



Ethological and procedural assessment of ballistics euthanasia for stranded cetaceans

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ABSTRACT

Euthanasia may be necessary at cetacean stranding events to end suffering. To ensure a humane death, verification of unconsciousness must be undertaken following application of the killing method. However, only limited information is reported on individual euthanasia events, including how unconsciousness and/or death is assessed. Here, we describe current practices for euthanising stranded cetaceans in New Zealand by analysing video footage of fourteen ballistics events involving various species. Specifically, we detail the ballistics procedures applied and the behavioural responses of the animals. Additionally, we sought to understand how animal unconsciousness was evaluated following each event by surveying the personnel involved. Video recordings ranged in length from 25 to 480 s after the initial shot and involved 14 cetaceans: one Cuvier's beaked whale, one pygmy sperm whale, one bottlenose dolphin, four pilot whales and seven false killer whales. Unconsciousness criteria were typically not observed being verified in the videos analysed, despite markspersons stating that death occurred in < 1 minute for most animals. Number of shots applied to an animal ranged from 1–3. Key behaviours indicative of unconsciousness included a continuously slack lower jaw and epaxial muscle relaxation. Based on behavioural observations, 66.7 % of animals for which an estimate could be made ($n = 12$) were likely unconscious within 30 s of the initial shot; half of these were likely unconscious within 10 s. The remaining animals appeared conscious for 30 s after the initial shot, and half of these were likely still conscious after one minute. Ten animals displayed post-shot behaviours suggestive of voluntary control, including tail lifting, beyond the point of presumed death reported by markspersons. The lack of verification of unconsciousness in most animals (12/14) hinders our ability to understand how these behaviours may correlate with awareness and thus welfare impacts of shooting. While the application of ballistics appeared to follow current national recommendations, mandated procedures for verifying death were rarely observed. We recommend exploring the reasons for this finding, to ensure that such procedures are appropriately undertaken, and welfare compromise minimised.

1. Introduction

Cetacean stranding events often result in animals with compromised welfare and low survival likelihood. Therefore, euthanasia may be required to reduce animal suffering (Harms et al., 2018). Three methods of euthanasia can be applied to stranded cetaceans: chemical, explosives and ballistics (Coughran et al., 2012; Dunn, 2006; Hampton et al., 2014). Ballistics euthanasia can result in instantaneous unconsciousness (insensibility) if appropriate techniques and equipment are applied (Grandin, 2006; Leary et al., 2020). For cetaceans, this involves the use of a high-powered firearm, usually a rifle, and a heavy calibre projectile to cause extensive damage to the brainstem and spinal cord that will

render the animal unconscious (Hampton et al., 2014; Leary et al., 2020; Øen and Knudsen, 2007).

When undertaking euthanasia, it is crucial that unconsciousness and/or death is achieved rapidly to ensure that additional animal welfare compromise is minimised (Leary et al., 2020; Mellor and Littin, 2004). The rapidity of unconsciousness and/or death can only be understood if criteria indicating these states are assessed following the application of the killing method. While death is the overall aim of applying euthanasia methods, it is the occurrence of unconsciousness which governs the humaneness of the procedure, as this determines the time during which the animal could consciously experience the effects of the method (Leary et al., 2020; Mellor and Littin, 2004).

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The ‘gold standard’ for verifying death is the cessation of heartbeat (Close et al., 1996), though in cetaceans this is complex to assess and likely not possible in many stranding scenarios. In farmed mammals such as cattle and sheep, ethological assessments during slaughter have been undertaken in combination with testing of neural reflex to understand how various behavioural indicators can be applied to assess unconsciousness (e.g. Blackmore et al., 1995; Verhoeven et al., 2015, 2016). Currently, it is recommended that unconsciousness in cetaceans be assessed through a combination of multiple behavioural and physiological criteria, including absence of palpebral and corneal reflexes, dilation of pupils, lack of jaw tone, absence of heartbeat and respiration, absence of pain reflexes and presence of unprovoked agonal convulsions (Barco et al., 2016; Brakes et al., 2006; Butterworth et al., 2004a). However, reporting of the criteria used to verify unconsciousness/death and recording of time to unconsciousness/death — used as a proxy for duration of potential suffering — in stranded cetaceans, is rare (Boys et al., 2021, 2022a, 2023, 2024).

Some ethological analyses have been conducted on marine mammals killed during hunts to inform understanding of the potential welfare implications of killing methods. In these studies, ‘directed movements’, such as coordinated, regular/rhythmic movements of the head, tail, flippers and mouth were interpreted as likely to be voluntary and their observation indicated the need to apply further procedures to render the animal unconscious (Butterworth et al., 2017, 2013; Butterworth and Richardson, 2013; Daoust and Caraguel, 2012). However, these authors also suggest that in some cases, animals may display a paralysis response and that the reliance on ‘directed movement’ alone as an indicator of unconsciousness may be problematic.

The examination and field application of such behavioural indicators to assess unconsciousness in euthanised stranded cetaceans is limited (Boys et al., 2024, 2023). Nonetheless, verifying unconsciousness/death is essential to enhance our understanding of the impacts of different euthanasia methods and the ways in which they are applied in practice if implemented and adhered to. Assessment and reporting of such data would allow refinement of techniques and understanding of any species-specific requirements, which will reduce any potential suffering due to euthanasia in stranded cetaceans. Additionally, such knowledge would support managers in educating the wider community on the importance of euthanasia and its appropriate use as a welfare-oriented option at stranding events.

In Aotearoa New Zealand (NZ), the agency legally responsible for managing strandings (Department of Conservation; DOC) utilises a Standard Operating Procedure (SOP) to guide decision-making (Boren, 2012). Currently ballistics is the only permitted method of euthanasia and the SOP recommends the use of multiple calibre firearms and soft point or standard sporting round projectiles. Additionally, it requires verification of death following application of the ballistics procedure (Boren, 2012; Boys et al., 2022a). Markspersons undertaking euthanasia are warranted officers with knowledge of firearms, health and safety procedures, and the application of ballistics to stranded cetaceans, which includes verifying death.

While DOC’s SOP for managing stranded cetacean end-of-life is clear and scientifically supported, recent insights suggest that updates to the SOP would improve animal welfare outcomes. For example, reports submitted by NZ to the International Whaling Commission suggest that soft-point projectiles are commonly used for ballistics euthanasia (Boys et al., 2021). These are understood to deform on impact and generally have lower penetration ability than solid projectiles, meaning that they frequently cause less and/or more variable disruption to the cranium and brain, which may result in prolonged time to unconsciousness or death (Boys et al., 2023, 2024; Hampton et al., 2014; Øen and Knudsen, 2007; IWC, 2000). Furthermore, limited information is provided in these reports on if, and how, unconsciousness/death are assessed and time to death calculated, even though most events are described as resulting in “presumed instantaneous” death (Boys et al., 2023, 2021).

The reasons for, and implications of, such apparent variations in the

practical application of ballistics euthanasia in NZ are not clear. It would be useful to better understand any challenges to following the recommendations in the SOP regarding equipment, application, and verification of unconsciousness/death. To facilitate this understanding, we describe the application of ballistics euthanasia to various species of stranded cetaceans in NZ and the animals’ behavioural responses via analysis of videos taken at recent events. We also evaluate how unconsciousness/death is being assessed and time to death calculated, by combining the same video analysis with surveys of the personnel involved in each of these filmed euthanasia events.

2. Methods

This project was evaluated and approved by Massey University Animal Ethics and Human Ethics Committees. Additionally, research permits from the NZ Department of Conservation (DOC) were approved following consultation with indigenous Māori (iwi). No animals were euthanised specifically for this study. Rather, all data presented here were collected opportunistically during strandings when euthanasia was *a priori* deemed necessary by DOC in partnership with iwi.

