accuracy and energy transfer. The authors questioned whether welfare outcomes were negatively impacted by the long shooting distance, the small target and the moving platform. It was further discussed that prior benchmark ballistics testing could be used to establish an optimal procedure. These tests could have identified an optimum calibre bullet and an optimum range at which to target animals. Additional anatomical examination of cadavers could also be used to inform future post-mortem examination.

The range of studies that have been conducted since the publication of EFSA (2007) demonstrate the approaches now being taken in the assessment of welfare in seal hunts. There remains inconsistency in the reporting of quantitative ante-mortem variables. Daoust & Caraguel (2012) presents a time to palpation, while Daoust et al. (2013) reports death as being *immediate* or *within a few seconds*. Nevertheless, post-mortem data is gathered, with the extent of damage to cranial bones confirming instantaneous death in some cases, thus providing inferences for IDR. Ryeng & Larsen (2021) utilised multiple cues to assess unconsciousness and death, followed by post-mortem examination for accurate reporting of both IDR and TTD in seals.

<u>Terrestrial mammals</u>

Since Knudsen (2005), several quantitative assessments of welfare outcomes combining ante- and post-mortem data have been conducted in terrestrial mammal hunts.

Cockram et al. (2011) assessed physiological parameters such as plasma cortisol and muscle glycogen concentrations from deer subject to shooting from helicopters, stalking, and domestic slaughter. Time recordings were made by observers conducting the study, with *time to apparent death* denoting the interval between shooting and the animal lying motionless with no obvious signs of life. Post-mortem assessments of bullet wound tracts were also conducted. No significant difference in median apparent TTD was found between hunting methods, however, the accuracy of the reported TTD was stated as less than one minute. Immediate collapse was reported in 66% of the wild deer, giving an IDR for the hunts. The inclusion of blood chemistry analysis aids in assessing stress induced by differing hunting methods. Helicopter shooting saw the greatest blood cortisol level in wild deer at 91 nmol L^{-1}, which may be an indicator of greater stress prior to shooting. This comparison is especially useful given that the rate of immediate collapse and time to apparent death were not significantly different. Interestingly, the farmed deer slaughtered by captive bolt pistol were reported to have a blood cortisol level of 92 nmol L^{-1}, with increased stress likely due to transport and handling.

As with whales which may submerge following shooting, terrestrial animals may flee once struck (i.e., flight distance), thus inhibiting accurate recording of time to unconsciousness or death (Aebischer et al., 2014; Bateson & Bradshaw, 1997; Kanstrup, Balsby & Thomas, 2016; Stokke et al., 2018). Stokke et al. (2018) attempted to account for this by discerning the allometric scaling associated with flight distance from the place of shooting to the point where the animal is incapacitated. Incapacitation was defined as the state where a wounded animal is recumbent, immobile, and regarded as unconscious. Flight distance was found to increase with body mass due to the inverse relationship between bleeding rate and animal size. Using flight distance as a proxy for time to unconsciousness or death, from this model it would therefore be possible to judge acceptable welfare standards based on an estimate of animal size and the distance travelled. While this would provide a simple means by which hunters can estimate welfare outcomes, it does not account for the extent or specificity of tissue damage caused by the bullet, or the precise duration of suffering perceived by the animal reported through accurate TTD recording. Further, it does not account for non-fatal wounding of animals, nor animals incapacitated by paralysing shots.

However, the incidence of non-fatal wounding during hunts is often neglected (Hampton, 2017). This regards animals that are struck and yet not recovered; the term *struck and lost* is used in the context of marine hunts (Hampton, Arnemo et al., 2021). From an animal welfare point of view, the unquantifiable duration of suffering caused by the escape of a wounded animal is perhaps the worst of all possible outcomes. An assessment of the rate of wounding in addition to TTD, also allows quantitative assessment of shooter skill, optimal ambient conditions, and projectile choice (Hampton et al., 2015).

