A review of recent research on Norwegian whale killing

A Butterworth[A] and P Brakes[B]

[A] University of Bristol Clinical Veterinary Science, Langford, N Somerset, BS40 5DU, UK
andy.butterworth@bris.ac.uk

[B] WDCS, the Whale and Dolphin Conservation Society, PO Box 81, Lyttelton, Canterbury, New Zealand
philippa.brakes@wdcs.org

(submitted by the Government of the UK)

Abstract
A number of reviewers (expert in the relevant fields) were asked to write concise summaries of the findings of the reports contained in Dr Knudsen's papers [1,2,3,4], and the PhD thesis which resulted from these studies [5]. The reviewers found that the histological and pathological techniques used were well executed and that the histological and pathological findings were accurately reported. The authors demonstrate a broad knowledge of related literature, including the criteria for determination of death in humans, food animals and cetaceans. The reviewers found that a comprehensive series of studies had been carried out, and that these resulted in Dr Knudsen's PhD thesis and a number of scientific papers published in peer-reviewed neuroscience journals. The reviewers noted that the description of the method by which the animals were selected for inclusion in the study were inadequate. It is also noted that some of the conclusions were sometimes over simplified, leading to over generalisation.

Secretariat note: The full text of the four reviews are provided in Appendices A to D.

Introduction to the papers under review

In the scientific papers[1,2,3,4] and PhD thesis [5] which are reviewed in this report, Siri Knudsen and her co-authors, Egil Øen and Sverre Mørk present a comprehensive study of the effects of grenade explosion and rifle shooting during the hunting of minke whales in the North Atlantic. Their work is a step towards improved data collection (and interpretation of the data) which is essential to informed debate on animal welfare issues surrounding the hunting and killing of cetaceans.

In this case, the debate concerns the question - *Is it humane to kill cetaceans using grenade tipped harpoons and rifles in the manner used by Norwegian, Japanese and some aboriginal hunts?*

The work under review in this report can be considered a valuable contribution to the call for 'real science' in category 1 of the IWC research requirements (Table 1). In view of this, the Norwegian studies [1,2,3,4] will receive wide critical examination, since their findings may significantly influence the whaling debate. These studies have the potential to impact the lives (and deaths) of cetaceans killed under the management of the IWC. With the significance of these reports in mind, it was considered of value to review this Norwegian work with the following aims -

Aims of the review of the Norwegian papers [1,2,3,4] and thesis [5]

1) To clarify some of the information provided in the papers [1,2,3,4] and gather the figures and facts given in the four papers and the PhD thesis together so that a summary picture of what is presented can be viewed in one place.

2) To explore the scientific basis of the studies[1,2,3,4,5] The interpretation of these findings is assessed by inviting the comments of a number of reviewers with expertise in areas relevant to this research. Although three of the four papers [1,2,4] have been peer reviewed as part of the publication process, one has not [3]. The opinion of other independent reviewers is intended to add a wider view of informed opinion of the four papers presented.

3) To examine how the papers [1,2,3,4] and thesis findings on welfare at slaughter compare to best practice for humane slaughter of other species killed for commercial purposes.

4) To use short extracts from the papers and thesis as 'headings' for short discussions during which issues raised in the papers [1,2,3,4] are briefly discussed.

1.0 Introduction

The International Convention for the Regulation of Whaling (ICRW) was signed on 2nd Dec 1946. The International Whaling Commission (IWC), created by this treaty, had its first meeting in 1949. At time of writing (April 2005) 61 nations are members of the organisation, and the convention emphasises that amendments to the schedule should be 'based on scientific findings'. Over a number of years, welfare aspects of the slaughter of whales have been discussed within the Commission in relation to commercial and scientific whaling.

The IWC has a mandate to consider the welfare issues associated with hunting cetaceans under the ICRW. In 1957 the IWC agreed the following definition for humane killing:

The process by which the animal is rendered instantaneously insensible until death supervenes.

During the first working party on humane killing, convened in 1959, it was agreed that the time taken for a cetacean to die would be the main indicator of the humanness of a hunt. This is an important quantitative premise and has been the main focus of all subsequent consideration of the humane aspects of the hunting of cetaceans by the Commission.