2.1. In-field data collection

Upon request to DOC and local iwi, permission was granted in each reported case to make observations of animal behaviour via video footage during euthanasia procedures. Video footage of cetaceans subject to ballistics euthanasia was opportunistically gathered from five stranding events around NZ between 2020 and 2024. Fourteen individual animals of six different odontocete species were assessed (Table 1): one Cuvier’s beaked whale (*Ziphius cavirostris*), one pygmy sperm whale (*Kogia breviceps*), two long-finned pilot whale (*Globicephala melas edwardii*), two short-finned pilot whales (*G. macrorhynchus*), and seven false killer whales (*Pseudorca crassidens*) and one bottlenose dolphin (*Tursiops truncatus*) that were involved in a mixed species mass stranding.

Video footage was collected opportunistically following Boys et al. (2022b, 2023, 2024), beginning whilst the animal was alive, with continuous recording peri- and post-ballistics procedure. Due to the stochastic nature of strandings, we often were not in attendance prior to most ballistics events, therefore video footage was filmed by a DOC officer involved in the stranding or by local iwi. All recordings were made with a handheld mobile except Case 5 which was filmed using a GoPro camera. We requested that filming continue for at least 2 minutes post-ballistics, but the actual time filmed varied by event. The first author (RMB) was present for euthanasia at the short finned pilot whale mass stranding, and attended the mixed species stranding but due to logistical constraints, arrived after ballistics procedures had been applied to all animals. However, in some cases this allowed for visual assessments of procedures, including orientation of shot entry and measurements of shot entry relative to anatomical landmarks. All ballistics applications were conducted by a warranted DOC officer (marksperson) as required in the NZ SOP (Boren, 2012). Animal age class was assessed based on approximate total body length from the video footage or strandings data collected by DOC as part of standard stranding response.

2.2. Ethological analysis

Orientation of firearm discharge (dorso-ventral: aiming posterior to the blowhole at 45 caudo-ventral; or lateral: between the eye and pectoral fin at eye level (Hampton et al., 2014; IWC, 2014)), approximate projectile entry location (relative to animal anatomical features), number of shots dispatched, and the behavioural response of the animal were determined. Video footage was examined manually at 0.5x speed, at least twice, by one observer (RMB) using program BORIS (Friard and Gamba, 2016) to identify all fine-scale behaviours. The ethogram

Table 1

Video footage collected of individual live cetaceans (n = 14) representing six odontocete species between November 2020 and March 2024, New Zealand. Note: False killer whales and bottlenose dolphin were part of a mixed species mass stranding event. NA= Whole body viewable. Note: Mobiles were handheld.

Case no.	Species	Age class	Stranding type	Refloat attempts	Time stranded pre-euthanasia	Recumbency position	Camera placement	Body area not viewable
1	Cuvier's beaked whale	Neonate	Single	0	< 24	Ventral	~2 m in front, adjacent to head; 0–45°	NA
2	Pygmy sperm whale	Sub/Adult	Single	4	< 24	Ventral	~2 m in front, adjacent to head; 0–45°	NA
3	Long-finned pilot whale	Adult	Mass	1	< 48	Lateral	~3 m in front, adjacent to head; 90°	NA
4	Long-finned pilot whale	Adult	Mass	1	< 48	Ventral	~3 m in front, adjacent to head; 90°	Tail fluke
5	Short-finned pilot whale	Adult	Mass	1	< 48	Ventral	~2 m in front, adjacent to head; 0–45°	NA
6	Short-finned pilot whale	Adult	Mass	1	< 24	Lateral	~2 m behind, adjacent to flukes; 0–45°	Eye, lower jaw
7	False killer whale	Adult	Mass	2	< 48	Ventral	~2 m in front, adjacent to head; 0–45°	NA
8	False killer whale	Adult	Mass	2	< 48	Lateral	~3 m adjacent to trunk; 90°	NA
9	False killer whale	Adult	Mass	2	< 48	Lateral	~3 m in front, adjacent to head; 90°	NA
10	False killer whale	Adult	Mass	2	< 48	Ventral	~2 m behind, adjacent to flukes; 0–45°	Eye, lower jaw
11	Bottlenose dolphin	Adult	Mass	2	< 48	Ventral	~3 m adjacent to trunk; 90°	NA
12	False killer whale	Adult	Mass	2	< 48	Lateral	~2 m in front, adjacent to head; 0–45°	NA
13	False killer whale	Adult	Mass	2	< 48	Lateral	~2 m in front, adjacent to head; 0–45°	NA
14	False killer whale	Adult	Mass	2	< 48	Ventral	~10 m, behind, adjacent to flukes; 90°	NA

specific to stranded cetacean euthanasia followed [Boys et al. \(2023, 2024\)](#), with any new behaviours being identified and described. All animal behaviours were coded per deci-second and quantified based on their frequency or duration. In some cases, it was not possible to see if the eyes were open or closed due to light conditions. In such events, eye-related behaviour has not been included in the behaviours mapped. Additionally, we noted respiration on the visual representation of the ethogram if this occurred. Where possible, time to unconsciousness was estimated from the video as the time taken from the first shot until absence of reflex responses when these were observed to be tested by the marksperson in the field. In cases where reflex testing was not undertaken, time to unconsciousness could not be estimated.

For [Cases 3 and 4](#) (long-finned pilot whales), filming was not continuous, with separate filming of each shot applied to the same animal (e.g., total of three videos, one of each shot being applied to one animal). For the first of these animals, three shots were applied but filming only occurred for the second and third shots. The two shots occurred over a period of 2.35 mins with video footage recorded for only 61 s. The second animal was shot three times over 4.6 mins, but only 48 s of this time was recorded. To provide an accurate description of when behaviours occurred in relation to the initial shot, we examined behaviours in “real-time” using the timestamp from the available video footage. This was achieved in BORIS by setting the separate videos to play in sequence with a time-offset determined by the timestamp on the video footage properties.

2.3. Follow-up procedural data collection

Within seven days of each of the stranding events, the marksperson involved in the euthanasia procedure was emailed a set of questions to gather additional information regarding the firearm type and projectile characteristics (soft deforming or solid non-deforming, and pointed or round nosed in shape). In the mass stranded animals in [Cases 7–14](#), two projectile grains (gr) were used but these were not recorded for each individual, as such we have included the details of both grains for each of these cases.

Additionally, we collected qualitative data from the marksperson on

what anatomical landmarks were used when aiming, whether (from their point of view) unconsciousness/death criteria were assessed and if so, what these criteria were, how assessments were made, what was perceived to be the estimated time to unconsciousness/death of the animal and whether any movements occurred after the assumed death. Markspersons were also given the opportunity to provide any additional comments or contextual information they wished. This information was integrated with the data from the video footage to provide further context to the ballistics procedure and explore any potential animal welfare concerns, such as compliance with the mandated procedures for verifying death.

2.4. Estimating time to unconsciousness/insensibility (TTI)

Estimated time to unconsciousness/insensibility (TTI) from video was based on the time from the initial shot to the final observation of key behaviours (continued open/slack lower jaw and muscle relaxation) and was categorized as: Immediate < 10 s post-shot; Rapid 10–29.9 s; Delayed 30–60 s; Prolonged > 60 s. Estimated time to death (TTD) from video was based on the time from the initial shot to the final observation of any behaviour, i.e. no further behavioural occurrence for at least 15 s. This cutoff time was based on the mean interval between episodes of (any) behaviour over all animals in the study. If behaviour had not ceased for at least 15 s at the end of the video, TTD was indicated as ‘greater than’ the duration of the video following the initial shot. Estimated TTI based on behaviour and reported TTD from markspersons was considered to be consistent when the reported and observed estimates were within 10 s of each other.

