

When and how to say goodbye: An analysis of Standard Operating Procedures that guide end-of-life decision-making for stranded cetaceans in Australasia

Rebecca M. Boys^{a,*}, Ngaio J. Beausoleil^{b,2}, Emma L. Betty^{a,3}, Karen A. Stockin^{a,b,**,4}

^a Cetacean Ecology Research Group, School of Natural Sciences, College of Sciences, Massey University, Private Bag 102-904, Auckland, New Zealand

^b Animal Welfare Science and Bioethics Centre, School of Veterinary Science, College of Sciences, Massey University, Private Bag 11-222, Palmerston North, New Zealand

ARTICLE INFO

Keywords:

Welfare
Death
Euthanasia
Marine mammal
Strandings
Management

ABSTRACT

Standard Operating Procedures (SOPs) are tools used to ensure management best practice during emergency incidents including wildlife interventions, such as cetacean strandings. The compromised state of stranded cetaceans means humane end-of-life decisions may be considered, and SOPs frequently guide this process. This study evaluated SOPs for end-of-life decision-making and technically enacting euthanasia of stranded cetaceans across Australasia. The aim was to highlight similarities and differences in management and explore directions to improve stranded cetacean welfare. SOPs were requested from the eight government authorities across Australia and New Zealand. All SOPs were evaluated for decision-making criteria, yielding 29 parameters for the implementation of end-of-life decisions. Euthanasia and palliative care were options for end-of-life, with palliative care recommended when euthanasia was not feasible or presented human safety risks. Three euthanasia methods were recommended. Ballistics was recommended in seven SOPs, chemicals in five and explosives in three SOPs. Variability existed in the exact procedures and equipment recommended in all three methods. Additionally, only five SOPs provided criteria for verifying death, while only two recommended time-to-death be recorded, hindering evaluation of the welfare impacts of end-of-life decisions and euthanasia procedures. Our findings highlight the need for detailed guidance and consistency in end-of-life decisions and euthanasia techniques to ensure reliable welfare outcomes. Systematic, standardised data collection at euthanasia events across regions is required to facilitate assessment of welfare impacts and develop evidence-based recommendations. International collaboration is key to developing objective criteria necessary to ensure consistent guidance for end-of-life decisions.

1. Introduction

Since the latter half of the 20th century, attention towards animal welfare in wildlife management has increased [1]. Government bodies, such as wildlife and environmental agencies, generally develop and implement Standard Operating Procedures (SOPs) to guide wildlife interventions in the context of animal welfare, human health and safety, management of risk and liability, and to optimise the success of the

intervention procedures. Such SOPs may be employed during interventions such as rescue, rehabilitation and end-of-life management and include descriptions of procedures relating to the capture, restraint, and killing of wild species [2,3]. Consequently, SOPs can have considerable influence on animal welfare, and it is therefore crucial that they are underpinned by quantifiable scientific data.

Fundamentally, SOPs are tools to ensure consistent results in policy and management by providing detailed instructions to an operator on

* Corresponding author.

** Corresponding author at: Cetacean Ecology Research Group, School of Natural Sciences, College of Sciences, Massey University, Private Bag 102-904, Auckland, New Zealand.

E-mail addresses: r.boys@massey.ac.nz (R.M. Boys), k.a.stockin@massey.ac.nz (K.A. Stockin).

¹ <https://orcid.org/0000-0001-6427-800X>.

² <https://orcid.org/0000-0003-4592-0460>.

³ <https://orcid.org/0000-0002-9187-1957>.

⁴ <https://orcid.org/0000-0002-2981-3983>.

<https://doi.org/10.1016/j.marpol.2021.104949>

Received 1 October 2021; Received in revised form 22 December 2021; Accepted 23 December 2021

Available online 18 February 2022

0308-597X/© 2021 Elsevier Ltd. All rights reserved.

how to carry out a specific activity or procedure [4]. The use of SOPs aims to minimise errors and ensure that skills and knowledge are transferrable within a team, which is particularly important where personnel turnover may be high. To ensure that SOPs are followed correctly, they should be written in a clear, objective, and detailed manner to assure uniformity in procedures. This is particularly crucial in wildlife management where inconsistencies or malpractice can create serious risks to human health and safety as well as animal welfare [5–7].

Cetacean strandings have been documented for centuries in most coastal nations [8]. However, in many regions human responses to these events have changed significantly over time, from historical harvesting of animals as a resource to today's desire to rescue and, in some cases, rehabilitate stranded individuals [9–12]. This evolving societal desire has made it necessary for the responsible authorities (i.e., management agencies legislatively responsible for marine mammals) to lead response efforts, mainly to ensure public safety. Managing such obligations is particularly challenging where the risks to human safety or animal welfare are exacerbated by the scale of the event, such as in live mass strandings, and when there is a legal and moral obligation to work in partnership across cultures [13].

Australasia (Australia and New Zealand) has an international reputation for its high incidence of live mass stranding events of long-finned pilot whales (*Globicephala melas edwardii*), which commonly occur on the coastlines of New Zealand and Australia [14–17]. Management of these stranding events can be logistically complex, with extensive public engagement and multiple stakeholders. In many cases, management of such large-scale events is undertaken via a Co-ordinated Incident Management System (CIMS) structure, with the responsible government agencies often implementing SOPs to guide decision-making and provide consistent field responses.

Management options for strandings include providing first aid to stranded cetaceans, refloating animals that are likely to survive, and deciding whether, and when, to euthanise or provide palliative care to animals that are debilitated or have low likelihood of survival, i.e., end-of-life decision-making. Criteria for end-of-life decision-making may include animal-related factors, such as the health and injury status of the animal, the predicted likelihood of survival if refloated, and resource/logistics-related factors such as manpower, human safety, and equipment availability [5]. Therefore, the SOPs implemented during strandings response must consider a range of issues including, but not limited to, animal welfare requirements.

When the decision to end the life of an animal is made, guidance on euthanasia and palliative care procedures is usually included in SOPs. However at a global scale, methods for the euthanasia of stranded cetaceans remain variable, with a lack of knowledge on welfare outcomes [18]. In addition, scientific data to support recommended euthanasia procedures in SOPs, in terms of welfare impacts and efficacy, are limited [19]. In particular, data are needed on the intensity and duration of any welfare impacts occurring before irreversible loss of consciousness [20] as well as on verification of death. This lack of data regarding the welfare implications of euthanasia may be further complicated by the varying availability and cost of equipment as well as differences in regulations between countries [5,19]. This is particularly notable in some areas where there is no centralised advice and/or regulations, which can lead to significant variability in management approaches [5]. This brings into question, at what point is euthanasia chosen over palliative care, and how and why are particular euthanasia methods recommended in cetacean stranding SOPs?

Although many SOPs used in wildlife management include aspects of animal welfare, their development is rarely guided by those with expertise in animal welfare science or with oversight from institutional welfare or ethics committees [21]. Instead, SOPs are assumed to represent 'best practice' for providing a humane outcome based on their adherence to guidelines about the equipment and materials required, and the process of operation [22]. While these input resources (e.g., equipment, resourcing and human safety analysis) do influence

animal welfare outcomes, they alone cannot be used to evaluate animal welfare impacts. Thus, whether the recommended procedures in SOPs result in the best animal welfare outcomes (i.e. as humane as possible) is not always clear and there is value in assessing animal-based outputs (e.g., behaviour, physiological responses) to minimise uncertainty as to the humaneness of recommended/mandated procedures [23].

This study reviewed current management practices for end-of-life decision-making and the euthanasia of stranded cetaceans in the region of Australasia. In undertaking this analysis, we aimed to highlight knowledge gaps and provide recommendations to ensure that procedures can be consistently followed to minimise animal welfare impacts. This was achieved by analysing current SOPs for cetacean stranding events across Australasia. SOPs from all geographical areas that respond to live cetacean stranding events were reviewed to assess (1) if and when end-of-life decisions should be undertaken, (2) methods of euthanasia and palliative care recommended, including any equipment and procedure details provided, and (3) verification of death.

2. Material and methods

Government authorities involved in the development and implementation of SOPs relating to live cetacean strandings within the region of Australasia (Australia and New Zealand) were identified and contacted to request all relevant SOPs. This included one government department SOP from each of the seven territories or states with coastline in Australia and one government department SOP in New Zealand. We used the guidelines and recommendations in the American Veterinary Medical Association (AVMA) Guidelines for the Euthanasia of Animals [20] and Barco et al. [19] to inform the key elements that should be included in SOPs for cetacean strandings where end-of-life decision-making is required. These key elements were the (1) criteria used to make end-of-life decisions and evaluating whether an animal is a suitable candidate for euthanasia or palliative care, (2) methods that should be implemented, including detailed information on procedures and equipment required to successfully undertake euthanasia and (3) process for verifying death, including the combination of criteria for verification post-mortem. We thoroughly reviewed each SOP to extract information on each of these key elements to facilitate comparison across countries and regionally to highlight any deficiencies in SOP guidelines.

Cetacean stranding events vary in their causation, which may include underlying health issues [9], social cohesion [16,24], out-of-habitat and abnormal distribution [25], and human impacts [26]. However, during the stranding event itself, both natural physiological stressors [27] and anthropogenic stressors due to stranding response [28] can occur. These stressors will impact upon the welfare of the animal and affect its survival probability. Based on the understanding of animal-based factors related to strandings and the guidelines for human stranding response [28], we assessed the criteria for end-of-life decision-making identified in the SOPs and collated these into categories. There were four animal-based categories: (1) medical (health e.g., illness, injury), (2) social (e.g., mass stranding, social dependence), (3) behavioural (e.g., swimming ability, re-stranding attempts) and (4) species (e.g., normal distribution, coastal vs oceanic); and one additional category related to human stranding response, which depended on logistical factors (e.g., personnel/equipment availability, weather). Data were subsequently compiled into a matrix to examine the total number of criteria in each category from the eight SOPs and to examine differences among SOPs. Each SOP was further examined to assess whether recommendations of euthanasia or palliative care were provided based on particular categories of end-of-life criteria.

The euthanasia methods provided in the SOPs were categorised based on Barco et al. [19] into chemical and physical methods. The specific procedures and equipment to be used to implement the method were also noted. For chemical methods, this included the types and quantities of chemical agents, administration routes and needle

Table 1
Criteria from seven unique Standard Operating Procedures (SOPs) used to evaluate if and when an end-of-life decision should be made for a stranded cetacean, compiled into four animal-related categories (behavioural, medical, social, species) and one resource-related (logistical) category. Total number of SOPs that included each criterion as indicated by “✓”.