In 1979 Professor H.C. Roswell of the University of Ottawa, presented an 'Assessment of harpooning as a humane method in whales' to the IWC (Roswell 1979). The presentation of Professor Roswell's report lead the Commission to adopt a series of Recommendations on the humane killing of whales. These recommendations included;

1 that more data on killing techniques were required and that data on the time the harpoon was first fired, the time of presumed death and the criteria used to determine death should be provided for an adequate and representative sample;
2 that data on the position of the harpoon in the carcass and if possible an evaluation of the nature of the injuries caused should be provided
3 that the IWC should seek to sponsor a workshop meeting of invited experts to consider methods of improving existing techniques, or to suggest alternative, more humane methods;
4 that the use of the cold grenade for killing all whale species larger than the minke whale should be prohibited; and
5 that every attempt should be made to investigate ways and means to shorten time-to-death by improving existing methods or developing alternative methods of killing small whales such as minke whales.

It was also recommended that the time from impact of the first harpoon to the time of presumed death and the position of the harpoon and the nature of the injuries caused should all be collected from the same whale so that times to death could be compared with the nature of the injuries caused.

Professor Rosswell's report, and the adoption of these recommendations marked a change in IWC philosophy, in which the Commission began to consider humane issues associated with hunting cetaceans in a systematic and scientific manner.

During the 1980's, instantaneous death rates remained low in all hunts and progress on improving times to death for hunted whales was slow. The Commission adopted a number of resolutions that addressed specific concerns relating either to the killing methods used, or to the collection and provision of data on whale killing. In total 16 resolutions relating to the killing of cetaceans have been adopted by the Commission, demonstrating both the will of the majority and the competency of the Commission to address these issues.

In recent years a Working Group on Whale Killing Methods and Associated Welfare Issues (WKM&AWI) has been convened annually. This group provides a forum for discussing the data on the killing of cetaceans presented by Contracting Governments. In addition a number of Workshops have also been convened, with the purpose of gathering experts to discuss the technical aspects of killing cetaceans.

The outcome of this work has been the development of an Action Plan on Whale Killing Methods. At subsequent meetings this action has been updated and revised to take into consideration any new issues raised or any technical developments. The purpose of the Action plan is to provide a clear direction for the Commission in addressing the welfare issues inherent in hunting and killing cetaceans. A workshop on whale killing methods, held in Glasgow 1992, recommended that further research should be carried out to determine criteria for the assessment of loss of sensibility and TTD (time to death) in hunted cetaceans.

In 1995 the IWC recognised that *'The IWC criteria used to indicate death in whales are incomplete and under some circumstances may be misleading'* - and identified that robust science was required in two major areas (Table 1);

Table 1 IWC Research requirements

- Examination of the trauma, and its consequences, caused by harpoons and other devices used to capture whales, and its relationship to the reactiona in captured whales. In partucular, this work should focus on elucidating the effect of explosive harpoons and projectiles.

- The determination of better criteria for determining the time of onset of permanent insensibility in whales.

Dr Knudsen[A] states in the thesis [5] that the following issues are addressed in the papers 1,2,3 & 4;

1) *Depending on where the grenade detonates, which pathological changes do the penthrite blast cause, in particular in the central nervous system (CNS) of minke whales, and what is the role of blast induced neurotrauma in loss of consciousness and death in hunted minke whales?*

2) *Do the currently used rifle calibres and ammunition cause sufficient damage to the CNS of minke whales to account for an instantaneous loss of sensibility?*

3) *Are the criteria for death in whales set by the IWC valid to determine TTD in whales?*

General Questions

Do the Norwegian studies fully address the areas which Dr Knudsen outlines above in points 1, 2 ,and 3? And how does this work relate to the IWC research requirements found in Table 1?

Do the papers [1,2,3,4] address point 1 (above) - The pathological and histological changes are fully described by Dr Knudsen, but the issue of loss of consciousness and death, which are the focus of the debate on the welfare impacts of whaling, are less clearly addressed. The comments in this review are intended to identify areas where Dr Knudsen has made claims that do not appear to be fully justified by the findings of her studies.

Do the papers [1,2,3,4] address point 2 - The issue of instantaneous loss of sensibility following shooting is once again adequately described in terms of the pathologies and histology, but the insensibility issues, and a commentary on the potential for animal suffering, is not tackled.