3. Results

Behavioural footage was collected from three mass stranding and two single stranding events. A total of 18 animal behaviours were identified from the video footage ([Table 2](#)). Two were point events and the rest were state behaviours, noting multiple behaviours could be displayed simultaneously by an individual animal.

Case 1. Cuvier's beaked whale

Table 2

Ethogram of stranded odontocete behaviour during ballistics euthanasia procedures, derived from observation of 14 individuals of six odontocete species at five stranding events in New Zealand between 2020 and 2024. Behaviours were classified following Boys et al. (2022b, 2023, 2024). State behaviours were measured in seconds.

Type	Behaviour	Description
State	Agonal convulsion	Unprovoked violent, rapid thrashing movements mainly involving peduncle and tail (clonic convulsions)
State	Body rocking	Entire body rocks laterally side to side
State	Body tenses	Entire body girth appears to expand without respiration, possibly tensing all muscles
State	Body tremble	Whole body trembles/shakes
State	Dorsal fin flutter	Dorsal fin makes small lateral shaking/tremor type movements
State	Eye closed	Right or left eye is closed continuously
State	Eye open	Right or left eye is open continuously
State	Head twitch	Slight lateral head movement to one side
Point	Jaw open	Slack/open lower jaw with mouth agape
Point	Muscle relax	Relaxation of epaxial musculature, so the body becomes 'limp' – loss of muscle tone
State	Pec fin flutter R/L	Pectoral fin right/left flutters in small shaking/tremor type movements dorso-ventrally
State	Peduncle stiffens	Peduncle muscles stiffen (tonic convulsion/spasm)
State	Tail arch	Tail fluke and entire peduncle are elevated high off the ground into a curved arch
State	Tail flutter	Tail fluke flutters, small shaking/tremor type movements dorso-ventrally without lifting peduncle
State	Tail lift	Tail fluke and caudal peduncle lift slightly off the ground
State	Tail side to side	Tail moves from side to side (lateral)
State	Terminal exhalation	'Groan'-type vocalisation that may occur, often in combination with musculature relaxation
State	Whole body arching/thrashing	Entire body thrashes/arches vigorously dorso-ventrally

Ballistics was applied using a .303 rifle with one 215gr solid round nose projectile. The shot orientation was dorso-ventral and entered caudal to the blowhole. The animal was in ventral recumbency in shallow (ca. <0.5 m) water when ballistics was applied. Criteria for unconsciousness/death were not assessed in the field following the application of ballistics.

Agonal convulsions began immediately (<1 s) following the shot and continued for 2.5 s. Immediately following the agonal convulsions, the animal rolled slightly (of its own accord) to be in lateral recumbency, with the blowhole submerged. Observation of open lower jaw and relaxation of epaxial musculature occurred simultaneously 5.1 s after the shot. However, tail lifting was observed 22 s post-shot and continued for 3.5 s (Supplementary Figure 1). The video recording ended immediately after the end of the tail lifting. The eyes could not be observed on the video footage due to the light conditions and positioning of the camera.

The marksperson stated that the shot was fired approximately 15–20 cm from the animal, aiming from the dorsal surface to the ventrum. The point of aim was the caudal area of the skull towards the occipital condyles; this was assessed using the anatomical landmark of being halfway between the forward insert of the pectoral flipper and the eye. The marksperson stated that they estimated time to death to be < 1 minute based on observation that the animal “*thrashed tail fluke (approx. 3 times) then ceased abruptly, rolled over slightly – pectoral flipper relaxed to the side of the carcass, blow hole submerged no exhalation. Close inspection - eye closed.*”

Case 2. Pygmy sperm whale

Ballistics was applied using a .308 rifle and three 150gr soft point projectiles. Three shots were dispatched in dorso-ventral orientation and entered caudal to the blowhole. The animal was in ventral recumbency out of the water on the beach when ballistics were applied. Criteria for

verifying unconsciousness/death were not examined in the field following application of ballistics. Notably, the marksperson stated that they “*would have touched the eyes, however circumstances with iwi being present, it seemed inappropriate.*”

The time between the first and second shot was 4.5 s, and between the first and final shot was 8.5 s (Supplementary Figure 2). Open/slack lower jaw, stiffening of the peduncle, dorsal fin flutter and right eye open occurred immediately (<1 s) after the first shot was dispatched. The right eye remained open for the rest of the 4.9-minute video. Dorsal fin fluttering lasted for 3 s and then ceased, it restarted 4.5 s after the final shot and continued for most of the next 272.5 s (4.5 minutes). Relaxation of the epaxial musculature occurred 5.2 s after the final shot followed by body trembling starting 8.8 s after the final shot and continuing for 272.5 s (4.5 minutes). Tail lifting began 19.5 s after the final shot and continued for 9.7 s. Pectoral fin fluttering began 37.8 s after the final shot and continued for most of the next 235.5 s (~4 minutes). Tail fluttering was observed 63 s after the final shot and continued for 218.2 s (Supplementary Figure 2). When the video footage terminated more than 4 minutes after the final shot, body trembling, dorsal fin fluttering, tail fluttering and pectoral fin fluttering remained ongoing (Supplementary Figure 2). Agonal convulsions were not observed in the time of the recording.

The marksperson stated that the shots were fired approximately 10 cm from the animal, aiming from the dorsal surface to the ventrum. The point of aim was mid-way between the blowhole and front insertion of the pectoral fin along the central line of the animal's body. The marksperson estimated time to death to be instant as the “*animal went floppy. Eyes went dull. Head shakes stopped after first shot.*”

Case 3. Long-finned pilot whale

Ballistics was applied using a 30-06 rifle and three 150gr soft projectiles. The animal was not filmed during the initial firearm discharge, therefore, only responses to the second and third shots were examined. The second firearm discharge occurred approximately 45 s after the first (according to the marksperson) and was oriented dorso-ventrally entering caudal to the blowhole. The third shot occurred 115.3 s after the second and was discharged in the lateral orientation, entering mid-way between the eye and insertion of the pectoral fin above eye height. The animal was in lateral recumbency out of the water on the beach during both shots. Examination of criteria for verifying unconsciousness/death was not observed on the intermittent video footage collected following the application of ballistics.

Video footage of the euthanasia procedure and the animal's responses was not continuous. The first video began 7.4 s prior to the second firearm discharge and lasted 12 s (Supplementary Figure 3). The second video began 80 s later, 40.2 s prior to the third firearm discharge, and was 49 s in length (Supplementary Figure 3). This provided one minute of intermittent video footage over a total time period of 2.2 minutes following the second shot.

In the 7 s prior to the second shot, respiration, open/slack lower jaw, body tensing and fluttering of the dorsal fin, left pectoral fin and tail were all evident. Immediately following the second shot, peduncle stiffening occurred, lasting for 1.9 s. Fluttering of the left pectoral fin and tail continued following this tonic spasm until the end of the first video (1.7 and 2.8 s, respectively; Supplementary Figure 3). Prior to the third shot, respiration, body tensing and trembling were observed in addition to fluttering of the dorsal fin, left pectoral fin and tail. Respiration was observed 78.8 seconds following the second shot and 36.5 seconds prior to the third shot. The animal also displayed tail side to side for 1.8 s, and tail lift for 10 s, prior to the final shot; during these movements the peduncle was curved ventrally. On application of the third shot, the lower jaw appeared to tighten and then became slack again immediately. All movements ceased on application of the third shot except for tail fluttering which continued until the video ended 4.8 s later (Supplementary Figure 3). Agonal convulsions were not observed in the intermittent video footage. Notably, rhythmic movement of the

skin on the ventrum medial to the left pectoral fin, indicative of heart-beat, was noted until the end of the video.