Animal or Resource	Category	Criteria	NZ	WA	SA	VIC	NSW	TAS	NT	# SOPs
Animal	Behavioural	Inability to swim		✓	✓					2
Animal	Behavioural	Persistently re-stranding				✓				1
Animal	Medical	Disabling injuries (dislocated/broken tailstock), deep penetrating injures (thorax, abdomen)	✓	✓	✓	✓	✓	✓		6
Animal	Medical	Absence of reflexes from anus, genital opening, blowhole, tongue, eyes	✓		✓	✓	✓	✓		5
Animal	Medical	Haemorrhaging from mouth, blowhole, genital opening or anus	✓		✓	✓	✓	✓		5
Animal	Medical	Excessive sloughing or blistering of skin over large portion of body	✓			✓	✓	✓		4
Animal	Medical	Poor body condition, obviously thin, emaciated	✓	✓		✓				3
Animal	Medical	Sustained muscle tremors, spasms, lateral or ventral flexion	✓			✓	✓			3
Animal	Medical	Protracted rapid breathing (> 10/min indicates severe stress, physiological abnormality)	✓			✓				2
Animal	Medical	Significant mucus discharge	✓			✓				2
Animal	Medical	Rectal temperature 42 °C or above				✓	✓			2
Animal	Medical	Loss of jaw tone				✓	✓			2
Animal	Medical	Prolapsed or protruding penis				✓	✓			2
Animal	Medical	Poor health			✓				✓	2
Animal	Medical	Fitness compromised by the stranding			✓					1
Animal	Medical	Rectal temperature 40 °C or above						✓		1
Animal	Medical	Rectal temperature less than 35 °C						✓		1
Animal	Social	Maternal dependence	✓	✓	✓	✓	✓	✓	✓	7
Animal	Social	Leader of group that precipitated mass stranding and is unfit			✓	✓				2
Animal	Social	Members of mass stranding that compromise survival of pod (injured, deteriorating)			✓	✓				2
Animal	Social	Social dependence				✓				1
Animal	Species	Coastal species	✓			✓				2
Animal	Species	Outside normal range for species				✓				1
Resource	Logistical	Resources are not available: equipment, people, cost	✓			✓	✓	✓		4
Resource	Logistical	Size too large for refloatation				✓	✓	✓		3
Resource	Logistical	Location is remote limiting access for rescue				✓		✓		2
Resource	Logistical	Weather/sea conditions are dangerous	✓			✓				2
Resource	Logistical	Time since stranding				✓				1
Resource	Logistical	Danger to other animals or humans			✓					1

specifications. For physical methods, this included size of the animal, anatomical landmarks used and energy requirements for penetration of the skull based on equipment type and dimensions. The collated data from each SOP were categorised into method, procedure and equipment and placed into a matrix which was used to examine differences in methods and level of information provided for undertaking euthanasia among SOPs.

Each SOP was examined to understand when palliative care may be undertaken and what procedures were recommended for palliative care of stranded cetaceans. The recommended procedures were compared among SOPs to examine for differences, and to assess how these procedures equated to those in the literature [29]. Palliative care procedures found in the literature include ensuring breathing is unimpeded, protecting from scavengers, making appropriate postural changes, providing shade, assisting in temperature regulation and minimising handling and disturbance [29].

The inclusion and completeness of criteria to verify death and calculate time-to-death following application of palliative care or the euthanasia method in the SOPs were assessed. Any criteria included were compared against those of Barco et al. [19]: absence of heartbeat, lack of jaw tone, absence of reflexes, fixed/dilated pupils, absence of respiration, lack of response to painful stimuli, no capillary refill time and ocular/skin temperature differential. We collated criteria to verify death provided in each SOP and categorised these based on the recommendations, including a category of ‘other’ for criteria provided in SOPs but not included by Barco et al. All criteria were compiled into a matrix, to examine the total number of verification criteria, whether there were differences in criteria applied to assess death among SOPs, and to examine how many criteria in combination are required to verify death in each SOP. The inclusion of recommendations to assess the time-to-death — based on the time from application of palliative care or the euthanasia method until death was verified — was also analysed to examine for differences in potential welfare implications among SOPs.

3. Results

Eight SOPs pertaining to live marine mammal stranding events that included end-of-life decisions for stranded cetaceans were obtained from government agencies across Australasia. These included one national SOP from Department of Conservation, New Zealand (NZ), one territory

and six state government SOPs from Australia, including Department of Land Resource Management Northern Territory (NT), Department of Environment and Science Queensland (QLD), Department of Planning, Industry and Environment New South Wales (NSW), Department of Environment, Land, Water and Planning Victoria (VIC), Department of Environment, Water and Natural Resources South Australia (SA), Department of Parks and Wildlife Western Australia (WA) and Department of Primary Industries, Parks, Water and Environment Tasmania (TAS).

3.1. Criteria for end-of-life decision-making

A total of 29 criteria in five categories were provided for end-of-life decision-making within the eight SOPs. The medical category contained the most criteria (n = 15), followed by logistical (n = 6) and social (n = 4) categories, with two criteria in each of the behavioural and species categories (Table 1). All SOPs contained at least one criterion for end-of-life decision-making. As QLD’s SOP stated that they follow the criteria provided by VIC, we present only the VIC criteria below to avoid duplication (Table 1). Each SOP varied in the categories of criteria provided (Table 1). The SOP with the most criteria, covering all five categories, was VIC, whilst NT outlined the fewest criteria, covering only two categories (social and medical). All SOPs included criteria in the social and medical categories, whilst criteria in the logistical category were included in four SOPs (NZ, VIC, NSW, TAS), criteria in the behavioural category were included in three SOPs (WA, SA, VIC) and criteria in the species category were only included in NZ and VIC SOPs (Table 1).

Importantly, in six of the seven unique SOPs, it was recommended that end-of-life decisions be made if an animal met any one of the animal-based criteria (Table 1). In the VIC SOP, if any one of eight animal-based “veterinary” criteria were met, an end-of-life decision should be made, whilst additional “non-veterinary” criteria were to be considered as part of the triage process. The eight “veterinary” criteria were: maternal dependence, disabling injuries, significant haemorrhage from orifices, rectal temperature above 42 °C, blistering/sloughing of a significant portion of skin, loss of reflexes, loss of jaw tone and prolapse of the penis, and emaciated animals. In all SOPs, the logistical criteria appeared to be important as part of the decision-making process, but alone were not used to recommend an end-of-life decision.

Table 2

National (NZ) and Australian state (WA, SA, VIC, NSW, QLD, TAS) cetacean stranding Standard Operating Procedures (SOPs) that include euthanasia with information provided on the method, procedures and equipment, where “✓” means information is provided, “X” not provided and “NA” not applicable. SA, VIC and QLD followed the WA SOP for ballistics recommendations, but did not contain some of the detailed information (X).

SOP element	Key elements	NZ	WA	SA	VIC	NSW	QLD	TAS
Method	Chemical euthanasia	X	X	✓: VIC SOP	✓	✓	✓	✓
Procedure	Administration route	NA	NA	✓	✓	✓	✓	✓
Procedure	Size of animal	NA	NA	✓	✓	✓	✓	✓
Equipment	Chemical type	NA	NA	✓	✓	✓	✓	✓
Equipment	Quantities	NA	NA	✓	✓	✓	X	✓
Equipment	Needle gauge	NA	NA	✓	✓	X	X	✓
Method	Ballistics euthanasia	✓	✓	✓: WA SOP	✓: WA SOP	✓	✓: WA SOP	✓: WA SOP
Procedure	No. shots recommended	X	✓	✓	✓	X	X	✓
Procedure	Anatomical landmark	✓	✓	✓	✓	✓	✓	✓
Procedure	Angle aim	✓	✓	✓	✓	✓	✓	✓
Procedure	Distance	X	✓	✓	✓	X	X	✓
Procedure	Size of animal	✓	✓	✓	✓	✓	✓	✓
Procedure	Diagrams provided	✓	✓	X	X	X	✓	✓
Equipment	Firearm type	✓	✓	✓	✓	✓	✓	✓
Equipment	Firearm calibre	✓	✓	✓	✓	✓	✓	✓
Equipment	Projectile type	✓	✓	✓	✓	✓	✓	✓
Equipment	Projectile grain	X	✓	✓	✓	X	✓	✓
Method	Explosives	X	✓: Follows Coughran et al. [31]	X	✓: Follows Coughran et al. [31]	X	✓: Follows Coughran et al. [31]	X

In terms of the criteria, all SOPs included maternal dependency, whilst six of the seven unique SOPs (86%) included disabling injuries, and five of the seven unique SOPs (71%) included loss of reflexes and haemorrhaging from orifices (Table 1). Other criteria that were included in almost half ($n = 3$) of the unique SOPs were poor body condition, excessive skin sloughing/blistering over a large portion of the body, sustained muscle tremors, size too large for refloatation and resource availability (Table 1). Criteria relating to rectal temperature were included in three SOPs (VIC, NSW and TAS) but varied in what temperature level would indicate an end-of-life decision (Table 1).

Review of these SOPs suggested that ‘no response’ may be chosen when weather conditions and sea state were dangerous and locations were inaccessible, which could lead to compromised human safety. Decisions for palliative care may be chosen when euthanasia was not feasible, and aside from the aforementioned safety considerations, were recommended based on logistical factors including the size of the animal and lack of appropriate equipment and skilled responders. The size of the animal that would necessitate palliative care rather than euthanasia did vary among SOPs, ranging from animals over 6 m in length in NZ to animals over 8 m in NSW, or with reference to a specific species in VIC (sperm whales *Physeter macrocephalus*). In NZ, one other criterion was also suggested as not conducive to undertaking euthanasia; this was where “significant antagonism” between the Department of Conservation (legislative agency) and local indigenous people (Māori) and/or the public is likely.

3.2. Methods, procedures and equipment for the implementation of stranded cetacean euthanasia

Seven of the SOPs provided information on the methods, procedures and equipment to be used for euthanasia (Table 2). However, the amount of detailed information on the recommended procedures and equipment highlighted differences among SOPs (Tables A.1, A.2, A.3). Although euthanasia was an option in the NT SOP, no information was provided on the euthanasia process itself, aside from stating that veterinary expertise must be involved.

Both chemical and physical means of euthanasia were evident across the SOPs, with physical methods including two techniques: ballistics and explosives (Table 2). While all seven SOPs included a ballistics method, five of the Australian SOPs stated they follow guidelines outlined by WA, which are based on ballistics trials [30], and are herein referred to as the

WA SOP. Similarly, for the five SOPs that included chemical euthanasia, one (VIC) was followed in another state (SA) and is herein referred to as VIC. Three SOPs (WA, VIC, QLD) included the physical method of explosives, all of which followed the guidelines outlined in a peer-reviewed study [31]. Overall, this provided three unique SOPs for ballistics, four for chemical and one for explosives euthanasia.

Aside from availability of equipment and trained personnel, the guidelines for selecting which euthanasia method to employ were also based on animal size. For animals up to 8-m in length chemical methods were recommended, ballistics were suggested for animals up to 9-m. Explosives were suggested as an option for animals that were between 6-m and 13-m in length.

3.2.1. Chemical

Five SOPs included the use of chemical euthanasia. Since two followed the same guidance (SA, VIC), we examined the four divergent SOPs (VIC, NSW, QLD, TAS) for differences. All the SOPs using chemical euthanasia provided information on the euthanising agent to be administered (Table A1). Two different euthanising agents were recommended, pentobarbital and potassium chloride. All five SOPs provided detailed information on the administration route, with three different administration routes identified (intravenous, intracardiac and via the blowhole). However, only VIC and TAS provided information on the needle gauge requirement. Three of the SOPs (VIC, NSW, TAS) further detailed dosages for each of the euthanising agents and additionally stated the use of sedatives prior to the euthanising agent. A total of seven different sedatives were suggested with midazolam and acepromazine being the most frequently recommended (Table A1). All three of these SOPs additionally provided information on the sedative dosages and the two administration routes (intravenous and intramuscular), although only VIC and TAS provided information on the needle gauge requirements. Importantly, sedatives were always required prior to administration of potassium chloride as an euthanising agent, however, only VIC stated the time at which the euthanising agent should be given following sedation.