Do the papers [1,2,3,4] **address point 3** - The third aim of the studies - *(Are the criteria for death in whales set by the IWC valid to determine TTD in whales?)* is not directly addressed in the thesis and papers. The papers [1,2,3,4,5] all intimate that the behavioural measures defined by the IWC are not adequate to define the moment of death - but statistics based on these measures are widely quoted in the papers to provide evidence of improvements in harpoon and grenade efficiency - and no improved 'real time' (as opposed to *post mortem*) measures for determining the time of death are either discussed or proposed. This deficiency is noted in review A (Wotton), Appendix A;

The determination of better criteria for assessing the time to onset of permanent insensibility in whales [5] *Is an area that has been largely ignored by the author* [A].

2.0 Sampling of the animals

In any study of this type it is important that it is made clear how the animals were selected. The animals were collected over four seasons (1997, 1998, 1999, 2000) and Dr Knudsen spent eight months in the field collecting the samples. There is no description of the chronology of the sampling and it would be of value if the following points were considered;

- Was every whale that was hunted sampled in order?
- Were animals only selected which showed a rapid death, and others excluded?
- Were animals which had experienced harpoon impacts in specific regions of the body chosed so as to explore the whole range of influences of impact site on TBI?
- As the study was carried out around about the time of the introduction of the 'Whalegrenade 99', were all, none, or a portion of the animals harpooned using this grenade, or the earlier version. This information is not clear from the sampling description and this makes a critical difference to references to effectiveness of current versus old harpoon designs.

If animals were selected in the order in which they were killed, this is not clearly apparent in the Knudsen papers [1,2,3,4].

Two of the reviewers comment specifically on this aspect, a quote from one illustrates this point

Throughout the thesis and papers the authors refer to, and discuss, the implications of their research on the debate relating to the welfare aspects of the Norwegian commercial whaling industry. Given the paucity of good scientific studies conducted on the welfare aspects of whaling, including the scientifically valid estimation or determination of time to death (TTD), the research of Dr Knudsen and colleagues reported in these papers is of undoubted merit and will be scrutinised widely. It is therefore critical to this debate that the 66 cases presented in these papers are as representative of the Norwegian whaling industry as a whole, and that no whales were excluded from this study if they met the relevant criteria of being either killed by a single grenade, or being killed by grenade impact followed by deployment of the back-up rifle. If any whales were excluded, despite satisfying these criteria, a full explanation for these exclusions should be provided in order to have complete confidence that these studies are entirely representative of the Norwegian whaling industry as a whole. [C]

2.1 Summary data

The information in the papers[1,2,3,4] is spread across a number of pages and is repeated with a different focus for each of the papers. Below is a simplified digest of the data to help clarify the numerical data presented in the studies and reduce the risk of confusion that can occur when the same samples are used in multiple reports, and interpreted in these reports in differing ways.

Figure 1. Summary chart for the outcomes of the 69 animals described in Dr Knudsen papers.

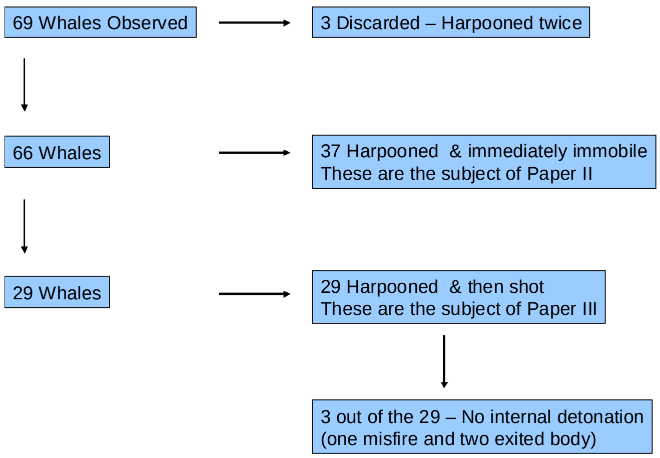


Table 2. Summary statistics for the processes performed on the 69 whales in Dr Knudsens studies [12,3,4].

Group	**Proportion**	**Est. Percentage**	**Lower 95% CI**	**Upper 95% CI**
Immediately immobile	37/69	54	42	68
Required re-shooting	32/69	46	35	58
Re-shot with rifle	29/69	42	31	54
Re-shot with harpoon	3/69	4.3	1.5	12.0
No internal detonation	3/69	4.3	1.5	12.0

Table 3. Summary of the organ and tissue damage findings from Dr Knudsens paper 2.