Flight distance was later utilised by Stokke, Arnemo, & Brainerd. (2019) to compare copper and lead bullets when hunting deer, concluding that lead-free bullets were effective alternatives to the more widespread lead-core designs. Additional information such as bullet location and wound tracts were utilised in this study, aiding in the assessment of hunting efficacy, and therefore providing a post-mortem assessment. While assessing flight distances does not allow precise TTD reporting, it may constitute a useful proxy for animal welfare assessment. Hunting terrestrial game in variable terrain presents inherent challenges to ante-mortem reporting, and often the animal disappears from site following shooting (Aebischer et al., 2014; Bateson, & Bradshaw, 1997; Cockram et al., 2011; Hampton et al., 2017; Lewis et al., 1997; Mellor & Littin, 2004; Stokke et al., 2018).

In recent years, combined ante- and post-mortem data have been utilised in a body of work on wildlife management in Australia. This literature includes a quantification of welfare outcomes from helicopter-shooting of feral dromedary camels (*Camelus dromedarius*), feral horses (*Equus caballus*) (Table 2), chital deer (*Axis axis*) and fallow deer (*Dama dama*) (Hampton, Bengsen et al., 2021; Hampton et al., 2014, 2017). It also includes night-shooting of European rabbit *(Oryctolagus cuniculus*) and peri-urban eastern grey kangaroos (*Macropus giganteus*) (Table 2) (Hampton et al., 2015; Hampton & Forsyth, 2016). Indeed, the studies mentioned based their assessment variables on those used in the assessment of cetacean welfare outcomes, demonstrating their applicability in diverse settings.

TTD in herbivore management programmes was determined based on the moment of bullet impact, to the moment of immobility (Hampton, 2017). Although it is argued that TTD and IDR should be used to provide consistency and facilitate comparison between hunts (Hampton et al., 2015), error remains where immobility is used as a proxy for death. For example, with strategies such as helicopter shooting it may be impossible to assess TTD in the strictest sense, and thus time to insensibility (TTI) was reported by Hampton, Bengsen et al. (2021), and repeat shooting is also performed to ensure there is no return to consciousness (Hampton et al., 2014). This discrepancy highlights the need for post-mortem assessments.

In all the studies, ante-mortem observations were performed by an independent observer during shooting, while post-mortem examinations were carried out by an independent veterinarian who recorded the location of bullet-wound tracts, as well as evidence of non-fatal wounding upon locating the animals. Application of this combined approach to quantitative assessment in herbivore management has also allowed for direct comparison of projectile choice (Hampton, DeNicola & Forsyth, 2020; Hampton et al., 2016), as well as how factors such as shooter identity (Hampton et al., 2014, 2017), surrounding vegetation and the behaviour of conspecifics (Hampton & Forsyth, 2016) influence the conclusions drawn.

Table 2. Adapted from Hampton et al. (2014, 2015, 2017), and Hampton & Forsyth (2016). Time to death (TTD) in seconds expressed as mean values with 95% confidence interval (CI) (brackets) and maximum survival time (ST), and instantaneous death rate (IDR) in percent with 95% CI for animals subject to lethal control measures. Number of animals assessed (n), and method of shooting stated for each. Helicopter shooting is defined as shooting targets from a helicopter platform with a rifle. Night shooting indicates shooting takes place after dark with a spotlight illuminating the target. **95% Confidence Intervals not reported.*

Year	Species	Method of shooting	n	TTD	Max ST	IDR
2012	European rabbit (*Oryctolagus cuniculus*)	Night Shooting	127	12 (8–16)	90	60 (50–69)
2013	Feral dromedary camels (*Camelus dromedarius*)	Helicopter Shooting	192	22 (11–33)	242	83 (77–88)
2013	Feral horses (*Equus caballus*)	Helicopter Shooting	937	19 (-*)	242	63 (60–66)
2015	Peri-urban kangaroos (*Macropus spp.*)	Night Shooting	134	12 (-*)	81	98 (95–100)

In the case of Hampton et al. (2017), hunter identity and skill corresponded significantly to welfare outcomes registered. This was confirmed by observations of variability in bullet placement between hunters, thus validating welfare variables through post-mortem assessments. Likewise, in cetaceans, data such as shooting angle are shown to significantly impact TTD, and this knowledge has been incorporated into training programmes for hunters (NAMMCO, 2015; Øen, 2021).