3.2.2. Ballistics

All seven SOPs included the use of ballistics methods. Since five SOPs followed the same guidance (WA, SA, VIC, QLD, TAS), we examined the three divergent SOPs (WA, NSW, NZ) to highlight differences. All SOPs included the use of rifles for euthanasia via ballistics, with one (NSW)

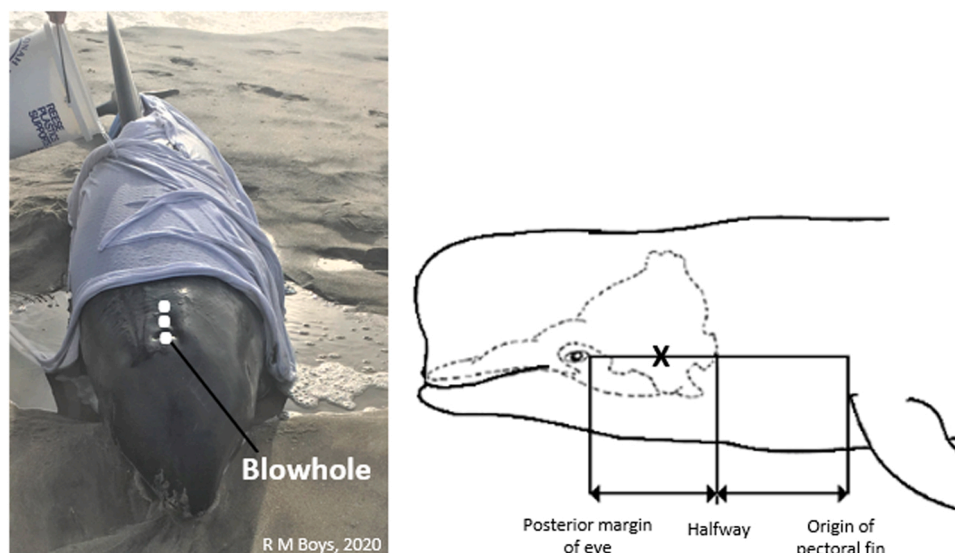


Fig. 1. Recommended landmarks for euthanasia via ballistics for stranded cetaceans, either aiming dorso-ventrally (left), each white dot depicts approximate target point (closest to rostrum: “through the blowhole”, middle dot: “slightly posterior to the blowhole”, furthest from rostrum: “handspan behind the blowhole”), or when aiming laterally (right) [32].

Table 3

Criteria to verify death of cetaceans following application of the euthanasia method that are provided in five cetacean stranding Standard Operating Procedures (NZ, WA, SA, VIC, TAS), where “✓” means the criteria is recommended to be used.

Category from Barco et al. [19]	Criteria	NZ	WA	SA	VIC	TAS
Reflexes	Absence of palpebral and corneal reflexes	✓	✓	✓	✓	✓
Pupil fixed/dilated	Dilation of pupils	✓	✓		✓	✓
Other	Unprovoked agonal convulsions	✓	✓		✓	✓
Lack of jaw tone	Slack lower jaw	✓	✓		✓	✓
Absence heartbeat	Absence of heartbeat	✓		✓		✓
Absence of respiration	Absence of breathing			✓		
Pain reflexes	Absence of deep pain reflexes			✓		

also including the use of a shotgun. Additionally, a total of 11 different firearm calibres were suggested for use across all the SOPs (Table A2). In NSW and NZ SOPs, multiple calibre firearms were suggested depending upon the body length of the animal. The WA SOP (employed in five states) was the only one to provide information on projectile shape that was required (blunt) and further stated that projectiles should be hydrostatically stabilised and solid. This SOP also required the largest projectile mass of 180 grain. The NSW SOP also stated that only solid projectiles should be used for rifles but did not provide required projectile grain. For the use of shotguns, this SOP stated a 28 gm slug or 9-lead pellet buckshot should be used. The NZ SOP was the only one that recommended the use of soft or standard sporting round projectiles instead of solid projectiles but did not provide information on the projectile grain required.

All the SOPs stated that the brain was the target, but three varied in landmarks for this target. Specifically, two SOPs (NSW and QLD) stated that the angle of aim should be “through the blowhole”, the WA SOP stated it should be “slightly posterior to the blowhole” and the NZ SOP suggested aim should be a “handspan behind the blowhole” (Fig. 1). However, all SOPs also stated that a lateral shot undertaken a third to mid-way between the eye and pectoral fin could also be used (Fig. 1). Only the WA SOP provided detail on the number of shots required, this was always three. WA was also the only SOP to provide detail on the distance from the cetacean at which the firearm should be discharged (0.5–1 m).

3.2.3. Explosives

The three SOPs that included the use of explosives (WA, VIC, QLD) all provided the peer-reviewed manuscript [31] in the SOP to enable the procedure to be followed. The method involves employing peri-cranial implosion to destroy the brain of large cetaceans (9–13-m), by constructing a triangular pyramid of explosives that is placed directly above the cranium. The study includes information on the type and amount of explosive required, as well as details on the placement and design of explosive charge (Table A.3). Importantly, the SOPs all note that this method can only be carried out by a licensed shot-firer (explosive detonation expert).

3.3. Procedures for palliative care

All SOPs, except one (WA), provided information on the recommended procedures to be used for palliative care. In all seven SOPs, these recommended procedures included first aid techniques. These procedures were similar to those suggested in the literature [29] and included maintaining the animal upright in sternal/ventral recumbency, cooling the animal by decanting water over the body, provision of shade and/or protection from sun by covering with wet sheets to prevent blistering, and minimising noise. Additionally, the VIC SOP also stated that “judicious use of sedative drugs” may be allowed to reduce animal suffering during the palliative process, with sedatives recommended following those for the euthanasia process (Table A1). The WA SOP was the only one to not provide recommendations for the use of palliative care, although palliative care is mentioned as an option to be considered when evaluating the logistics of the stranding situation.

3.4. Criteria for verifying death

The verification of death was recommended in five SOPs (NZ, WA, SA, VIC, TAS) following the application of euthanasia, with only the VIC SOP also stating that death should be confirmed following palliative care. Additionally, in only two SOPs (WA, NZ) was the time-to-death required to be recorded, although a recording form provided as an appendix in one other SOP (TAS) also contained a section to record time-to-death.

These same five SOPs provided criteria for death and instructed that verification of death be conducted following application of the euthanasia method. A total of seven criteria for verifying death were stated within these SOPs, with all SOPs using a combination of at least three criteria to verify death (Table 3). All five SOPs used absence of palpebral and corneal reflexes, and four of the SOPs (NZ, WA, VIC, TAS) used a further three of the same death criteria: fixed dilated pupils, agonal convulsions and slack lower jaw (Table 3). Only three of the SOPs (NZ, SA, TAS) recommended the absence of a heartbeat as a criterion and only one SOP (SA) suggested absence of breathing and deep pain reflexes as criteria. Six of these criteria for death were included in the recommendations by Barco et al. [19], whilst one criterion (unprovoked agonal convulsions) stated for use in four SOPs was not included in the Barco et al. [19] recommendations.

4. Discussion

Our study reveals several notable differences among SOPs being employed across Australasia for stranded cetacean end-of-life decision-making. The criteria applied for deciding upon end-of-life management for stranded cetaceans were variable among SOPs. Furthermore, there was a lack of detailed information on how to assess or quantify some criteria. When euthanasia was the chosen management option, the broad methods available were similar among SOPs, although varied in the detail provided. Specifically, details on recommended procedures and/or equipment were highly variable and, in some cases, lacking. These findings highlight the need to improve the level of detailed, specific guidance provided within SOPs.

Of particular concern was that only five of the eight SOPs required verification of death and provided criteria to assess death. Only one of these SOPs recommended death be verified following the application of palliative care measures, whilst all five recommended verifying death following application of euthanasia. This is particularly concerning since, without verifying death, there is the possibility that the animal is left alive albeit severely debilitated and injured, significantly impacting welfare. Data on the verification of death and assessment of time-to-death should be routinely and systematically collected to enable an evaluation of any welfare impacts associated with each procedure.

4.1. Criteria for end-of-life decision-making

All SOPs provided some criteria to assess whether an end-of-life decision is required for a stranded animal. Most of the criteria were animal based, with approximately 76% relating to the animal’s welfare state (behavioural, medical, social) and/or being predictive of

Case Study: Management of the stranded killer whale calf “Toa” in New Zealand [34]
<p>“Toa” a 2.15m killer whale (<i>Orcinus orca</i>) estimated to be less than 4 months old [34], with remnant foetal folds, yellow eye patch and no fully erupted teeth [34], stranded on the afternoon of 11th July 2021 in Plimmerton, Wellington, New Zealand (NZ). The animal was cared for by various national organisations as well as public volunteers over a period of 12 days and eventually died on 23rd July, while end-of-life-decision-making was still underway. Several features of the decision-making process for Toa appeared to contradict with the recommendations of the NZ Standard Operating Procedure (SOP).</p> <p>Searches from land and sea conducted during the days following the stranding failed to locate Toa’s pod [34]. From the outset of the stranding and throughout the period of human care, unequivocal national and international advice from experts, including veterinarians, welfare specialists and cetacean biologists, was to euthanise Toa on the grounds of maternal dependency [34]. This concurs with the recommendations in all Australasian SOPs, as well as in wider international guidelines such as National Oceanic and Atmospheric Administration’s Standards for Release [33]. However, the extensive public engagement resulted in Toa remaining under human care, despite the maternal dependency criterion in the NZ SOP. Deviation from the national SOP in this instance likely occurred due to the potential for “significant antagonism” with the public, a rationale detailed in the NZ SOP for not undertaking euthanasia (see Discussion section 4.1 for further details).</p> <p>In addition, the only method of euthanasia recommended in the NZ SOP is ballistics, due to the lack of veterinary personnel within NZ specifically trained to administer chemical euthanasia to marine mammals and concerns about eco-toxicity associated with chemical methods. However, when euthanasia options were considered for Toa from 14th July, chemical methods were proposed because of concerns about public perceptions of ballistics euthanasia. Had this course of action eventuated, it would have further contravened the NZ SOP.</p> <p>Of the Australasian SOPs, only NZ and Western Australia (WA) do not contain recommendations for chemical euthanasia. Despite this, the method was contemplated in this case due to consideration of public perception and the strong media attention. Future attention should be given to how training of personnel to apply chemical methods might be addressed, to facilitate euthanasia when it appears warranted according to the SOP’s current decision-making criteria. The reluctance to promptly euthanise a maternally dependent killer whale and the proposal to use a euthanasia method not recommended in the SOP, highlight how public perceptions and good intentions may, at times, lead to decision-making that is not in the interests of animal welfare. This case highlights the need to review the NZ SOP for stranded cetacean end-of-life decision-making and, specifically, to explore how animal welfare can be prioritised while taking into account public perceptions.</p>

Fig. 2. Case study illustrating end-of-life decisions and consideration of euthanasia methods during a maternally dependent killer whale (*Orcinus orca*) stranding in New Zealand (NZ), with reference to the current NZ Standard Operating Procedure [version 2013; [35]].

survivorship for the individual (behaviour, medical, species, social: maternal and social dependence). Notably, only approximately 20% of the criteria reflected human safety and logistical considerations. Based on the SOPs this only appeared to influence end-of-life management by leading to provision of palliative care rather than euthanasia.

Notably, only one criterion was recommended for use in all SOPs, this being maternal dependency in the social category. This suggests that dependent calves without a presumed mother would always be euthanised, as has been recommended previously [5,33]. Despite this being a unanimous criterion across all Australasian SOPs, there are examples of this not being followed (See Fig. 2 Case Study [34]). The next most recommended criteria were all in the medical category; disabling injuries was recommended in six SOPs, followed by haemorrhaging from orifices and the absence of reflexes, recommended in five of the SOPs. Criteria recommended in four of the SOPs included excessive sloughing/blistering of skin (medical) and resource availability (logistical).