The marksperson stated that the three shots were fired approximately 50–80 cm from the animal. According to the marksperson, the aim for the dorso-ventral orientation used the blowhole as a reference point and was angled at 10° backwards. For the lateral orientation, the eye was used as a point of reference with the aim being a third of the way between the eye and the pectoral fin and angled at 10° caudal. The marksperson estimated time to death to be 45 s from the first shot (i.e., immediately following the second shot) based on the “*initial exhalation, fibrillation ceased at the junction with the flipper and no reaction to touching the eye*”

Case 4. Long-finned pilot whale

Ballistics was applied using a 30-06 rifle and three 150gr soft projectiles. All shots were applied in dorso-ventral orientation, entering caudal to the blowhole. The animal was in ventral recumbency out of the water on the beach during the initial shot but rolled slightly (of its own accord) to be in lateral recumbency prior to the subsequent two shots. Examination of criteria for verifying unconsciousness/death was not observed on the intermittent video footage collected following the application of ballistics.

The video footage was not filmed continuously. The first video began 6.8 s prior to the first firearm discharge and lasted 15 s (Supplementary Figure 4). The second video began 136 s later, 6.6 s prior to the second shot and lasted 13 s. The final video began 92 s later, 14.6 s prior to the third shot and was 20 s in length (Supplementary Figure 4). This provided intermittent footage over a total time period of 4.6 minutes (Supplementary Figure 4). The time between the first and second shot was 135.8 s (2.3 minutes) and between the second and final shot was 100.0 s (1.7 minutes). For the first and second shots, the tail fluke was not observable on the video footage, hindering assessment of tail-related behaviours.

In the 7 or so seconds prior to the first shot, dorsal fin and right pectoral fin fluttering and respiration were observed. Dorsal fin fluttering ceased briefly on application of the first shot but then began again almost immediately (<1 s) and continued for 7.8 s, whereas pectoral fin fluttering continued. Immediately (<1 s) following the first shot, agonal convulsions began and lasted for 6 s. Similarly, slack lower jaw occurred 1.5 s after the initial shot. Following agonal convulsions, the animal rolled into lateral recumbency. Peduncle stiffening began 2.3 s after the shot and lasted for 5.8 s, at which point the video ended (Supplementary Figure 4).

In the time filmed prior to the second and third shots no behaviours were observed. Following both shots, peduncle stiffening began immediately and lasted for 2.5 and 2 s respectively, while dorsal fin flutter began immediately and lasted for ca. 1 s in both cases. Terminal exhalations were audible following the initial and second shot; these began 1 and 2 s post-shot, respectively.

The marksperson stated that the three shots were fired approximately 50–80 cm from the animal. According to the marksperson, the aim for dorso-ventral orientation used the blowhole as a reference point and was angled at 10° backwards. The marksperson estimated time to death to be instant after the first shot based on the “*initial exhalation, fibrillation ceased at the junction with the flipper and no reaction to touching the eye*”.

Case 5. Short finned pilot whale

Ballistics was applied using an 8x57 mm rifle and one 170gr Woodleigh hydrostatically stabilised projectile. The animal was in ventral recumbency out of the water on the beach during the shot. A single firearm discharge occurred in dorso-ventral orientation, with the marksperson standing to the left side of the animal’s head, angled straight down along the animal’s dorsal midline, aiming caudal to the blowhole. The shot entered caudal to the animal’s blowhole. The corneal reflex was tested 34.5 s post application of ballistics, verifying animal

unconsciousness (corneal reflex was absent). Nine animal behavioural responses were characterised following application of the shot (Supplementary Figure 5).

Tail lift, terminal exhalation and peduncle stiffening occurred immediately (<1 s) post-shot, with tail lifting occurring for < 0.5 s and the peduncle remaining in tonic contraction for 2 s. The right eye, which had been closed, was observed open 1.3 s following application of ballistics and remained open for the rest of the video footage (8.2 minutes). The lower jaw became slack 4.5 s after the shot and relaxation of the epaxial musculature occurred 15.6 s post-application. Dorsal fin fluttering, which was observed prior to application of ballistics, occurred intermittently for 14.8 s following the shot. Notably, right pectoral fin fluttering, which was not observed prior to application of ballistics, began occurring immediately after the shot and this fluttering continued intermittently for a total of 2 minutes over a period of 4.2 minutes post-shot.

The marksperson stated that the shot was fired approximately 5 cm from the animal, aiming from the dorsal surface to the ventrum. The point of aim was the caudal area of the skull towards the occipital condyles; this was assessed using the anatomical landmark of being “*one third of the way back from the blowhole to the front edge of the front flipper*”. The marksperson stated that they estimated time to death to be instant based on observation that the animal “*lay still after initial shock of bullet. Eye checked after 5–10 s: no sign of life seen.*” The marksperson also noted that the projectile used exited the animal “*at midpoint on vertical axis*” and was found approximately 20 cm deep in the compact sand under the animal.

Case 6. Short finned pilot whale

Ballistics was applied using an 8x57mm rifle and one 170gr Woodleigh hydrostatically stabilised projectile. The animal was in lateral recumbency out of the water on the beach during the shot. A single firearm discharge occurred in dorso-ventral orientation, with the marksperson kneeling to the left side of the animal’s head, aiming along the animal’s dorsal midline caudal to the blowhole. The shot entered caudal to the animal’s blowhole. The corneal reflex was tested 27.2 s post-application of ballistics, verifying animal unconsciousness (reflex was absent). Six animal behavioural responses were characterised following application of the shot (Supplementary Figure 6).

Tail lift, tail flutter and peduncle stiffening occurred immediately (<1 s) post-shot, with peduncle remaining in tonic contraction for 3.2 s. Tail fluttering and tail lift continued during the peduncle stiffening and then ceased. Tail lifting and peduncle stiffening occurred as a ventral curvature. Relaxation of the epaxial musculature occurred 5.5 s post-application of ballistics, additionally the tail fluke was observed to relax 15.2 s after the shot. Right pectoral fin fluttering, which was observed prior to application of ballistics, ceased < 1 s after the shot but began again 25 s later and continued for 5.5 s at which point the video footage ended. The eye and lower jaw could not be observed due to the angle of filming.

The marksperson stated that the shot was fired approximately 5 cm from the animal, aiming from the dorsal surface to the ventrum. The point of aim was the caudal area of the skull towards the occipital condyles; this was assessed using the anatomical landmark of being “*mid-point between the blow hole and the front edge of the front flipper*”. The marksperson stated that they estimated time to death to be instant based on observation that the “*whale lay still after initial shock of bullet. Eye checked after 5 s; no sign of life seen*” The marksperson also noted that the projectile used exited the animal “*at midpoint on vertical axis*”.

Case 7. False killer whale #1

Ballistics was applied using a 30-06 calibre rifle and two soft point projectiles of 140gr or 186gr. The animal was in ventral recumbency out of the water on rocks during the shots. Two firearm discharges occurred with the marksperson standing in front of the animal’s head, angled at 45° in dorso-ventral orientation along the animal’s dorsal midline,

aiming caudal to the blowhole. The shots entered approximately 20 cm caudal to the animal's blowhole. Examination of criteria for verifying unconsciousness/death was not observed on the video footage collected following the application of ballistics.