Organ & tissue damage	Animals killed by a single detonation	Animals re-shot with rifle (paper III)
Skull	5	0
Spinal cord and thoracic organs	6	2
Spinal cord, thoracic and	1	1
Thoracic organs	19	1
Thoracic/abdominal organs	2	0
Abdominal organs	2	3
Muscle	2	19
Total	37	26

Table 4. Summary of the number of bullets used during re shooting described in Dr Knudsen papers [1,2,3,4].

Number of bullets required	Number of animals
1 bullet	15
2 bullets	10
3 bullets	3
>3 (6 bullets required)	1
Total number of animals	29

Table 5. Summary of the behavioural observations described in Dr Knudsen papers [1,2,3,4].

Animal behaviour	Animals killed by a single penthrite detonation
No movement, slacken jaw and flippers alongside the body 7	7
No movement and relaxed flippers, but closed jaw (animal on its back) 6	6
No movement, slackened jaw, but flippers erected 2	2
Tail shivering, with or without relaxed flippers and jaw 4	4
Convulsions (opisthotonus* and/or tail thrashing) 7	7
Not able to verify the criteria until the whale was at the boat side 9	*9 (after some minutes, 1-5)*
Total	35

*Opisthotonus = Spasm of the body where the head and heels are bent backward and the body is bowed forward.

Table 6. Use of secondary killing methods during Norwegian Commercial Whaling and Japanese JARPA hunts (IWC/55/WK22 2003).

	Season	% of total whales killed on which rifles were used
Norway	1999	57%
	2000	43%
	2001	45%
Japan	1998/99	60.7% (mean bullets 2.6)
	2000/2001	63%(mean bullets 2.2)
	2001/2002	68.4% (mean bullets 2.2)

Paper 3 reports the neuropathological findings in 29 whales deemed not to have been killed by the harpoon-mounted penthrite grenade and were subsequently shot by a .375 or .458 calibre rifle. Of these, 8 had been shot with a .375 calibre rifle and 21 with a .458 calibre rifle. Fifteen had received a single shot, 10 received two shots, three whales received three bullets and one whale received six bullets.

3.0 Harpooning data

The harpoon has two roles - to cause damage to the animal, which will result in its death, and to tether the animal to the boat to allow it to be retrieved. It is has evolved from a device designed primarily for capture rather than killing. One of the reviewers points out the implications of the dual role of the harpoon;

The harpoon is a method designed originally for capture rather than a method designed to result in the immediate loss of consciousness and death of the mammal as the target area for the harpoon is the thorax of the whale and not the head. [A]

As Dr Knudsen states [5] the target area is the thorax of the whale -

'*As in other forms of large game hunting, the gunner is aiming at the thorax of the whale above the white band on the flipper.*

The combination of these factors results in the fact that;

a) The harpoon is not ideally adapted to deliver energy close to the head.
b) The target area is not the head, but the thorax.

Dr Knudsen concludes that the penthrite grenade cannot reliably deliver sufficient energy to cause brain damage if it impacts any further away than 1m from the brain if the impact is in the dorsal musculature, or further caudally than the thorax.

Dr Knudsen notes:

The results suggest that the penthrite grenade does not exert (sufficient) force to induce brain damage when it detonates in the back muscles farther than 1 metre from the brain [5]

The instantaneous or very rapid lethal detonating area ranged from the dorsal skull to the rostral abdomen. [5]

Because hunters are trained to aim at the pectoral fin, and the animal is usually moving (forward) between the moment of firing and the moment of impact, the number of animals in which the harpoon hits in front of the pectoral fin is very small. Calculation shows that the target zone which is likely to induce immediate insensibility is a narrow band of the body about 50cm wide. This narrow effective target zone is approximately 10% of the body length, and shots outside of this zone will not deliver sufficient energy to be assured that the animal is rendered immediately insensible. Harpoon impacts in front of this zone, i.e. those that hit closer to the brain by impacting the rostrum, are rare.