Thus, it seems that most end-of-life decisions are related to the animal itself and largely to its physical health status.

Although no explicit information was provided in the SOPs about the relative weighting of each of the criteria, it is likely that these most recommended criteria have the highest impact on decision-making. Importantly, in all but the VIC SOP, an end-of-life decision was indicated if any one of the animal-based criteria were met. In the VIC SOP, there were eight specific “veterinary” animal-based criteria (out of 18), the observation of any of which indicated an end-of-life decision. These eight criteria included maternal dependence in the social category, and seven others in the medical category.

Logistical criteria were mentioned in all SOPs to guide decisions about whether any intervention could occur at all. All SOPs used logistical criteria to make decisions of palliative care versus euthanasia, with palliative care suggested in situations considered dangerous for personnel or where euthanasia was not feasible due to accessibility or

the large size of the animal. In seven SOPs, recommended procedures for palliative care were provided and these followed those suggested for first aid in the literature [28,29]. These procedures are recommended to minimise animal welfare impacts by reducing the risk of pain or discomfort due to injuries such as dislocations of pectoral joints, blistering of skin and fluid loss when blisters rupture, and hyperthermia [28,29].

Notably, in the NZ SOP another reason for not undertaking euthanasia was presented. Euthanasia was not recommended where “significant antagonism” between the agency legally charged with managing stranding events (Department of Conservation) and members of local indigenous Māori and/or the public may occur. New Zealand law mandates collaborative decision-making between the Crown and local Māori in such situations (e.g., Conservation Act 1987 [36]), but different worldviews about wild animals and animal welfare [37] may lead to conflict about the most appropriate way to respond. Although it is clearly important that cultural and public expectations are met in wildlife management, an ethical dilemma may arise when such expectations appear to override consideration of the animal’s welfare, as understood from the dominant Western ‘animal welfare science’ perspective which emphasises the acute mental experiences of the animal itself [38]. Such concerns have been highlighted previously in relation to delays in euthanasia of stranded cetaceans due to societal desires to rescue debilitated individuals [34,39]; see Fig. 2 Case Study]. To ensure that animal welfare is a high priority at stranding events, it is critical for decision-makers to have clear, objective, scientifically based criteria to inform end-of-life decisions and that these are transparently communicated with all stakeholders. Ideally such criteria should be publicly socialised prior to stranding incidents so that when high profile species strand, the public are aware that individual animal welfare concerns should be the focus of management options [5,40,41].

Most of the end-of-life criteria recommended in these SOPs were similar to those suggested in the published scientific literature, such as disabling locomotor injuries, wounds with full penetration into the thoracic and abdominal cavity, blistering to a large percentage of body surface area and significant haemorrhaging from anus, genital, blowhole and mouth [5,28,29,42]. However, some criteria were poorly described and for others variable thresholds for decision-making were suggested. The ambiguity of such criteria makes it not only difficult to be confident in decisions but also to evaluate the potential animal welfare implications of such decisions [43].

To illustrate, rectal temperature was recommended as a criterion in three SOPs, but the temperature value at which an end-of-life decision should be considered varied among SOPs. The critical value was given as ‘above 42 °C’ in two SOPs and ‘below 35 °C or above 40 °C’ in another SOP. Current recommendations in the literature are that prolonged hypo- or hyperthermia where core body temperature is below 35 °C or above 40 °C should lead to an end-of-life decision for cetaceans [44]. Hyperthermia, indicative of overheating, commonly occurs in stranded cetaceans due to their compromised thermoregulatory ability out of water [29] and is worsened by exposure to direct sunlight [28]. This likely causes increased thermal discomfort to an already compromised animal and in some cases can lead to acute mortality [45]. Furthermore, hyperthermia often occurs alongside dehydration, which contributes to hypovolaemia and electrolyte imbalance [29]. Hypovolaemia may also be indicative of hypothermia, which is less common in stranded cetaceans [29], but will also lead to thermal discomfort.

Likewise, ‘excessive skin sloughing/blistering over a large proportion of the body’ was a criterion used in four SOPs, yet there was no quantification of what constitutes a large area. A similar lack of quantification is also evident in the literature [28,44]. When excessive, these sunlight-induced thermal burns can be equivalent to second-degree burns, with associated pain and fluid loss when blisters rupture [29]. Such injuries have the potential to cause dehydration and hypovolaemic shock [46,47]. Three SOPs also included the criterion of ‘sustained spasms/muscle tremors’, yet no further description of

spasms/tremors was provided in terms of how these may appear, e.g., involving the entire body, and over what time frame they should be considered as “sustained”. Muscle tremors have been noted in stranded cetaceans and are generally linked to neurological abnormalities and worsening prognosis [10,27,44,48]. Accordingly, such tremors likely reflect a poor welfare state, however it should be additionally noted that descriptions of these tremors also remain limited within the scientific literature.

The lack of precise descriptors for end-of-life criteria may reduce their usefulness for identifying compromised individuals and may mean that inappropriate management action, such as refloating a severely debilitated animal, is undertaken. This is particularly pertinent when personnel charged with decision-making at stranding events are not veterinarians and/or have limited knowledge of cetacean biology and behaviour. Furthermore, the high pressure situation of a stranding event may also mean that managers have difficulties following recommendations in SOPs [e.g., Fig. 2 Case Study 34]. Therefore, it is of critical importance that the criteria used to assess the need for end-of-life decisions are well defined, objective and transparently discussed with all stakeholders to prevent prolonged suffering. The authors of the most comprehensive recommendations to date [5,19] acknowledge the need to improve knowledge and understanding of when to euthanise stranded cetaceans, further highlighting the limited data and expertise around end-of-life decision-making in this context.

4.2. Methods, procedures and equipment for the implementation of stranded cetacean euthanasia

4.2.1. Chemical euthanasia

Chemical euthanasia can be rapid and effective if executed correctly, however the logistical complexity in stranding situations often makes it an unviable option without trained veterinarian input [29]. In the five SOPs that contained guidance on chemical euthanasia, the most recommended chemical agent was sodium pentobarbital, a barbiturate. Barbiturates are the most accepted chemical agents for animal euthanasia [20]; however, as controlled substances they can only be administered by a licensed veterinarian. For cetaceans, they are also required in large quantities to provide a lethal effect [19], causing concerns around eco-toxicity [49–52]. Due to these high eco-toxicological risks, alternatives have been sought in some regions [5,53]. These alternatives typically involve the use of sedatives prior to injection of a large quantity of potassium chloride (KCl) [52]. Two of the SOPs suggested the use of KCl (NSW, TAS) which is non-toxic in the environment. These SOPs also provided details on the use of pre-euthanasia sedatives, including midazolam, acepromazine and xylazine, which are commonly reported in the literature [18,52,54]. Sedatives may be used to reduce anxiety, however, importantly the use of KCl for euthanasia is only considered acceptable in an unconscious animal, since KCl acts as a neuromuscular blocking agent on the heart, respiratory and skeletal muscles. Without deep sedation, significant welfare compromise can occur, as an animal may experience suffocation/breathlessness due to respiratory arrest through diaphragm paralysis, and/or pain due to the heart muscle arresting and body muscular spasms before loss of consciousness [20,55,56].

To administer the appropriate dosage of sedative or euthanizing chemicals, an accurate estimate of animal weight is necessary. In stranding situations, these can be estimated through length-to-weight equations [19,57]. However, details on the chemical dosage and needle gauge required in relation to animal size were provided only in three SOPs (NSW, TAS, VIC). This could lead to inaccurate dosages being applied in other jurisdictions, causing extended time to loss of consciousness and death, and potentially, increased suffering [e.g., [5]].

Intravenous administration is generally accepted as the most reliable and rapid route to administer euthanasia agents [20]. In stranded cetaceans the most accessible vessels are those in the fluke, however, working around the fluke can be dangerous to personnel as animals may

move suddenly and with force [28]. Furthermore, debilitated cetaceans commonly display vasoconstriction, and so superficial peripheral vessels may not be easily accessible [29]. Nonetheless, this route was recommended in three SOPs (QLD, NSW, VIC). An alternative route which results in rapid death and provides a safer working environment for personnel [52] is through intracardiac administration, where the chemical agent is delivered directly into the heart. This route was recommended for use in four SOPs (QLD, NSW, TAS, VIC). However, administering euthanasia agents this way can be particularly challenging, requiring specialised needles and skilled marine mammal veterinary personnel to accurately access the heart chamber [5,52,58]. Therefore, although recommended most in the SOPs, intracardiac administration may often not be a viable option at stranding events.

4.2.2. Physical euthanasia

4.2.2.1. Ballistics euthanasia. Seven SOPs included ballistics euthanasia as an option, but notably five of these followed the WA SOP which is based on ballistics trials on cetacean cadavers [30]. All seven recommended the use of rifles as the firearm type, with a calibre of .30 being most recommended. These endorsements are in line with those based on ballistics trials and the wider peer-reviewed literature [5,28–30,59]. However, lower calibre firearms were also stated for use in two SOPs, including .260 and .270 in NZ and .223 and .243 in NSW. In fact, based on data reported by NZ to the International Whaling Commission (IWC), a total of 16 different firearm calibres have been employed in the country for stranded cetacean euthanasia since 2007 [18]. This is notable since previous research has highlighted the importance of using high calibre firearms to cause sufficient pathology for loss of brain function, through temporary cavitation in inelastic tissues such as the brain [5,30,60].

The NZ SOP was also the only one recommending the use of soft-nose projectiles. Soft-nose projectiles begin to deform as they hit tissue. Due to the thick blubber and extensive muscle on the nuchal, parietal and occipital regions of the cetacean skull, much of their kinetic energy will be absorbed [29]. This could lead to lower penetration depth [61,62] and reduced killing efficiency [20,63]. Therefore, solid, non-deforming projectiles are typically endorsed for cetacean euthanasia [30,64]. The reason for NZ's recommendation of soft-nose projectiles is unknown, though it may be due to the reduced likelihood of projectiles exiting the body and ricocheting [20].

Projectile shape was only included in the WA SOP, where blunt-tipped projectiles are recommended to maximise penetration depth [29,30]. The projectile shapes recommended for use in NZ remain unknown, however based on reported data to the IWC, pointed-nose projectiles are often employed [18]. This differs from recommendations in the literature which highlight that pointed projectiles may not penetrate the cetacean skull and can deviate when impacting with the skull due to the thickness and slope of the cranium [63,65], leading to ineffective killing. Similarly, projectile grain is also an important factor to ensure an efficient death. In the Australian SOPs, projectile grains were provided. Though these varied from 125 to 180 grain, they generally aligned with the peer reviewed literature which suggests a minimum of 140 grain should be used [28,59,63]. The NZ SOP did not provide information on the projectile grain required, although based on reported data similar (140–180 grain) grain projectiles have been previously employed [18].

If applied appropriately, ballistics can cause instantaneous death as the brain is targeted directly [66]. All seven SOPs indicated that the brain was the target for ballistics euthanasia, with slight differences in the anatomical landmarks used. Both the dorso-ventral [28,30,67] and lateral approaches [19,59,67] were recommended in all SOPs. For the dorso-ventral approach, there were slight differences in aim; two SOPs recommended the aim be slightly posterior to the blowhole, whilst three recommended the aim be through the blowhole itself. Defined angle aim for ballistics euthanasia is a crucial detail to include since the melon,

concave frontal surface and extensive sinuses of the cetacean skull, are likely to deflect a bullet [68]. Furthermore, due to the variability in skull morphology among species [69–71], it is important that species-specific knowledge of anatomy, including diagrams, for the most accurate approach be provided to correctly target the brain [5,20,30,31,63]. Further work via necropsies should be carried out on a variety of species to record anatomical differences and provide species-specific recommendations for euthanasia via ballistics [5].