Eight animal behavioural responses were characterised following application of the shot (Supplementary Figure 7). Peduncle stiffening and slack lower jaw occurred immediately (<1 s) following the first shot, with the peduncle remaining in tonic contraction for 3 s. The right eye, which had been closed, was observed open 3.3 s following the first shot and remained open for the rest of the video footage (2 minutes). Terminal exhalation occurred 2.3 s after the first shot and tail fluttering, which began prior to the application of ballistics, ceased 2 s after the first shot.

The second shot occurred 5.3 s after the initial dispatch. Relaxation of the epaxial musculature occurred 11 s after this second shot. Notably, head twitching, which was not observed prior to application of ballistics, began occurring 86.7 s after the second shot and continued for 1.5 s.

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s after the first shot, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 8. False killer whale #2

Ballistics was applied using a 30-06 calibre rifle and two soft point projectiles of 140gr or 186gr. The animal was in lateral recumbency in shallow water (<0.5 m) among rocks during the shots. Two firearm discharges occurred in lateral orientation, with the marksperson standing to the right side of the animal's head, angled laterally, aiming caudal to the eye. The shots entered approximately 20 cm caudal to the animal's eye. Examination of criteria for verifying unconsciousness/death was not observed on the video footage collected following the application of ballistics.

A total of 10 animal behavioural responses were characterised following application of the shot (Supplementary Figure 8). Peduncle stiffening and slack lower jaw occurred immediately (<1 s) following the first shot, with the peduncle remaining in tonic contraction curved ventrally for 2.5 s. The right eye, which had been closed, was observed open 4.8 s following the first application of ballistics and remained open for the rest of the video footage (2 minutes). Tail lifting, which began prior to the first shot, and tail fluttering, which began 5.3 s after the first shot, occurred intermittently throughout the 2 minutes of video footage. Right pectoral fin fluttering began 2.3 s after the first shot and was observed almost continuously throughout the rest of the footage.

The second shot occurred 5.5 s after the first dispatch and peduncle stiffening with ventral curvature followed immediately (<1 s), lasting for 3.3 s. Notably, the open lower jaw did not remain slack, closing 21.8 s after the second shot and staying closed for the remainder of the 2-minute video. The animal began whole body thrashing 24 s post-application of the second shot and rolled itself into dorsal recumbency, where it remained for 2.5 s before rolling back into lateral recumbency.

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 9. False killer whale #3

Ballistics was applied using a 30-06 calibre rifle and one soft point projectile of 140gr or 186gr. The animal was in lateral recumbency out of the water on rocks during the shots. The firearm discharge occurred in lateral orientation with the marksperson standing in front and to the right of the animal's head, angled straight down, aiming caudal to the eye. Examination of criteria for verifying unconsciousness/death was

not observed on the video footage collected following the application of ballistics.

Eight animal behavioural responses were characterised following application of the shot (Supplementary Figure 9). Peduncle stiffening, tail lifting and fluttering, and open right eye occurred immediately (<1 s) following the shot, with the peduncle remaining in tonic contraction for 3.3 s. Peduncle stiffening occurred in dorsal curvature. The right eye remained open for the rest of the video footage (44 s). Terminal exhalation occurred 1.3 s after the shot and slack lower jaw was observed 4 s after the shot.

Notably, tail fluttering continued to occur intermittently throughout the 44 s video footage after the shot, and tail lifting started again 41.8 s post-application of ballistics. Whole body movements including side to side rocking and tensing of the body occurred 10.5 and 40 s after the shot, respectively. Visible heartbeat, based on movement of the ventrum medial to the left pectoral fin, remained observable until the end of the video footage (44 s).

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 10. False killer whale #4

Ballistics was applied using a 30-06 calibre rifle and one soft point projectile of 140gr or 186gr. The animal was in ventral recumbency out of the water on rocks during the shots. The firearm discharge occurred in dorso-ventral orientation, with shot entry caudal to the blowhole, however this happened prior to video footage beginning. Based on 28 s of video footage that began at some point after the application of ballistics, criteria for verifying unconsciousness/death were not observed to be examined.

Five animal behavioural responses were characterised following the shot (Supplementary Figure 10), but the time at which these occurred in relation to the shot remains unknown. Additionally, due to the angle of video footage collection the mouth and eyes were not observable in this animal.

From the start of the video footage (post-ballistics), the animal displayed whole body thrashing for 5.7 s, and tail lifting and fluttering for 14 s. Tail lifting and fluttering began again 8 s later and occurred continuously for approximately 3 s at which point the video footage ended. Dorsal fin fluttering began 8 s after the video footage started and continued for 9.5 s, paused but then restarted 5 s later and continued until the end of the video footage (2.3 s later). Whole body shaking (tremors) lasting 1.8 s began to occur 23 s after video footage began.

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 11. Bottlenose dolphin

Ballistics was applied using a 30-06 calibre rifle and two soft point projectiles of 140gr or 186gr. The animal was in ventral recumbency out of the water on rocks during the shots. Two firearm discharges occurred in lateral orientation, with the marksperson standing to the right of the animal's head, aiming caudal to the eye. The shots entered approximately 10 cm caudal to the animal's eye. Examination of criteria for verifying unconsciousness/death was not observed on the video footage collected following the application of ballistics.

Seven animal behavioural responses were characterised following application of the shot (Supplementary Figure 11). Peduncle stiffening and slack lower jaw occurred immediately (<1 s) following the first shot, with the peduncle remaining in tonic contraction for 8 s. Tail lift began with peduncle stiffening and continued for 9.8 s. Agonal convulsions began 1.3 s after the first shot and lasted for 8.7 s. Terminal

exhalation occurred 1.5 s after the first shot. The right eye was observed open 5 s post-application of ballistics and remained open for the rest of the video footage (1.3 minutes).

The second shot occurred 10.8 s after the first and was followed immediately by peduncle stiffening which lasted for 1 s. Relaxation of the epaxial musculature occurred 6 s post-application of the second shot (16.8 s after the first shot).

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 12. False killer whale #5

Ballistics was applied using a 30-06 calibre rifle and two soft point projectiles of 140gr or 186gr. The animal was in lateral recumbency out of the water on rocks during the shots. Two firearm discharges occurred in dorso-ventral orientation, with shot entry caudal to the blowhole. Criteria for verifying unconsciousness/death were not observed to be examined on the video footage collected.

Eight animal behavioural responses were characterised following application of the shot (Supplementary Figure 12). Peduncle stiffening, slack lower jaw and left eye opening occurred immediately (<1 s) following the first shot, with the peduncle remaining in tonic contraction for 1.5 s. The left eye remained open for the rest of the video footage (2 minutes). Terminal exhalation occurred 1.5 s after the first shot. Left pectoral fin fluttering began immediately after the initial shot and continued for 2.7 s.

The second shot occurred 6.8 s after the first and was followed by relaxation of the epaxial musculature 2.5 s later (9.3 s after the first shot). Dorsal fin and tail fluttering began 18.5 and 21.8 s after the second shot, respectively. Both behaviours occurred intermittently for the rest of the video footage, with a bout of 39 s of tail fluttering beginning 77 s after the initial shot. Notably, an assumed heartbeat — based on rhythmic movement of the ventrum medial to the left pectoral fin — remained visible in this animal until video footage ceased 2 minutes after the initial shot occurred.

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 13. False killer whale #6

Ballistics was applied using a 30-06 calibre rifle and three soft point projectiles of 140gr or 186gr. The animal was in lateral recumbency out of the water on rocks during the shots. Two firearm discharges occurred in lateral orientation, followed by a third in dorso-ventral orientation. Lateral shots entered caudal to the eye and the dorso-ventral shot caudal to the blowhole. Criteria for verifying unconsciousness/death were not observed to be examined on the video footage collected.