In two of the whales studied, in which detonation of the grenade occurred within the lungs, macroscopically visible haemorrhage was confined to small foci within, and deep to, the dura over the cerebrum[2]. This dural and subdural haemorrhage would not, of itself, be expected to produce significant brain dysfunction. However, the authors also describe microscopic haemorrhages in the thalamus, deep to the fourth ventricle in the brain stem and in the white matter of the cerebellar vermis. One of these two brains had been compressed on the side of the left cerebral hemisphere, presumably during fixation, and it is not altogether clear from the account whether deep brain haemorrhages were found in both of the whales in which detonation of the grenade had occurred within the lungs, or only one of them. In the table that summarises the injuries to the head and brain in these two whales, the findings on microscopy are described as "inconclusive".

Dr Knudsen suggests that, along with the local damage caused by the grenade, that the explosion may also accelerate the whole torso;

However, other mechanisms may also explain the intracerebral haemorrhages in the whales, including that the blast causes rapid acceleration of the torso that cause displacement of the brain resulting in deep intracranial haemorrhages and tearing of the many bridging veins in the meninges [5]

It seems unlikely that this comparatively small mass of explosive, combined with the kinetic energy of the harpoon, could cause sufficiently rapid acceleration of the whole mass of the animal (5000 to 8000 kg) so as to cause intracranial haemorrhages and tearing of bridging veins. This statement is not supported by measurement or by a calculation of whether the energy available could achieve this acceleration - and so should be viewed as speculation only and not the basis of a proven part of the process of killing, or as a clear finding of the studies.

3.1 Mis-fire of the grenade

Mis-fire of the grenade at the tip of the harpoon results in the potential for significant suffering, and Dr Knudsen does not acknowledge this possibility. Data from the 2001/2002 Japanese Whale Research Program season indicated that the Norwegian grenade (the newest design) mis-fired on 4.8% of occasions, and the Japanese (original design) on 14% of occasions. It would appear that, in the hunts conducted by Japan in the Southern Ocean, at least 4.8% of harpoons mis-fire, and it must be assumed that this can result in prolonged TTD for whales subject to a misfire, as they must be killed using a second harpoon, or by rifle shooting. In the papers reviewed here, the grenade did not misfire on any occasion, but 3 animals (4.3%) required two harpoons, and in 3 animals (4.3%) the grenade exploded outside of the body.

3.2 Claims for percentage harpooning efficiency

Dr Knudsen refers to previous data gathered in 1993 (Øen 1995, 1999) in which Instantaneous deaths were recorded for 54% of whales. The summary of data from Dr Knudsen studies (Table 1) indicates, that based on the established IWC criteria, 54% of whales described in Dr Knudsen's papers and thesis [1,2,3,4,5] became immediately immobile. It would appear that both the 1993 data and the Knudsen study closely agree on the percentage of instantaneous deaths, and that this figure, of just over half the animals, can still be considered as a good indicator for animals clearly rendered dead very rapidly. For the remaining 44%, it cannot be assured that insensibility occurred very rapidly, although Dr Knudsen's pathological evidence would promote this view. For the 44% of animals which these studies [1,2,3,4] indicate are not rendered immediately insensible, concern for the animal welfare implications of this will remain a focus for debate within the IWC working groups.

It is apparent that the studies presented by Dr Knudsen do not in fact compare favourably with the percentage of instantaneous deaths of 79.8% stated by Dr Knudsen in paper 5 (p35 referencing Øen, 2001) for the *'whalegrenade 99'* in the 2000 season.

Dr Knudsen quotes Øen (Øen, 2002) with regard to the percentage of animals recorded instantaneously dead in the 2001 season, indicating that in this season 45% of the animals were re-shot with the rifle. This figure agrees very closely with the figures from Dr Knudsen's papers where, of the 69 animals studied, 46% were re shot with the rifle. Dr Knudsen's pathological study implies that many of these re-shot animals were dead before they were re-shot, and Øen maintains that many of the animals were re shot as a matter of routine. However - the facts remain, that in both of these studies, the hunters felt it necessary to re shoot 45% and 46% of animals respectively.