Finally, it is worth noting that wildlife managers who are required to use firearms in their profession often receive minimal training regarding the selection of firearms, projectiles and their use to ensure humane application to wildlife [72]. It is, therefore, critical that SOPs recommending the use of firearms for the humane killing of stranded cetaceans provide detailed information on the equipment and procedures required to ensure a humane death, and that regular training is undertaken [5].

4.2.2.2. Explosives. Three Australian SOPs contained recommendations for the use of explosives for euthanasia via peri-cranial implosion. The details provided for this technique referred solely to the study by Coughran et al. [31]. Few studies have mentioned the use of explosives for euthanasia of stranded cetaceans [31,42], likely due in part to the potential danger to personnel and social unacceptability [73]. Nevertheless, few alternative techniques are available to reliably euthanise large cetacean species [5]. In NZ, a specialised firearm specific for sperm whales (SWED) [35] may be applied, but most areas implement chemical euthanasia [52]. However, in areas where veterinary personnel and/or appropriate chemical agents are not available, such large cetaceans are left to die naturally, which may take several days [5,54,74]. Therefore, the use of physical methods that do not require veterinary training or large quantities of specialised chemicals may enable a more humane death, though licensed personnel will still be required when implementing explosives. Since the SOPs examined here only provided the peer-reviewed study for this technique, we have provided an additional checklist of equipment (Table A3) that was collated — but not previously published — by Coughran et al. [31], which can simply be added to current SOPs and may allow for planning of large cetacean euthanasia via peri-cranial implosion at future stranding events.

4.3. Verifying death

Five of the SOPs provided criteria and explicitly required verification of death. In all, except the VIC SOP, verifying death was only required following application of euthanasia and not following palliative care. Two of the SOPs that did not include criteria for verifying death (NSW and QLD), did recommend assessing whether a stranded animal was alive using several criteria in the 'first response' section of the SOPs. It is therefore possible that following euthanasia, these criteria are applied to verify death. However, without verification of death being explicitly required, it is not possible to ascertain whether this occurs as part of strandings management in these jurisdictions.

The only criterion for verifying death included in all five SOPs was absence of palpebral and corneal reflexes. Other common criteria included complete dilation of pupils, unprovoked agonal convulsions, and slack lower jaw [75,76]. Importantly, although absence of breathing is recommended in one SOP (SA) as a criterion to verify death, this needs to be carefully applied for cetaceans, since many species — such as beaked whales — may go into a dive reflex which can result in extended breath holds [77]. Therefore, absence of breathing alone should not be taken to indicate mortality [5,75].

Three quarters of the criteria recommended by Barco et al. [19] were suggested in the five SOPs, whilst one additional criterion (agonal convulsions) was provided in four of the SOPs. Although not included in the recommendations by Barco et al. [19], this criterion has been included in other studies for assessing death in cetaceans [75,76]. Two criteria recommended in the literature [19,75,76] that were not

Table 4

Recommended information to include in Standard Operating Procedures to ensure consistent application of euthanasia methods for stranded cetaceans.

Method	Recommended information	Examples
Chemical	Administration routes	IV, IM, IC
	Anatomical areas for administration with diagrams	Peripheral vessels of fluke, dorsal fin, pectoral fin, epaxial musculature
	Chemical agents including sedatives	
	Dosages of each chemical agent and sedative based on animal weight or length	
	Guidance on combinations of sedatives and chemical agents	Use of sedatives prior to KCl
	Needle gauge requirements	
	Species-specific knowledge of any adverse reactions to specific chemical agents	
	Criteria to verify death	
	Recording of time-to-death/unconsciousness	
	Disposal of carcass following chemical euthanasia	
Ballistics	Firearm type	Rifle
	Firearm calibre	
	Projectile shape	Pointed, round, blunt
	Projectile nose characteristics	Soft, solid
	Projectile energy	
	Projectile weight/grain	
	Number of shots required	
	Recommended approach based on species skull morphology	Dorso-ventral or lateral
	Anatomical landmark with diagrams, including species specific recommendations	Blowhole, mid-point between eye and insertion of pectoral fin
	Angle of aim	
	Distance from cetacean at firearm discharge	
	Criteria to verify death	
	Recording of time-to-death/unconsciousness	
Explosives	Explosive charge type	
	Explosive quantity	
	Detonator type	
	Anatomical landmark with diagrams	
	Design of explosive	Pyramid charge shape
	Size of animal	
	Criteria to verify death	
	Recording of time-to-death/unconsciousness	
Additional equipment	See Table A3	

included in the SOPs were “capillary refill time” and “ocular/skin temperature differential”. It is likely that these were not included in SOPs for logistical reasons. Capillary refill is typically tested in the gums or tongue, requiring personnel to place their hands inside the mouth of a potentially live cetacean, which risks personnel safety [75,76]. In contrast, assessing ocular temperature requires the use of specialised, costly infra-red thermography cameras [75,76]. However, the use of a combination of the other criteria recommended in the SOPs is likely sufficient to verify death.

Verification of death following euthanasia is critical to ensure that the technique is efficient and humane, by determining the duration of any suffering before an animal becomes insensible [20]. Although the criteria in the SOPs followed those in the literature, there are limited data to validate how some of the criteria relate to stages of insensibility and death. Further work using electroencephalography, similar to that carried out in the farming sector [78,79], should be undertaken to validate these death criteria along with any behavioural events that may be displayed. In the absence of valid criteria for recognising loss of consciousness in cetaceans, time-to-death is a key metric for understanding the welfare impacts of management procedures and for improving techniques [80]. However, only two SOPs (WA, NZ) required time-to-death be recorded, suggesting that in only these jurisdictions would continuous monitoring of the animal occur following the implementation of the euthanasia method.

To the best of our knowledge, data to assess the verification and time-to-death in euthanised stranded cetaceans are not publicly available for Australia. However, NZ data on stranded cetacean euthanasia have been provided to the IWC, and a recent analysis of these data revealed that 4% (n = 22; 2018–2019) of animals have been recorded as ‘presumed

instantly killed’ [18]. These data suggest that in some cases verification of death may not occur, despite the mandate to do so in the SOP. As noted above, failing to routinely verify death and report such data precludes improvements to euthanasia procedures.

5. Recommendations

Whilst acknowledging the differing political, cultural and geographical considerations, our study highlights the need for a consistent, unified approach to end-of-life decision-making and euthanasia procedures to improve the animal welfare outcomes. However, to achieve such goals, all the elements of these SOPs must be consistently followed, which as demonstrated, may not always occur. Here, we provide some recommendations for further thought.

First, end-of-life decision-making should be informed using criteria that are objective, science-based, well-defined and transparent. These criteria should include outcome/animal-based indicators of welfare state that are appropriate for the species encountered and implementable across regions. Given the current lack of empirical data, we recommend an international expert workshop as a first step to establishing such criteria and developing protocols to enable standardised data collection [5,53].

Systematically collecting data on behavioural and physiological animal responses both during and following euthanasia procedures, would provide animal-based evidence to improve our understanding of the relative welfare impacts of procedures. Importantly, this should include routine data collection for verification of death, including the time taken from the start of the euthanasia procedure until loss of consciousness or death can be confirmed. Additionally, various criteria for death should

be assessed, as highlighted in this study, to ensure that any welfare impacts can be robustly evaluated.

Currently, application of specific euthanasia methods and procedures may be limited due to the lack of species-specific recommendations. As an example, while chemical euthanasia was commonly recommended in the Australasian SOPs, there was limited advice on needle gauges and chemical dosages required for different species, though some are detailed elsewhere [19,53]. Since robust data on the euthanasia of stranded cetaceans are limited [18], standardised, routine reporting of the procedures applied and outcomes of euthanasia events is strongly recommended [5]. This may be achieved by standardising data collection forms (e.g., [5,19,53]) across regions and establishing a centralised online, open-access database to help stranding managers worldwide evaluate the potential options for different species. Information on both successes and failures should be collected to improve and prevent errors [5]. The information gathered should include the following:

- Reason for considering end-of-life options for an individual animal.
- Rationale for selecting euthanasia or palliative care.
- Method, procedure, and equipment employed for euthanasia.
- Rationale for choosing the method employed.
- Criteria assessed to verify death.
- Time from application of euthanasia method until death is confirmed.
- Behavioural reactions during or post euthanasia.

An additional challenge to effective euthanasia is the requirement to have specialised equipment and training [5]. To illustrate, the most recommended method for administering chemical euthanasia in the Australasian SOPs was intracardiac injection, which requires substantial skill and training. Likewise, for ballistics euthanasia, there is a need for training to select the most appropriate firearm and projectiles and ensure correct application for the humane death of wildlife [72]. Providing detailed open-access information on the available options and training would contribute to improving the skill and confidence of local personnel to undertake the appropriate euthanasia procedure for the species and situation. However, this would need to be reinforced with regular practical training of personnel involved in stranding responses to optimise both animal welfare and human safety. In some cases, additional research on cadavers is needed to determine the most appropriate method, equipment and application for a wider range of species [5,18].

While it is acknowledged that the procedures and equipment required for euthanasia will vary depending upon the methods employed, sufficient details should always be included in guidelines such as SOPs. Table 4 illustrates the level of information that should be included in SOPs to ensure consistent application of various cetacean euthanasia procedures.

6. Conclusions

Overall, Standard Operating Procedures (SOPs) across Australasia contained some pertinent information to undertake end-of-life decisions and application of euthanasia methods. Nonetheless, clear variability among SOPs was evident in our study. Specifically, we found differing criteria being applied for end-of-life decision-making among SOPs and limited detail to facilitate assessment of these criteria. SOPs should include standardised, defined criteria to guide assessments of individual animals when considering end-of-life decisions.

A lack of detail provided in most SOPs regarding the necessary equipment and appropriate procedures for euthanasia methods was of concern. The use of inappropriate equipment or incorrectly applied procedures may lead to severe impairment rather than mortality, significantly compromising welfare. To achieve reliable outcomes, detailed information must be provided to ensure that there is no ambiguity surrounding the implementation of euthanasia procedures, such as the most suitable equipment or method.

Concerningly, only two SOPs required time-to-death be recorded and only five provided criteria for verifying death of cetaceans following euthanasia or palliative care. Assessment of such parameters is critical to ensure that the duration of any welfare compromise is minimised. Therefore, verifying death following application of euthanasia methods or palliative care should be mandatory and criteria for verifying death and calculating time-to-death should be included in all SOPs.

The NZ case study presented illustrates how public perceptions and good intentions can lead to decision-making that is not necessarily in the best interests of animal welfare. International collaboration is needed to develop SOPs that guide best practice global stranding response. Detailed, evidence-based criteria to guide end-of-life decisions should be provided. SOPs that recommend appropriate euthanasia methods, detail the necessary equipment and procedures, and encourage standardised data collection will be associated with better animal welfare outcomes.