A total of 11 animal behavioural responses were characterised following application of the shot (Supplementary Figure 13). Peduncle stiffening, tail lifting and right eye opening occurred immediately (<1 s) following the first shot, with the peduncle remaining in tonic contraction for 5.5 s, while tail lifting lasted for < 1 s. The right eye remained open for the rest of the video footage (2.4 minutes). Tail and pectoral fin fluttering, which began prior to the first shot, ceased immediately following application of ballistics. However, these fluttering behaviours and dorsal fin fluttering then recommenced 6.5, 13.5 and 22.5 s after the first shot and continued until after the second shot.

The second shot occurred 22.5 s after the first and was followed immediately (<1 s) by peduncle stiffening and slack lower jaw; peduncle stiffening lasted 14 s. Terminal exhalation occurred 1.2 s after the second shot. Tail lifting occurred 3.8 s post-shot and continued for 11.5 s. Notably, in this time the slack lower jaw was observed to close 10.3 s

after the second shot. This was followed by whole body thrashing which began 16 s after the second shot (38.5 s after the first shot) and occurred continuously for 8.8 s. When this thrashing ceased the peduncle remained stiffened in a tonic contraction for 8 s.

The marksperson applied a third shot during the tonic contraction, 30.5 s after the second shot and 53 s after the initial shot. Terminal exhalation and slack lower jaw occurred immediately after this third shot, and relaxation of the epaxial musculature occurred 9 s later. Dorsal and pectoral fin fluttering, and tail lifting ceased within 2.5 s of this third shot. However, tail fluttering continued for 6.5 s, ceased and then restarted 25.5 s later, occurring continuously for 42 s. Notably, a visible heartbeat (rhythmic movement of the ventrum medial to the left pectoral fin) could still be observed when the video footage ended 2.4 minutes after the initial shot.

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson estimated time to death to be between 0 and 30 s, stating that “a big exhale could be heard when you got it just right the first time. Tapping of the eye was used to check if animal was dead”.

Case 14. False killer whale #7

Ballistics was applied using a 30-06 calibre rifle and one soft point projectile of 140gr or 186gr. The animal was in shallow (ca. 0.5 m) water and was shot prior to video footage being undertaken. When filming began, and throughout the video footage until filming stopped (>1.5 minutes), the animal was in ventral recumbency continuously thrashing the whole body (Supplementary Figure 14). Due to the amount of animal movement and concern for human safety, no additional shots were fired until the animal stopped moving at least 4 minutes after the initial shot (according to the marksperson); this second shot was not observed on the video footage.

The marksperson stated that the shots were fired approximately 0.5–1 m from the animal, using the blowhole as an anatomical landmark. The marksperson stated that after the initial shot the “animal was presumed dead but wasn't and started thrashing round and couldn't be shot again until it stopped, time to death approximately 4 min”.

3.1. Estimated time to unconsciousness/insensibility (TTI) and time to death (TTD)

Table 3 presents a summary of the estimated time to unconsciousness based on (1) behavioural observations from the video versus (2) those reported by the markspersons. Based on observations of behaviour from the videos, 66.7 % of animals for which an estimate could be made ($n = 12$) were likely unconscious within 30 s of the initial shot; half of these (4/12; 33.3 %) were likely unconscious within 10 s. The remaining animals for which TTI could be estimated appeared to still be conscious 30 s after the initial shot, and half of these (2/12; 16.7 %) were likely still conscious after one minute. In only two out of 14 (14.3 %) cases was loss of consciousness confirmed on video using reflex testing – in both scenarios, this occurred approximately 30 s after the initial shot, although it was reported by the marksperson to occur much sooner.

Only two of the 14 animals (14.3 %) were apparently dead within 30 s of the first shot. Nine animals (64.3 %) were definitely still alive 60 s after the first shot. Seven of the 13 animals for which minimum TTD could be estimated from video (53.8 %) were still alive two min after the first shot, four (30.8 %) were still alive 3 min after the first shot and two (15.4 %) were still alive 5 min after the first shot.

In most cases, markspersons' reports of time to death were inconsistent with time to death estimates based on filmed behaviour (91.7 % of 12 cases for which consistency could be judged); in all such cases, death was reported to occur more quickly than was suggested by behaviour. However, markspersons' reports of TTD were often consistent with estimates of TTI based on behaviour: 81.8 % of the 11 reports for which consistency could be judged were consistent. In the other two cases, where TTD was inconsistent with TTI, both reports suggested

Table 3

Estimated time to unconsciousness/insensibility (TTI) or death (TTD), based on filmed behaviour versus retrospective reports of markspersons. Observed TTI was categorized as: Immediate < 10 s post-shot; Rapid 10–29.9 s; Delayed 30–60 s; Prolonged > 60 s. Consistency between *reported* estimate for TTD and *observed* estimate (based on behaviour) for TTI and TTD is noted. *Consistent* was assigned when the reported and observed estimates were within 10 s of each other. *No evaluation observed* indicates that the marksperson was not observed to test the animal's reflexes in the video. Projectile types were solid, soft and HS Hydrostatically stabilized. *Eye open* indicates continuous open state till end of video.

Case	No. shots, projectile type and inter-shot interval	TTI (behaviour)	Basis of behavioural estimate	TTD (behaviour)	TTD (reported)	Basis of report	Consistent?	Comments
1	1 solid round nose	Immediate	Open lower jaw Muscle relaxation	≥ 25.5 s	< 1 min	End tail thrash Roll Flipper relaxed Blowhole submerged “Eye closed on close inspection”	TTD UN† TTI UN	Video ended when tail lifting had occurred < 15 s prior. No evaluation observed
2	3 soft; ~10 s intervals	Rapid	Open lower jaw Muscle relaxation	≥ 5 min	Instant	Floppy Eyes dull Head shakes stopped after first shot	TTD No TTI Yes	Flutterings continued at end of video 5 min after first shot No evaluation observed
3	3 soft; First interval 45 s*, second interval ~2 min	Prolonged	Open lower jaw Muscle relaxation immediately after third shot	≥ 3 min	45 s after first shot/ immediately after second	Exhalation Fibrillation at flipper junction stopped “No reaction to touching eye”	TTD No TTI No	Missing data between shots Respiration observed between shots 2 and 3 (78.8 s post second shot) Flutterings and heart rate continued at end of video ~3 min after first shot No evaluation observed (video ended ~10 s after third shot)
4	3 soft; 2 min intervals	Immediate	Open lower jaw Only fluttering behaviour observed post-shot	≥ 5 min	Instant	Exhalation Fibrillation at flipper junction stopped “No reaction to touching eye”	TTD No TTI Yes	Flutterings continued at end of video 5 min after first shot No evaluation observed (intermittent video footage)
5	1 HS	Rapid	Open lower jaw Muscle relaxation	~ 4 min	Instant	Lay still Eye check 5–10 s	TTD No TTI Yes	Flutterings continued until 4 min after first shot Evaluation of reflexes observed ~30 s after shot (confirmed absent)
6	1 HS	Immediate	Muscle relaxation Only fluttering behaviour observed post-shot	~ 30 s	Instant	Lay still Eye check 5 s No sign of life	TTD No TTI Yes	Flutterings continued at end of video 30 s after shot Evaluation of reflexes observed ~30 s after shot (confirmed absent)
7	2 soft; 5 s interval	Rapid	Open lower jaw Muscle relaxation	≥ 1 min	0–30 s	Big exhale “Tapping eye used to check if dead”	TTD No TTI Yes	Head twitch > 1 min after final shot No evaluation observed (2 min video)
8	2 soft; 5 s interval	Prolonged	Open lower jaw (closed and remained closed) Last active behaviour (tail lift)	≥ 2 min	0–30 s	Big exhale “Tapping eye used to check if dead”	TTD No TTI No	Flutterings continued at end of video 2 min after first shot Lower jaw remained closed at end of video No exhalation seen on video No evaluation observed
9	1 soft	Delayed	Open lower jaw Last active behaviour (tail lift)	≥ 44 s	0–30 s	Big exhale “Tapping eye used to check if dead”	TTD No TTI Yes	Flutterings, tail lift and heart rate continued at end of video 44 s after first shot No evaluation observed
10	1 soft	Unknown	No key behaviours observed	≥ 30 s	0–30 s	Big exhale “Tapping eye used to check if dead”	TTD No TTI UN	Missing data (shot not captured on video) No key behaviours observed No evaluation observed
11	2 soft; 10 s interval	Rapid	Open lower jaw Muscle relaxation	~ 17 s	0–30 s	Big exhale “Tapping eye used to check if dead”	TTD Yes TTI Yes	No fluttering behaviour No evaluation observed