3.2 The difficulty of assessing the animal which dives

After harpooning a significant number of whales dive immediately, and this make assessment of the state of consciousness impossible for a number of minutes;

A significant problem, besides the practical difficulties in performing a post mortem, has been that when an animal sinks or dives after impact it may take several minutes before the criteria can be checked (Øen 1995, 1998, 1999, 2001, 2002) [5]

When animal suffering is a potential outcome of humans' activities (particularly where those activities are conducted for commercial gain), many people consider that the precautionary principle should be applied - i.e. one should assume that suffering may take place until clear and reliable proof is available that suffering is not occurring. The precautionary principle requires us to assume that, during the period when the whale dives following the impact of a harpoon, although we cannot see the animal we should assume that it may be suffering until we can clearly determine that it is not. All calls to assume that submerged animals have died or are insensible should be treated with caution, particularly in view of the fact that a dive may represent a flight response and may require some conscious physical propulsion. Dr Knudsen's pathological techniques may enable a determination of immediate TTD for animals which have dived and could not be assessed for some period until they re-surfaced. The risk of this would be that the hunters, supported by Dr Knudsen's pathological findings, would assume that animals which dive can be considered as likely to be dead or unconscious - whereas it is more logical to assume that a whale which stays submerged for five minutes is actively diving (and so likely to be functioning at a high level, not suggestive of unconsciousness), since it is clear that a dead whale floats on, and to, the surface.

4.0 Rifle shooting issues

Tables 2 and 4 indicate the number of whales on which a large calibre rifle was used as a 'secondary killing' method, in recent years. The rifle is used often - 29 out of 69 (42%) whales in Dr Knudsen's study were shot with a rifle as well as being harpooned. The studies [1,2,3,4] propose that many of the animals were in fact unnecessarily shot as they were either already dead, or showed evidence of sufficient neurotrauma to have been rendered insensible by the harpoon, and so the rifle was used only to 'be sure' and was not essential in many cases.

Dr Knudsen suggests that one round from the rifles used in the Norwegian hunt is highly efficient at causing permanent and very severe brain damage when it hits 'in', or near, the brain or in the upper cervical spine. however, Dr Knudsens work[1,2,3,4] indicates that an average of 2.13 bullets was fired for each of the 29 animals in which the rifle was used (Table 4). From these findings, it may be concluded that, although it appears to be possible to achieve permanent and severe damage with a well placed rifle shot, in practise, achieving this well placed shot is not always possible. During aboriginal hunts, the number of bullets used to kill animals can be very high. Published figures for Gray and Bowhead whales provided by the Russian Federation for the 2002 season, indicate that an average of 52 (small calibre) bullets were used per animal (Anon, 2002).

The size of the brain is described by Dr Knudsen as being 20cm x 20cm x 15cm [5]. The position of the brain is described as in the centre line 55 cm back from the opening of the blowhole in a 5.25 m whale and 75 cm back in a larger whale of 8.50 m. The mean fixed brain weight for the animals studied was 2775g (S.D. 212, range 2322 - 3265 g; n=34) [5] and the mass of the whales in the study was approximately 6000 kg. From this data we can calculate that the brain forms about 0.05 % of the animals mass. The mean body length of the whales in the study was 764 cm (95% CI : 736-791, range 485-885; n=37) and the brain length was 20cm approx. From this data we can calculate that the brain is equivalent to about 2.5% of the length of the animal. Dr Knudsen asserts that a rifle shot within 20cm of the brain will effectively impair nervous function in the animal. This assertion would give a total maximum target area = 20+20+20cm = 60cm in diameter which is approximately 7% of the animals length, a comparatively small target area (Knowles & Butterworth, 2006).

The skull of the minke whale is covered with an extensive layer of blubber (2-10cm) and musculature (10-30cm) [5]. Caudally, near the atlantooccipital joint, the skull is relatively thin (1-2cm) and comprised of hard solid bone tissue. Rostrally, over the brain and in front of it, the skull is thick (5 -15 cm) with a fatty and porous character. The nature of the skull has a bearing on the energy required by a projectile to either penetrate the skull, or to deliver sufficient energy by hydrostatic pressure to cause damage to nervous tissue within the skull.

The following statements are made by Dr Knudsen in the paper on the wounding effects of rifle shooting;

a) The two whales, where the bullet had hit the skull more than 20cm from the brain, were almost identical. They were both re-shot with a rifle because the flippers were held out in an angle and the jaw was closed, and weak movements could be seen in the tail. The first round seemed not to give any particular effect on the animals behaviour. After the second round the flippers relaxed. [3]

b) Three whales were probably dead before the rifle shot, and the damages revealed in the brain may be attributed to the grenade detonation (Knudsen & Øen, 2003 [2]) [3]

c) The overall effect of a high-velocity projectile will therefore generally be much greater than a low-velocity projectile. One of the bullets used in this study had a muzzle velocity well below 750 m/s (622 m/s). However, the results showed that both missiles examined in this study had generated changes in the brain, which are associated more with high- than low-velocity missiles .[3]