Funding

This manuscript is part of the Ph.D. research of Rebecca M Boys. Rebecca M Boys was supported by an Association of Commonwealth Universities Doctoral Scholarship, Karen A Stockin was supported by a Royal Society Te Apārangi New Zealand Royal Society Fellowship (2019–2024). The research was additionally supported by Animal Ethics Inc Research Grant USA, Wildbase Research Trust Fund New Zealand, New Zealand Veterinary Association Marion Cunningham Memorial Fund Grant and Animal Behavior Society Amy R Samuels Grant USA. The funding sources had no involvement in study design, data collection, analysis or interpretation, or in the writing of the article.

CRediT authorship contribution statement

Rebecca M Boys: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Funding acquisition. **Ngaio J Beausoleil:** Validation, Writing – review & editing, Supervision. **Emma L Betty:** Writing – review & editing, Supervision. **Karen A Stockin:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision. All authors have read and agreed to the published version of the manuscript.

Declarations of interest

None.

Acknowledgments

We thank the mana whenua (representing the Indigenous people of Aotearoa New Zealand), especially Ngāti Toa Rangatira, and Department of Conservation Te Papa Atawhai New Zealand, Department of Primary Industries, Parks, Water and Environment Tasmania, Department of Planning, Industry and Environment New South Wales, Department of Environment, Land, Water and Planning Victoria, Department of Environment and Science Queensland, Department of Land Resource Management Northern Territory, Department of Environment, Water and Natural Resources South Australia, and Department of Parks and Wildlife Western Australia for their assistance in the provision of national and state/territory SOPs for marine mammal strandings. We also thank the two anonymous reviewers for their comments which greatly improved our manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2021.104949](https://doi.org/10.1016/j.marpol.2021.104949).

References

- [1] S.E. Baker, T.M. Sharp, D.W. Macdonald, Assessing animal welfare impacts in the management of European rabbits (*Oryctolagus cuniculus*), European moles (*Talpa europaea*) and Carrion crows (*Corvus corone*), *PLoS One* 11 (2016) 1–24, <https://doi.org/10.1371/journal.pone.0146298>.
- [2] K. Broome, C. Golding, K. Brown, P. Corson, P. Bell, Rat Eradication Using Aerial Baiting: Current Agreed Best Practice Used in New Zealand, New Zealand Department of Conservation, Wellington, New Zealand, 2017.
- [3] T. Sharp, Ground baiting of wild dogs with sodium fluoroacetate (1080), The Centre for Invasive Species Solutions, Australia, 2012. (<https://pestsmart.org.au/toolkit-resource/ground-baiting-of-wild-dogs-with-1080>), (Accessed 8 June 2021).
- [4] N. Edelson, C. Bennett, Process Discipline: How to Maximize Profitability and Quality Through Manufacturing Consistency, Quality Resources, New York, 1998.
- [5] IWC, Report of the IWC Workshop on Euthanasia Protocols to Optimize Welfare Concerns for Stranded Cetaceans, International Whaling Commission, Cambridge, UK, 2014.
- [6] M. Cattet, J. Boulanger, G. Stenhouse, R.A. Powell, M.J. Reynolds-Hogland, An evaluation of long-term capture effects in ursids: implications for wildlife welfare and research, *J. Mamm.* 89 (2008) 973–990, <https://doi.org/10.1644/08-MAMM-A-095.1>.
- [7] C. Jacques, J. Jenks, C. Deperno, J. Sievers, T.W. Grovenburg, T. Brinkman, C. Swanson, B. Stillings, Evaluating ungulate mortality associated with helicopter net-gun captures in the northern Great plains, *J. Wildl. Manag.* 73 (2009) 1282–1291, <https://doi.org/10.2193/2009-039>.
- [8] Aristotle, *Historia animalia*, in: 350AD, p. Ch.48.
- [9] K.M. Moore, C.A. Simeone, R.L. Brownell Jr., Strandings, in: B. Würsig, J. Thewissen, K.M. Kovacs (Eds.), *Encycl. Mar. Mamm.*, Academic Press/Elsevier, USA, 2018.
- [10] N. Cámara, E. Sierra, A. Fernández, M. Arbelo, Y. Bernaldo de Quiros, M. Arregui, F. Consoli, P. Herráez, Capture myopathy and stress cardiomyopathy in a live-stranded Risso's dolphin (*Grampus griseus*) in rehabilitation, *Animals* 10 (2020) 220, <https://doi.org/10.3390/ani10020220>.
- [11] C.A. Manire, H.L. Rhinehart, N.B. Barros, L. Byrd, P. Cunningham-Smith, An approach to the rehabilitation of *Kogia* spp, *Aquat. Mamm.* 30 (2004) 257–270, <https://doi.org/10.1578/am.30.2.2004.257>.
- [12] M.S. Mazzoil, S.D. McCulloch, M.J. Youngbluth, D.S. Kilpatrick, E.M. Murdoch, B. Mase-Guthrie, D.K. Odell, G.D. Bossart, Radio-tracking and survivorship of two rehabilitated Bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida, *Aquat. Mamm.* 34 (2008) 54–64, <https://doi.org/10.1578/am.34.1.2008.54>.
- [13] R. Suisted, D. Neale, Department of Conservation Marine Mammal Action Plan for 2005–2010, Department of Conservation, Wellington, New Zealand, 2004.
- [14] C.J.A. Bradshaw, K. Evans, M.A. Hindell, Mass Cetacean strandings—a plea for empiricism, *Conserv. Biol.* 20 (2006) 584–586, <https://doi.org/10.1111/j.1523-1739.2006.00329.x>.
- [15] C. Groom, D. Coughran, Three decades of cetacean strandings in Western Australia: 1981–2010, *J. R. Soc. West. Aust.* 95 (2012) 63–76.
- [16] M. Oremus, R. Gales, H. Kettles, C.S. Baker, Genetic evidence of multiple matrilineal and spatial disruption of kinship bonds in mass strandings of long-finned pilot whales, *Globicephala melas*, *J. Hered.* 104 (2013) 301–311, <https://doi.org/10.1093/jhered/est007>.
- [17] E.L. Betty, B. Bollard, S. Murphy, M. Ogle, H. Hendriks, M.B. Orams, K.A. Stockin, Using emerging hot spot analysis of stranding records to inform conservation management of a data-poor cetacean species, *Biodivers. Conserv.* 29 (2020) 643–665, <https://doi.org/10.1007/s10531-019-01903-8>.
- [18] R.M. Boys, N.J. Beausoleil, E.L. Betty, K.A. Stockin, Deathly silent: exploring the global lack of data relating to stranded Cetacean euthanasia, *Animals* 11 (2021) 1460, <https://doi.org/10.3390/ani11051460>.
- [19] S.G. Barco, W.J. Walton, C.A. Harms, R.H. George, L.R. D'Erri, W.M. Swingle, Collaborative Development of Recommendations for Euthanasia of Stranded Cetaceans, US NOAA, Silver Spring, Maryland, USA, 2016, <https://doi.org/10.7289/V5/TM-OPR-56>.
- [20] S. Leary, W. Underwood, R. Anthony, S. Cartner, T. Grandin, C. Greenacre, S. Gwaltney-Brant, M. McCrackin, R. Meyer, D. Miller, J. Shearer, T. Turner, R. Yanong, AVMA Guidelines for the Euthanasia of Animals: 2020 Edition, American Veterinary Medical Association, Schaumburg, Illinois, 2020.
- [21] J. Hampton, T. Hyndman, M. Laurence, A. Perry, P. Adams, T. Collins, Animal welfare and the use of procedural documents: limitations and refinement, *Wildl. Res.* 43 (2016) 599–603.
- [22] T. Sharp, G. Saunders, Development of a Model Code of Practice and Standard Operating Procedures for the Humane Capture, Handling or Destruction of Feral Animals in Australia, New South Wales Department of Primary Industries, Orange, NSW, Australia, 2004.
- [23] D.C.J. Main, A.J.F. Webster, L.E. Green, Animal welfare assessment in farm assurance schemes, *Acta Agric. Scand. Sect. — Anim. Sci.* 51 (2001) 108–113, <https://doi.org/10.1080/090647001316923171>.
- [24] S. Mazzariol, C. Centelleghé, B. Cozzi, M. Povinelli, F. Marcer, N. Ferri, G. Di Francesco, P. Badagliacca, F. Profeta, V. Olivieri, S. Guccione, C. Cocumelli, G. Terracciano, P. Troiano, M. Beverelli, F. Garibaldi, M. Podesta, L. Marsili, M. C. Fossi, S. Mattiucci, P. Cipriani, D. De Nurra, A. Zaccaroni, S. Rubini, D. Berto, Y. B. de Quiros, A. Fernandez, M. Morell, F. Giorda, A. Pautasso, P. Modesto, C. Casalone, G. Di Guardo, Multidisciplinary studies on a sick-leader syndrome-associated mass stranding of sperm whales (*Physeter macrocephalus*) along the Adriatic coast of Italy, *Sci. Rep.* 8 (2018) 11577, <https://doi.org/10.1038/s41598-018-29966-7>.
- [25] A.M. Chit, B.D. Smith, M.T. Tun, An extreme extra-limital record of a strap-toothed beaked whale *Mesoplodon layardii* from the northern Indian Ocean in Myanmar, *Mar. Biodivers. Rec.* 5 (2012), e5, <https://doi.org/10.1017/S1755267211001060>.
- [26] Y. Bernaldo de Quiros, A. Fernandez, R.W. Baird, R.L. Brownell Jr., N. Aguilar de Soto, D. Allen, M. Arbelo, M. Arregui, A. Costidis, A. Fahlman, A. Frantzis, F.M. D. Gulland, M. Iniguez, M. Johnson, A. Kommenou, H. Koopman, D.A. Pabst, W. D. Roe, E. Sierra, M. Tejedor, G. Schorr, Advances in research on the impacts of anti-submarine sonar on beaked whales, *Proc. R. Soc. B Biol. Sci.* 286 (2019) 20182533, <https://doi.org/10.1098/rspb.2018.2533>.
- [27] A. Fernandez, Y. Bernaldo de Quiros, S. Sacchini, E. Sierra, Pathology of marine mammals: what it can tell us about environment and welfare, in: A. Butterworth (Ed.), *Mar. Mammal Welf.*, Springer International Publishing, Switzerland, 2017.
- [28] J.R. Geraci, V. Lounsbury, *Marine Mammals Ashore: A Field Guide for Strandings*, 2nd ed., National Aquarium in Baltimore, Baltimore, USA, 2005.
- [29] C.A. Harms, L. Greer, J. Whaley, T.K. Rowles, Euthanasia, in: *CRC Handb. Mar. Mammal Med.*, 3rd ed., CRC Press, Boca Raton, 2018, pp. 675–691.
- [30] J. Hampton, P. Mawson, D. Coughran, S. Vitali, Validation of the use of firearms for euthanising stranded cetaceans, *J. Cetacea Res. Manag.* 14 (2014) 117–123.
- [31] D.K. Coughran, I. Stiiles, P. Mawson, Euthanasia of beached humpback whales using explosives, *J. Cetacea Res. Manag.* 12 (2012) 137–144.
- [32] IWC, Workshop on whale killing methods and associated welfare issues. Euthanasia of Stranded Cetaceans in New Zealand, International Whaling Commission, Cambridge, UK, 2006.
- [33] NOAA, U. FWS, Policies and Best Practices: Marine Mammal Stranding Response, Rehabilitation, and Release: Standards for Release, NOAA National Marine Fisheries Service, Silver Spring, Maryland, USA, 2009.
- [34] DOC, Orca Calf Stranding Response, Dep. Conserv. NZ, 2021. (<https://www.doc.govt.nz/orca-calf-stranding-response/>), (Accessed 22 September 2021).
- [35] L. Boren, Area Operational Plan for Marine Mammal incidents, Guidelines, Department of Conservation, Wellington, New Zealand, 2012.
- [36] Conservation Act, New Zealand, 1987.
- [37] J. Woodhouse, A. Carr, N. Liebergreen, L. Anderson, N.J. Beausoleil, G. Zobel, M. King, Conceptualizing indigenous human–animal relationships in Aotearoa New Zealand: an ethical perspective, *Animals* 11 (2021), <https://doi.org/10.3390/ani1102899>.
- [38] D. Mellor, N.J. Beausoleil, K. Littlewood, A. McLean, P. McGreevy, B. Jones, C. Wilkins, The 2020 five domains model: including human–animal interactions in assessments of animal welfare, *Animals* 10 (2020) 1870, <https://doi.org/10.3390/ani10101870>.
- [39] N. Gales, R. Woods, L. Vogelneust, Marine mammal strandings and the role of the veterinarian, in: L. Vogelneust, R. Woods (Eds.), *Med. Aust. Mamm.*, CSIRO Publishing, Clayton, Australia, 2008.
- [40] J. Hampton, K. Teh-White, Animal welfare, social license and wildlife use industries, *J. Wildl. Manag.* 83 (2019) 12–21.
- [41] R. Chapple, The politics of feral horse management in Guy Fawkes River National Park, NSW, Aust. Zool. 33 (2014) 233–246, <https://doi.org/10.7882/AZ.2005.020>.
- [42] D. Needham, Cetacean strandings, in: M. Fowler (Ed.), *Zoo Wild Anim. Med. Curr. Ther.* 3, WB Saunders, Philadelphia, 1993, pp. 415–425.
- [43] J.O. Hampton, T.H. Hyndman, Underaddressed animal-welfare issues in conservation, *Conserv. Biol.* 33 (2019) 803–811, <https://doi.org/10.1111/cobi.13267>.
- [44] F.M.D. Gulland, L.A. Dierauf, K.L. Whitman, *CRC Handbook of Marine Mammal Medicine*, 3rd ed., CRC Press, Boca Raton, 2018.
- [45] J. Diaz-Delgado, A. Fernandez, E. Sierra, S. Sacchini, M. Andrada, A.I. Vela, O. Quesada-Canales, Y. Paz, D. Zucca, K. Groch, M. Arbelo, Pathologic findings and causes of death of stranded cetaceans in the Canary Islands (2006–2012), *PLoS One* 13 (2018), e0204444, <https://doi.org/10.1371/journal.pone.0204444>.
- [46] L.M. Martinez-Levasseur, D. Gendron, R.J. Knell, E.A. O'Toole, M. Singh, K. Acevedo-Whitehouse, Acute sun damage and photoprotective responses in whales, *Proc. Biol. Sci.* 278 (2011) 1581–1586, <https://doi.org/10.1098/rspb.2010.1903>.
- [47] K.R. Groch, J. Diaz-Delgado, M.C.C. Marcondes, A.C. Colosio, E.B. Santos-Neto, V. L. Carvalho, G.S. Boos, A.C. Oliveira de Meirelles, H. Ramos, J.P. Guimarães, J.C. G. Borges, J.E. Vergara-Parente, J.A. Leger St, A. Fernandez, J.L. Catao-Dias, Pathology and causes of death in stranded humpback whales (*Megaptera novaeangliae*) from Brazil, *PLoS One* 13 (2018), e0194872, <https://doi.org/10.1371/journal.pone.0194872>.
- [48] M. Moore, S. Sharp, S. Raverty, Health, in: B. Würsig, J.G.M. Thewissen, K. M. Kovacs (Eds.), *Encycl. Mar. Mamm.*, Third edition, Academic Press, USA, 2018, pp. 457–462, <https://doi.org/10.1016/B978-0-12-804327-1.00147-3>.
- [49] L. Greer, T. Rowles, Humane euthanasia of stranded marine mammals, in: *Proc. Am. Assoc. Zoo Vet. Int. Assoc. Aquat. Anim. Med. Jt. Conf.*, New Orleans, LA, 2000, pp. 374–5.
- [50] K. O'Rourke, Euthanized animals can poison wildlife: veterinarians receive fines, *J. Am. Vet. Med. Assoc.* 220 (2002) 146–147.
- [51] K. Bischoff, R. Jaeger, J.G. Ebel, An unusual case of relay pentobarbital toxicosis in a dog, *J. Med. Toxicol.* 7 (2011) 236–239, <https://doi.org/10.1007/s13181-011-0160-8>.
- [52] C.A. Harms, W.A. McLellan, M.J. Moore, S.G. Barco, E.O. Clarke 3rd, V.G. Thayer, T.K. Rowles, Low-residue euthanasia of stranded mysticetes, *J. Wildl. Dis.* 50 (2014) 63–73, <https://doi.org/10.7589/2013-03-074>.
- [53] J. Barnett, A. Knight, M. Stevens, *British Divers Marine Life Rescue Marine Mammal Medicine Handbook*, British Divers Marine Life Rescue, East Sussex, UK, 2013.
- [54] C. Kolesnikovas, K. Groch, K. Groch, A. Moraes, P. Flores, D. Pretto, R. Freitas, M. Gaidzinski, L. Moreira, Euthanasia of an adult southern right Whale (*Eubalaena*