(continued on next page)

Table 3 (continued)

Case	No. shots, projectile type and inter-shot interval	TTI (behaviour)	Basis of behavioural estimate	TTD (behaviour)	TTD (reported)	Basis of report	Consistent?	Comments
12	2 soft; 7 s interval	Immediate	Open lower jaw Muscle relaxation	≥ 2 min	0–30 s	Big exhale “Tapping eye used to check if dead”	TTD No TTI Yes	Flutterings and heart rate continued at end of 2 min video No evaluation observed
13	3 soft; First interval 20 s, second interval 30 s	Delayed	Open lower jaw (closed again, open again after third shot) Muscle relaxation after third shot	≥ 2.4 min	0–30 s		TTD No TTI Yes	Final behaviour occurred > 2 minutes after initial shot Heart rate continued at end of video 2.4 min No evaluation observed
14	2 soft; ~4 min interval*	Unknown	No key behaviours observed	Unknown	~4 min	Moved for > 4 min after first shot. Presumed dead after first shot but started thrashing.	TTD UN TTI UN	Neither shot captured on video No key behaviours observed Thrashing for entire 1.45 min video

† UN (unknown) was assigned for consistency when reported TTD may have been within 10 s of observed TTD or TTI but this could not be ascertained because the video ended while behaviour continued, the reported range for TTD was too broad or when TTI could not be estimated from behaviour because of missing video.

* Inter-shot interval reported by marksperson; no video of first shot.

death occurred more quickly than unconsciousness was judged to have occurred from the videos.

4. Discussion

This study revealed several welfare-relevant concerns relating to the application of ballistics. In particular, these were the apparent failure to immediately and systematically verify unconsciousness/death following shooting and the use of soft/deformable projectiles. Neither failure aligns with international best practice standards and/or requirements outlined in the DOC SOP for stranded cetacean management (Boren, 2012; Boys et al., 2022a). In addition, most reports of estimated time to death did not align with estimates based on animals filmed behavioural responses.

4.1. Assessing the welfare performance of ballistics as a euthanasia method for stranded cetaceans

Currently, two behavioural indicators are suggested for verifying unconsciousness in cetaceans, to be used in combination with physiological indicators: unprovoked agonal convulsions and a slack lower jaw (Barco et al., 2016; Boys et al., 2022a; Brakes et al., 2006; Butterworth et al., 2004b). In farmed mammals, agonal convulsions are considered to be indicative of spinal cord dysfunction (Dawson et al., 2007; Erasmus et al., 2010), while loss of jaw and overall muscle tone are taken to reflect loss of cerebral cortex control (EFSA et al., 2013, 2020; Erasmus et al., 2010; Saxmose Nielsen et al., 2020).

In this study, 79 % of animals displayed either or both continual slack/open lower jaw or relaxation of the epaxial musculature in the video footage available following shooting. In contrast, agonal convulsions were only observed in three of the 14 animals; this always occurred during approximately the same timeframe as the other two behaviours. Thus, time to unconsciousness/insensibility (TTI) was estimated using open lower jaw and/or relaxation of the epaxial musculature following the first shot.

However, in some cases it was necessary to evaluate subsequent behaviour to be sure that time to irreversible unconsciousness was estimated. Farmed animals may not be irreversibly unconscious even after displaying loss of jaw and muscle tone (Grandin, 2002). A few cetaceans showed slack jaw and/or body relaxation followed only by fluttering behaviours or by fluttering behaviours, peduncle stiffening and terminal exhalation. In these cases, the final incidence of slack jaw or body relaxation was taken as the point of irreversible unconsciousness

because these other behaviours do not appear to reliably indicate consciousness/unconsciousness.

Fluttering behaviours probably reflect spinal cord dysfunction and are likely involuntary (Erasmus et al., 2010; Kline et al., 2019). This is supported by the fact that fluttering of various body parts continued after confirmation of unconsciousness in the two animals for which absent reflexes were verified. Similarly, Boys et al. (2024) observed that fluttering behaviours continued following loss of the corneal reflex and when brainstem disruption was evident in euthanised cetaceans. When peduncle stiffening and terminal exhalations were displayed by an animal in this study, they happened immediately and simultaneously after almost every shot. Sometimes, they were followed by a range of other behaviours, some apparently purposeful. Thus, they seem to be direct responses to being shot, rather than reliable indicators of consciousness/unconsciousness, although the animal was obviously still alive when they were displayed.

In farmed mammals, return to consciousness following slack jaw and muscle relaxation can be indicated by the presence of a righting reflex, which indicates cerebral cortex control, proprioception, and muscular tone (Grandin, 2002; Leary et al., 2020). In the present study, a number of animals displayed tail lifting that was not associated with agonal convulsions or peduncle stiffening, after having exhibited a slack jaw and/or muscle relaxation; this may have represented a righting reflex. Others closed their jaw again once it had become slack after the initial shot. These cases may have represented a return to consciousness/sensibility, therefore irreversible unconsciousness was conservatively estimated as the time at which the last tail lift (following the final display of slack jaw and/or muscle relaxation) was observed.

On the basis of these indicators, two-thirds of the 12 cetaceans for which time to unconsciousness/insensibility (TTI) could be estimated, were likely to have become irreversibly unconscious within 30 seconds of the initial shot and one-third within 10 seconds. The other four were likely conscious/sensible for longer than 30 seconds, with two of these likely sensible for more than a minute. Generally, these results suggest that most of the animals had what might be considered a relatively ‘good death’ in that they were only capable of welfare impacts associated with shooting for seconds to minutes (Baker et al., 2016; Hampton et al., 2022, 2016). However, most animals were not rendered instantaneously unconscious, as is the goal with ballistics killing, and accordingly improvements in the humaneness of the procedure are recommended. As a comparison, these results would fail to meet the highest standard for acceptable welfare performance of lethal traps; this would require that no more than 1 in approximately 12 test animals was still conscious

30 seconds after the killing action was applied (NAWAC, 2019). Improvements in the welfare performance of ballistics application in this context might be achieved by consistently and systematically verifying irreversible unconsciousness and by following national and international recommendations for the type of projectile used.