As recognised by assessment of welfare in slaughterhouses, care should also be given to the time preceding the application of killing processes, such as rearing and transport (European Commission, 2009; EFSA, 2007; Grandin, 2010; Shaw & Tume, 1992; Verhoeven et al., 2015). In line with this, it may also be of value to the assessment of welfare in hunts to account for stress caused prior to killing or stunning.

Observations from helicopter shooting programmes for feral horses and deer recorded the *chase time*, defined as the time between initial avoidance behaviour and the impact of the first shot (Cockram et al., 2011; Hampton, Bengsen et al., 2021; Hampton et al., 2017). With some animals being pursued for 10 minutes or more, performing an instant kill is likely to still result in negative welfare outcomes due to excess stress caused in the preceding moments. Elevated stress inflicted during a hunt, particularly those with a prolonged pursuit period, is associated with increased cortisol concentrations in muscle tissue following death (Bateson & Bradshaw, 1997; Urquhart & McKendrick, 2006). Negative welfare outcomes may indeed persist long-term in non-target animals (Bryan et al., 2015; Burke, Page, Van Dyk, Millspaugh & Slotow, 2008), or those animals that survive the hunt and nevertheless die due to capture myopathy (Bateson & Bradshaw, 1997; Nuvoli et al., 2014).

While the body of work on terrestrial mammals has derived its methodology from large cetacean welfare assessments (Hampton et al., 2016; Knudsen, 2005), observations and assessments reporting on prior stress would be valuable if incorporated back into whale hunts. Methods of cetacean capture vary between regions (NAMMCO, 2015), yet quantitative assessment of initial behavioural responses to hunters has not been factored into cetacean welfare assessments. In contrast to the opportunistic Norwegian minke whale hunt, in some Japanese whaling operations, animals are pursued by whaling vessels using sonar to drive them to the surface (Ishikawa, 2010; NAMMCO, 2015). Introducing a method of assessing the duration to which stress is induced prior to killing, such as chase time (Hampton, Bengsen et al., 2021; Hampton et al., 2017), would be essential to fully appraising welfare outcomes in hunts.

CONCLUSIONS

We conclude that the assessment of welfare outcomes in hunted mammals subject to rifle shooting has seen some developments since knowledge gaps were identified by Knudsen (2005) and EFSA (2007). Welfare assessments of whaling operations in Norway have continued, with the combined approach of ante- and post-mortem observations being expanded to other whaling nations in the North Atlantic. This model for welfare assessment has now seen application more broadly in the hunting and killing of seals, and terrestrial wildlife shooting programmes. Further development of this approach should also include wider assessment of behaviour and stress prior to shooting where appropriate. Disregarding whales, where the IWC criteria are used by consensus, the moment of immobility is often the proxy for recording TTD in quantitative assessments of welfare outcomes in other hunted species, particularly terrestrial mammals. However, this still allows for error in welfare assessment. Whenever possible, the state of consciousness following shooting should be examined using multiple indicators to reduce this error, and methodologies that involve repeat shooting can also account for this.

Across hunts where clinical examination of the animal's the state of consciousness following shooting is difficult to perform, further investigations are needed for better examination techniques, and consensus for a standardised criteria would be desirable. In recognising that there are practical issues surrounding the most accurate assessment of TTD, an assessment framework incorporating post-mortem examinations will continue to be crucial to validate ante-mortem observations.

AUTHOR CONTRIBUTION STATEMENT

Samuel D. G. Smith: Conceptualisation, Resources, Writing - original draft, Writing - review & editing.

Kathrine A. Ryeng: Resources, Supervision, Writing - review & editing.

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