- australis* in Brazil, *Aquat. Mamm.* 38 (2012) 317–321, <https://doi.org/10.1578/am.38.3.2012.317>.
- [55] IWC, Report of the Workshop on Humane Killing Techniques for Whales, Cambridge, UK, 1981.
- [56] B. Close, K. Banister, V. Baumans, E.M. Bernoth, N. Bromage, J. Bunyan, W. Erhardt, P. Flecknell, N. Gregory, H. Hackbarth, D. Morton, C. Warwick, Recommendations for euthanasia of experimental animals: Part 2. DGXT of the European Commission, *Lab. Anim.* 31 (1997) 1–32, <https://doi.org/10.1258/002367797780600297>.
- [57] C. Lockyer, Body weights of some species of large whales, *ICES J. Mar. Sci.* 36 (1976) 259–273, <https://doi.org/10.1093/icesjms/36.3.259>.
- [58] R. Adams. *Veterinary Pharmacology and therapeutics*, 8th edition, Iowa State University Press, Ames, IA, 2001.
- [59] RSPCA, Stranded Cetaceans: Guidelines for Veterinary Surgeons, Horsham, UK, 1997.
- [60] J. Zhang, N. Yoganandan, F.A. Pintar, T.A. Gennarelli, Temporal cavity and pressure distribution in a brain simulant following ballistic penetration, *J. Neurotrauma* 22 (2005) 1335–1347, <https://doi.org/10.1089/neu.2005.22.1335>.
- [61] J. Hampton, P. Mawson, D. Coughran, Standard Operating Procedure No. 15.5. Euthanasia of small stranded cetaceans using firearms, Department of Parks and Wildlife, Western Australia, 2014.
- [62] A.J. Knox, B. Lardner, A. Yackel Adams, R.N. Reed, Evaluating airsoft electric guns for control of invasive brown treesnakes, *Wildl. Soc. Bull.* 42 (2018) 534–539, <https://doi.org/10.1002/wsb.909>.
- [63] E. Øen, S. Knudsen, Euthanasia of whales: the effect of .375 and .485 calibre round nosed, full metal-jacketed rifle bullets on the central nervous system of the common minke whale, *J. Cetacea Res. Manag.* 9 (2007) 81–88.
- [64] P.J. Duignan, D. Anthony, Marine mammal strandings – a vet’s role, *Kokako* 7 (1) (2000) 3–5.
- [65] IWC, Report of the Working Group on Whale Killing Methods and Associated Welfare Issues, 30 June 2000, Adelaide, International Whaling Commission, Adelaide, Australia, 2000.
- [66] J.A. Longair, G.G. Finley, M.A. Laniel, C. Mackay, K. Mould, E.D. Olfert, H. Rowsell, A. Preston, Guidelines for euthanasia of domestic animals by firearms, *Can. Vet. J.* 32 (1991) 724–726.
- [67] D.K. Blackmore, P. Madie, M.C. Bowling, A. Nutman, A.S. Davies, W.R. McLeod, J. Taylor, M. Degen, The use of a shotgun for euthanasia of stranded cetaceans, *N. Z. Vet. J.* 43 (1995) 158–159, <https://doi.org/10.1080/00480169.1995.35878>.
- [68] J. Barzdo, P. Vodden, Report of Stranded Whale Workshop, A Practical and Humanitarian Approach, RSPCA, Horsham, UK, 1983.
- [69] S. Rommel, A. Costidis, A. Fernandez, P.D. Jepson, D.A. Pabst, W. McLellan, D. S. Houser, T. Cranford, A. van Helden, D. Allen, N. Barros, Elements of beaked whale anatomy and diving physiology and some hypothetical causes of sonar-related stranding, *J. Cetacea Res. Manag.* 7 (2006) 189–209.
- [70] J.G. Mead, Beaked Whales, Overview: ziphiidae, in: W.F. Perrin, B. Würsig, J.G. M. Thewissen (Eds.), *Encycl. Mar. Mamm.*, Second ed., Academic Press, London, 2009, pp. 94–97, <https://doi.org/10.1016/B978-0-12-373553-9.00027-4>.
- [71] P. Gol’din, ‘Antlers inside’: are the skull structures of beaked whales (Cetacea: Ziphiidae) used for echoc imaging and visual display? *Biol. J. Linn. Soc.* 113 (2014) 510–515, <https://doi.org/10.1111/bij.12337>.
- [72] J. Caudell, B. West, B. Griffin, K. Davis, Fostering greater professionalism with firearms in the wildlife arena, in: *Proc. Wildl. Manag. Conf.*, Saratoga Springs, NY, 2009, pp. 95–99.
- [73] L. Greer, J. Whaley, T. Rowles, Euthanasia, in: L.D., F. Gulland (Eds.), *CRC Handb. Mar. Mammal Med.*, 2nd ed., CRC Press, Florida, 2001, pp. 729–738.
- [74] P. Daoust, A. Ortenburger, Successful euthanasia of a juvenile fin whale, *Can. Vet. J.* 42 (2001) 127–129.
- [75] A. Butterworth, L. Sadler, T. Knowles, S. Kestin, Evaluating possible indicators of insensibility and death in cetacea, *Anim. Welf.* 13 (2004) 13–17.
- [76] P. Brakes, A. Butterworth, M. Donoghue, Investigating criteria for insensibility and death in stranded cetaceans in New Zealand, International Whaling Commission, Impington, Cambridgeshire, England, 2006.
- [77] N.J. Quick, W.R. Cioffi, J.M. Shearer, A. Fahlman, A.J. Read, Extreme diving in mammals: first estimates of behavioural aerobic dive limits in Cuvier’s beaked whales, *J. Exp. Biol.* 223 (2020), <https://doi.org/10.1242/jeb.222109>.
- [78] D.K. Blackmore, C.C. Daly, C.J. Cook, Electroencephalographic studies on the nape shooting of sheep, *N. Z. Vet. J.* 43 (1995) 160–163, <https://doi.org/10.1080/00480169.1995.35879>.
- [79] T.J. Gibson, S.E.O. Oliveira, F.A.D. Costa, N.G. Gregory, Electroencephalographic assessment of pneumatically powered penetrating and non-penetrating captive-bolt stunning of bulls, *Meat Sci.* 151 (2019) 54–59, <https://doi.org/10.1016/j.meatsci.2019.01.006>.
- [80] J. Hampton, D. Forsyth, D. Mackenzie, I. Stuart, A simple quantitative method for assessing animal welfare outcomes in terrestrial wildlife shooting: the European rabbit as a case study, *Anim. Welf.* 24 (2015) 307–317, <https://doi.org/10.7120/09627286.24.3.307>.