4.2. How consistent were reported times to unconsciousness/death?

Despite being mandated in the SOP, only two of the 14 animals were apparently checked to verify unconsciousness following shooting. A similar deficiency has been noted in studies of seal hunting in other countries (Butterworth and Richardson, 2013). When reflex testing did occur, it was not done immediately following the shot as was reported, but typically 30 seconds later. The SOP does not state specifically when verification should occur (Boren, 2012), which may lead to these checks becoming deprioritized. However, failure to confirm unconsciousness promptly increases the risk of additional animal welfare compromise if subsequent shots are not applied to conscious animals or conversely, may increase the risk to human safety if additional shots are applied unnecessarily.

The reasons for the apparent failure to verify unconsciousness in most cases are not clear. One marksperson stated that it seemed inappropriate when iwi (local indigenous Māori) were present. This indicates that at least in this instance, the marksperson was aware of the requirement to verify unconsciousness/death, but concerns of human perceptions/sensitivities overrode animal welfare considerations (Boys et al., 2022a; Stockin et al., 2022). It is also possible that markspersons were reluctant to approach or touch the animals following shooting. Killing animals, especially those considered to have similar cognitive, social and emotional abilities to humans such as cetaceans, can cause distress (Bennett and Rohlf, 2005; Stockin et al., 2022; Yeung et al., 2021), which may have deterred the shooters from completing the recommended verification.

In almost all cases, time to death was reported to occur sooner than was estimated via behavioural video analysis. While approximately 80 % of animals were reportedly dead instantaneously or within 30 seconds, only two were observed to be so. More than half the animals were unequivocally still alive two minutes after the first shot, about a third after three minutes and two after five minutes, despite additional shots being applied to some. In many cases, behaviour was still occurring at the end of the recorded period, meaning it was not possible to estimate the actual time to death.

Rather, reported times to death appeared to align better with our estimates of time to unconsciousness/insensibility (TTI) based on behaviour. While this does not seem problematic in practice, the criteria reportedly used by markspersons to recognize 'death' do not demonstrate clear understanding of either unconsciousness or death. For example, for one animal the marksperson estimated time to death based on observing fibrillation had stopped at the junction with the flipper, but rhythmic movement of the ventrum, indicative of heartbeat, was still evident on the video following the third shot, nearly two minutes later. Overall, few of the internationally recognised criteria for verifying unconsciousness in cetaceans were reported. Instead, markspersons reported using indicators including 'eyes closed', 'dull eyes', 'big exhale' and 'animal went floppy', some of which are not included in the SOP. In the case of the seven false killer whales, the reported time to deaths and other information in the reports were identical for every animal, suggesting that details of euthanasia were not recorded individually. These findings highlight inconsistencies in the assessment and interpretation of indicators of unconsciousness/death and emphasise the importance of open discussions and additional regular, ongoing training. Mass stranding events are logistically complex but recording details of euthanasia for each individual animal should be a priority for both animal welfare and human safety. We recognise this is difficult under current personnel resourcing at mass strandings but urge this be an imperative consideration to ensure international best practice animal

welfare standards are upheld.

4.3. How effectively was ballistics applied?

The procedures and equipment employed for ballistics euthanasia influences the efficacy of killing in terms of degree and rapidity of brain damage and irreversible unconsciousness (DeNicola et al., 2019; Gilliam et al., 2012; Lund et al., 2021; Millar and Mills, 2000). In this study, similar firearm calibres (.30) were as recommended, employed for all the animals (Hampton et al., 2014). However, varying projectile characteristics were reported. The most common use of soft point projectiles aligns with the current NZ SOP (Boys et al., 2022a, 2021). However, this contrasts with international best practice which recommends the use of only solid projectiles (Hampton et al., 2014; IWC, 2000; Øen and Knudsen, 2007), a key motivation of current national SOP revisions in preparation (Mike Ogle, DOC, pers. comm.).

The number of projectiles dispatched ranged from 1–3, with varying intervals between shots. In Case 1, all three shots were conducted in quick succession (<10 s intervals) and in the same orientation, suggesting that the decision for three shots was made *a priori*. However, for three other cases, there were protracted intervals between shots. The decision to apply additional shots may have been made in the moment to ensure unconsciousness/death, although systematic verification of unconsciousness was not observed immediately following each shot, as would be expected. Nor was such assessment retrospectively reported by the marksperson involved, and in each case the animal was reported dead before the third shot was applied, an observation not supported by the behavioural data. Both time delays between shots and an apparent lack of systematic assessment of unconsciousness after each shot, risk extended welfare compromise if the animals remained aware until or even following the third shot. Additionally, the application of unnecessary shots greatly increases the risk to human safety.

4.4. Limitations to the study

Due to the stochastic nature of strandings, data collection was undertaken opportunistically and relied on several factors, including the permission of iwi to film, the consent of the marksperson to be filmed and the presence of a second party to record the video footage. This constrained data collected, to only fourteen animals, of the more than 235 that were euthanized in NZ between 2020 and March 2024. These cases represent six different species, with mostly only one or two animals of each being examined. Therefore, the generalisability of our findings may be limited. However, the similar behaviours exhibited among animals in this study and in other studies (Boys et al., 2024, 2023) suggests reasonably consistent behavioural responses to the application of ballistics.

A key limitation of this study was the non-continuous or prematurely truncated nature of the footage available on which to base estimates of time to unconsciousness/insensibility and death. For two animals, very little actual footage was available over the period following shooting. In all cases video recording was terminated prior to certainty of death. Indeed, eight of the animals displayed ongoing behaviour and four still had a visible heartbeat when recording ended. In future studies, at least 10 minutes of continuous video is recommended following the final shot to allow such determination.

5. Conclusions and recommendations

The majority of animals in this study were probably unconscious relatively rapidly (within 30 s) and likely dead within minutes, arguably a more expedited death than would occur naturally following stranding. However, improvements are needed to minimise the potential duration of suffering. Behaviour in conjunction with assessments of unconsciousness via reflex testing and/or electroencephalography (Verhoeven et al., 2015; 2016), supported by post-mortem imaging (e.g., Boys et al.,

2024; Schwenk et al., 2016) are strongly recommended.

Importantly, our study has highlighted that there may be under-emphasis on the importance of systematic verification of unconsciousness/death immediately following application of ballistics using the criteria outlined in the current SOP. We also noted discrepancies between the instantaneous or rapid deaths reported and estimated time to death, with behaviours occurring for minutes in some cases after the time death was reported. Furthermore, in some cases, despite reporting that death of the animals had already occurred, additional shots were applied. Finally, we found that the equipment and application procedure (orientation and angle) used to shoot the animals varied, which can significantly impact killing effectiveness using ballistics. Further research should be undertaken to investigate the severity of brain disruption caused by differing projectile types and in varying species to enable better informed decision-making around equipment used (e.g., Boys et al., 2024).

Further exploration is needed to address the general failure to verify unconsciousness/death following ballistics euthanasia of stranded cetaceans in NZ. We recommend additional training of field personnel on the importance of doing so in every case and the methods of confirming unconsciousness and death. Overall, the findings of this preliminary study contribute to understanding of the welfare implications of ballistics euthanasia for stranded odontocetes.

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CRedit authorship contribution statement

Boys Rebecca M: Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Beausoleil Ngaio J:** Writing – review & editing, Validation, Supervision. **Stockin Karen A:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Institutional Review Board Statement

This project was evaluated by Massey University Animal Ethics Committee and approved under notification numbers 20/10 and 20/27. The project was also evaluated by Massey University Human Ethics Committee and approved under notification number NOR 20/53. Research permits from the New Zealand Department of Conservation were approved following indigenous Māori (Iwi) consultation, under permit numbers 86298-MAR (live animals) and 39239-MAR (biological samples).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2025.106537.

Data availability

Due to the sensitive nature of the data used in this study, raw data remains confidential and cannot be shared.

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