d) The full-jacketed bullet is designed to penetrate solid objects and deep into animals without being damaged or deformed. [3]

e) Water has a considerable braking effect on the rifle projectile. In trials on dead minke whales, Øen (1995) found that a 20mm x 66 mm high velocity bullet with impact energy 60kJ, which is about 10 times the impact energy of the rifle projectiles used in the present study, travelling one meter or more through water before hitting the whale, stopped in the blubber. Only direct hits went sufficiently deep into the animal to give the potential to kill the whale. [3]

f) The post mortem examination demonstrated that one single round with round nosed full jacketed bullets of calibre .375, 19.4g / 300gr and calibre .458, 32.4g / 500gr, respectively, are fully capable of penetrating the skull of minke whales. In some whales the bullets have penetrated the whole head and exit holes were demonstrated in the blubber on the ventral side of the whale. [3]

g) For all three calibres markmanship is imperative for the result. It is highly important and essential that the marksman have sufficient and proper anatomical knowledge regarding the position of the brain and cervical spine and have proper training using the gun. [3]

h) *In 2001 79.6% of the animals were recorded instantaneously dead from the grenade detonation. Nevertheless, the hunters used the rifle on 45% of the whales as many fire a round at the brain as a matter of routine when the whale is at the boat side (Øen 2002)*[3]

The comments noted by Dr Knudsen above in points a) to h) highlight a number of points - that marksmanship is imperative, that 45% of animals were shot with a rifle, that bullets can penetrate the skull and travel right through the head, that water has a very pronounced braking effect on the bullets, and that an impact greater than 20 cm from the brain is not likely to bring about an assured death.

Two of the reviewers comment on the interpretation that Dr Knudsen has made of the rifle shooting data produced in the study;

It is interesting to note that the experimental use of different ammunition with rifles for the destruction of minke whales[3] *showed that when soft point bullets were used, none penetrated the skull. The advice given when a firearm is used for the humane killing of livestock (HSA, 1999), is to use soft point bullets, because jacketed rounds will fail to distort sufficiently on penetration to cause the requisite amount of physical damage to the brain.*[A]

And the statistician comments that the combined pathological effects of harpooning and rifle shooting combined make the links and claims the effectiveness of each method difficult to quantify;

The other consideration is that the 'treatment' was not 'being shot using a rifle' but was 'being shot with a harpoon, grenade detonation (in most cases) and then being shot with a rifle'. Thus, for some types of shot the results should certainly not be extrapolated to 'the use of a rifle shot alone'. [B]

Additionally, the paper does not appear to fully address any possible confounding effect of the result of the harpoon hit and grenade detonation and the additive/different effect of the bullet [B]

The Knudsen studies indicate that many animals are shot after harpooning *'as a matter of routine'* It would be of value to receive some clarification on this point - as either the harpoon is effective, or the pathological data suggest that in significant numbers of animals, both a harpoon and a rifle is required to produce the combined neurotrauma described in the studies.

5.0 Issue of sea state

The author indicates that the Norwegian hunt takes place in calm seas, and that this gives a stable platform for accurate harpooning;

'*Hence the hunt is depending on calm sea and little wind (not much more than 5 m/s)* [5]

However, within the same document, the difficulties of carrying out the post mortem work on the moving deck of the ship are discussed;

'*The use of a circular saw and chemicals under additional adverse conditions, such as the time constraints, on a small platform and with the boat rocking in the swells, compounded the difficulties of the procedure* [5]

It seems probable that the movements of the ship, which caused difficulties in carrying out the pathological procedures, would also cause the same difficulties in the accurate firing of a harpoon. One of the reviewers makes the following point;

The problem that may arise is that the current method of choice relies too heavily on the ability of a marksman to hit a moving target from a moving vessel and that the percentage of instantaneous death may never reach an acceptable level. [A]

6.0 Slaughter comparison issues

With livestock species that are processed for food, legislation (WASK, 1995) defines stunning, slaughter and killing as follows:

Stunning - in relation to an animal, means any process which causes immediate loss of consciousness which lasts until death

Killing - in relation to an animal, means causing the death of the animal by any process other than slaughter

Immediate - occurring, acting, or accomplished without loss or interval of time

(**Instantaneous** - an infinitesimal space of time, no death can in fact be instantaneous.)