Appendix

Table A.1. Information provided in SOPs for employing chemical euthanasia on stranded cetaceans in Victoria (VIC), Southern Australia (SA), Tasmania (TAS), Queensland (QDL) and New South Wales (NSW).

SOP	Cetacean size	Example animals	Sedation agent	Sedation dose	Sedation route	Needle gauge	Euthanasia agent	Euthanasia dose	Euthanasia route	Needle gauge	Additional information
VIC Used in: SA	<2m	Juvenile pygmy sperm whale: length 2 metres, est. 200–250kg Common dolphin: length 2 metres, est. 110kg	Midazolam	0.02-0.1mg/kg	IV	NA	Pentobarbitone sodium	325mg/ml at 25ml/metre	IV	NA	20 minutes after sedative
VIC Used in: SA	<2m	Juvenile pygmy sperm whale: length 2 metres, est. 200–250kg Common dolphin: length 2 metres, est. 110kg	Acepromazine	1mg/kg, ca. 35mg/metre	IM	1.5 inch (14-18g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IV	NA	45 minutes after sedative
VIC Used in: SA	2-4m	Pygmy sperm whale: maximum length 3.66m, maximum body mass 480kg (female), 374kg (male) Bottlenose dolphin: length 3 metres, est. 650kg	Acepromazine	1mg/kg, ca. 35mg/metre	IM	2-3.5 inch (14-18g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IV, IC	IC: 6-12 inch	45 minutes after sedative

VIC Used in: SA	2-4m	Pygmy sperm whale: maximum length 3.66m, maximum body mass 480kg (female), 374kg (male) Bottlenose dolphin: length 3 metres, est. 650kg	Medetomidine	0.04-0.08mg/kg	IM	2-3.5 inch (14-18g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IV, IC	IC: 6-12 inch	45 minutes after sedative
VIC Used in: SA	4-7m	False killer whale: length 5–6m, est. 1,000–1,400kg Long-finned pilot whale: length 4.5–6m, est. 1,200–1,800kg	Acepromazine	1mg/kg, ca. 35mg/metre	IM	3.5 inch (14-18g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IV, IC	IC: >12 inch	45 minutes after sedative
VIC Used in: SA	4-7m	False killer whale: length 5–6m, est. 1,000–1,400kg Long-finned pilot whale: length 4.5–6m, est. 1,200–1,800kg	Medetomidine	0.04-0.08mg/kg	IM	3.5 inch (14-18g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IV, IC	IC: >12 inch	45 minutes after sedative
VIC Used in: SA	>7m	Killer whale female length 7–8m, est. 4,000kg Killer whale, male: length 8–9.5m, est. 6,000–8,000kg	Acepromazine	1mg/kg, ca. 35mg/metre	IM	10 inch (14-16g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IC, blowhole	IC: >12 inch, blowhole: 75cm flexible catheter after	45 minutes after sedative

										expirati on	
VIC Used in: SA	>7m	Killer whale female length 7–8m, est. 4,000kg Killer whale, male: length 8–9.5m, est. 6,000–8,000kg	Medetomidine	0.04- 0.08mg/k g	IM	10 inch (14-16g)	Pentobarbitone sodium	325mg/ml at 25ml/metre	IC, blowhole	IC: >12 inch, blowho le: 75cm flexible cathete r after expirati on	45 minutes after sedative
VIC Used in: SA	Large cetacean	Humpback whale, Southern right whale	Midazolam, Acepromazine , Xylazine	0.05mg/k g, 0.15mg/k g, 3.5mg/kg	IM	11 inch (16-18g)	Pentobarbitone sodium	10mg/kg			
NSW	<8m		Benzodiazepin e, Midazolam	15mg/me tre	IM		Potassium chloride (KCl)	60mg/kg	IV		
NSW	<8m		Diazepam	0.1mg/kg	IM		Potassium chloride (KCl)	60mg/kg	IV		
NSW	<8m		Acepromazine	100mg/m etre	IM		Potassium chloride (KCl)	60mg/kg	IV		
NSW	<8m		Pentobarbiton e	200- 300ml	IV		Potassium chloride (KCl)	60mg/kg	IV		
NSW	<8m						Pentobarbitone	50-100mg/kg (25- 35ml/metre) at 325mg/ml	IC, IV		

TAS	>7m		Midazolam	0.05-0.1mg/kg	IM	16-18g 300-500mm	Potassium chloride (KCl)	75-200mg/kg (300mg/ml; 4mmol/ml)	IC	11g, 1000m m	Pentobarbital sodium can be used where ecotoxicity is not an issue
TAS	>7m		Acepromazine	0.2-1mg/kg	IM	16-18g 300-500mm	Potassium chloride (KCl)	75-200mg/kg (300mg/ml; 4mmol/ml)	IC	11g, 1000m m	Pentobarbital sodium can be used where ecotoxicity is not an issue
TAS	>7m		Xylazine	3-4mg/kg	IM, IV	16-18g 300-500mm	Potassium chloride (KCl)	75-200mg/kg (300mg/ml; 4mmol/ml)	IC	11g, 1000m m	Pentobarbital sodium can be used where ecotoxicity is not an issue
TAS	>7m		Tiletamine/Zolazepam	1-5mg/kg	IM	16-18g 300-500mm	Potassium chloride (KCl)	75-200mg/kg (300mg/ml; 4mmol/ml)	IC	11g, 1000m m	Pentobarbital sodium can be used where ecotoxicity is not an issue
TAS	>7m		Medetomidine	0.01-0.03mg/kg	IM	16-18g 300-500mm	Potassium chloride (KCl)	75-200mg/kg (300mg/ml; 4mmol/ml)	IC	11g, 1000m m	Pentobarbital sodium can be used where ecotoxicity is not an issue

TAS	>7m		Ketamine	2.5mg/kg	IM	16-18g 300- 500mm	Potassium chloride (KCl)	75-200mg/kg (300mg/ml; 4mmol/ml)	IC	11g, 1000m m	Pentobarbita l sodium can be used where eco- toxicity is not an issue
QDL	Upto pilot whale size	Pilot whale					Pentobarbitone		IV, IC		

Table A.2. Information provided in SOPs for employing ballistics euthanasia on stranded cetaceans in Western Australia (WA), Victoria (VIC), Tasmania (TAS), Queensland (QDL), Southern Australia (SA), New South Wales (NSW) and New Zealand (NZ).

SOP	Cetacean size	Firearm type	Firearm calibre	Projectile shape	Projectile characteristics	Projectile grain	No. of shots required	Aim	Angle of aim	Distance from cetacean at discharge
WA Used in: VIC, TAS, QDL, SA	<7m	Bolt action rifle	.308 Winchester or .300 Winchester Magnum	Blunt	Solid, hydrostatically stabilised	180 grain	3	Hindbrain	Slightly posterior to the blowhole, angled backwards at 45° along the animal's midline. Midway between the eye and the pectoral fin when the animal is viewed laterally	0.5-1.0m
NZ	<2m	High power rifle	.260, .270, .303, .308	Not provided	Standard sporting round	Not provided	Not provided	Rear of brain	Hand span behind blowhole or one-third ofway between eye and origin pectoral fin	Not provided

NZ	2-6m	High power hunting rifle	.303, .30-06	Not provided	Soft nose	Not provided	Not provided	Rear of brain	Hand span behind blowhole or one-third of way between eye and origin pectoral fin	Not provided
NSW	Small cetacean: dolphins	Rifle	.223, .243	Not provided	Solid	Not provided	Not provided	Brain	Through the blowhole, angled backwards to an imaginary mid-point on a line between the pectoral flippers. Alternatively, a lateral aim can be directed midway between the eye and the ear aperture	Not provided
NSW	Medium cetaceans : pilot whales	Rifle	.308, .375, .458	Not provided	Solid	Not provided	Not provided	Brain	Through the blowhole, angled backwards to an imaginary mid-point on a line between the pectoral flippers. Alternatively, a lateral aim can be directed midway between the eye and the ear aperture	Not provided
NSW	<5m	Shotgun			Slug or buckshot (nine lead pellets)	28gm	Not provided	Brain	Through the blowhole, angled backwards to an imaginary mid-point on a line between the pectoral flippers. Alternatively, a lateral aim can be directed midway between the eye and the ear aperture	Not provided
QDL	<9m	Rifle	7.62x39, .308 Win	Not provided	Not provided	125gr, 150gr	Not provided	Brain	Through the blowhole angled slightly backwards or a temporal shot	Not provided

Table A.3. Information on euthanasia via explosives following [31] that is recommended in SOPs for Western (WA), Victoria (VIC) and Queensland (QLD) Australia, and the related equipment required for such peri-cranial implosion techniques [31 and *pers. comm.* Peter Mawson]

Cetacean size	Cetacean species	Explosive	No. sticks	Size of sticks	Additional boosters	Shape for detonation	Placement of explosives	Machinery required	Reference
10.5m	Humpback whale	Powergel Magnum	5	125g	None	Triangular pyramid	Cranium dorsally	D9 or D65EX bulldozers	[31]
9.8m	Humpback whale	Powergel Magnum	14	125g	None	Triangular pyramid	Cranium dorsally	D9 or D65EX bulldozers	[31]
12.7m	Humpback whale	Powergel Magnum	22	125g	2x 50g	Triangular pyramid	Cranium dorsally	D9 or D65EX bulldozers	[31]
9.5m	Humpback whale	Powergel Magnum	15	125g	None	Triangular pyramid	Cranium laterally	D9 or D65EX bulldozers	[31]

Equipment List

- 30 x 20kg sand bags for tamping explosive and stabilizing the whale
- Shovels for filling sand bags
- 50 x medium cable ties for sealing and securing the sand bags to rope (see Figure 5 in [31])
- 4 used car tyres with loops to act as anchors for securing ropes
- waterproof camera
- wet suits and booties for personnel entering water
- modified dolphin cradle to manoeuvre the whale
- 100m of 10-12mm diameter nylon rope for securing explosives
- 200m of 40mm nylon rope to stabilize whale and to tow it up the beach (after euthanasia)
- 50m of 2-3 mm nylon string.

- 2 x sharp rope cutting knives (Green River® or Spyderco® serrated edge knife)
- D-9 dozer
- 5/8th inch Chain sling to be shackled to Dozer blade to attach 40mm towing rope.
- 18 x sticks of 125g Power Gel® (ICI Australia Ltd)
- 6 x electric detonators
- 10m of detonating cord.
- 2 x 75m lengths of 2-core low resistance electrical cable. Check cable continuity and resistance with multi-meter. Short out cable ends when finished
- 2 x 12V heavy-duty truck batteries or 2 x exploders
- 2 x rolls of self-amalgamating electrical tape (for waterproof detonator electrical joins)
- 4 x rolls of plastic electrical insulation tape (to tape electrical cable to rope)
- 2 x pairs pliers
- 1 x wooden or brass skewer for making holes in explosive for detonating cord
- .300 Winchester Magnum or .308 Winchester bolt-action, 3x solid, hydrostatically stabilised 180 grain bullets (updated based on Hampton et al. [30])
- Radio contact from blast site with both ends of beach, hinterland and offshore. Ensure radios and mobile telephones are switched off prior to detonators being removed from shielded metal box and inserted into explosives.
- Guard boat to control offshore traffic
- Air horn