In his review of Dr Knudsens work, Steve Wotton outlines the best practice of stunning followed by killing that is recognised as offering the best potential to avoid suffering during commercial slaughter;

Stunning and slaughter procedures have the potential to cause fear and pain in animals, therefore stunning should produce brain dysfunction (unconsciousness) before the animal can feel any pain associated with the applied stunning method. It has been suggested that pain perception takes about 100 - 150 ms in mammals (Wotton, 1996). The two permitted methods for stunning livestock prior to slaughter, are mechanical stunning and electrical stunning (electronarcosis) (WASK, 1995). Both these methods meet the criteria for immediacy described above. [A]

The same reviewer points out that the harpoon is a modified capture device, and that it's function and the target site are not optimal in relation to the best practice needed to deliver energy to the head to reliably bring about reliable insensibility;

The harpoon is a method designed originally for capture rather than a method designed to result in the immediate loss of consciousness and death of the mammal. The target area for the harpoon is the thorax of the whale and not the head. The addition of the penthrite grenade could be considered as an adaptation that may produce an effective stun/kill rather than a method specifically designed for this purpose. [A]

It is clear from Dr Knudsens work that she is aware of the limitations of the harpoon as a delivery mechanism for effective stunning energy, and she makes the following points about stunning and it recognition in commercially slaughtered species;

In cattle it has been shown that if the site of stunning is more than 4-6cm from the ideal position, the stunning efficiency is reduced by 60% (Daly 1987) [4]

In practice the effect of stunning has to be judged by more simple means. [4]

NINDS (National Institute of Neurological Disorders & Stroke, USA) criteria cerebral unresponsivity, apnoea, dilated fixed pupils, absent cephalic reflexes and electrocerebral silence. [4]

7.0 TTD & sensibility issues

The criteria stated by the IWC to define death (and hence Time To Death, TTD) are (Anon / IWC 1980);

a) Relaxation of the lower jaw
b) No flipper movement
c) Sinking without active movement

Dr Knudsen makes it clear that the Norwegian hunters have their own interpretation of the criteria;

Immobility was the mostly used criterion in practice in the Norwegian investigations and reports on TTD (ie. Any whale that moved or breathed had to be registered as being alive until all movements ceased unless the inspectors were able to register post mortem findings that clearly indicated that the animal died prior to this (Oen 1995, 1998, 1999, 2000, 2001, 2002) [4]

Table 7 The criteria that gunners applied to judge the death of whales during the 2002/2001 Japanese whale research program.

Criteria	Number
Motionless	514
Slackened Jaw	6
Slackened pectoral fins	8
No reaction to stimulation	1
Tensionless harpoon line	9
Motionless & slackened jaw	24
Motionless & slackened pectoral fins	3
Motionless & tensionless harpoon line	1

It is apparent that these criteria are applied in a non uniform way by the whaling nations (Butterworth *et. al.*, 2003). Table 7 indicates the criteria that gunners applied to judge the death of whales during the 2002/2001 Japanese whale research program. As Dr Knudsen points out in her review, concerns have been raised as to the value of these comparatively simple criteria for defining death. Dr Knudsen argues that, by looking for the histological changes characteristic of Traumatic Brain Injury (TBI) it would be possible to revise the TTD figures provided by applying the IWC criteria. It is likely that any revision would be;

TBI present = defined as immediate death if a harpoon used alone,
or as a reduction in TTD if a rifle used after the harpoon.

TBI not present = retain the TTD derived from observation and
application of the IWC criteria.

It would appear that both the 1993 data and the Knudsen study closely agree on the percentage of instantaneous deaths, and that this figure, of just over half the animals, can still be considered as a good indicator for animals clearly rendered dead very rapidly. For the remaining 44%, it cannot be assured that insensibility occurred very rapidly, although Dr Knudsen's pathological evidence would promote this view. For the 44% of animals which these studies [1,2,3,4] indicate are not rendered immediately insensible, concern for the animal welfare implications of this will remain a focus for debate within the IWC working groups.

In the introduction to the papers [1,2,3,4] Knudsen states that the work carried out addresses the second IWC Research Requirement (Table 1), under the Action Plan on Whale Killing Methods;

The determination of better criteria for determining the time of onset of permanent insensibility in whales.

The reviewers of this research do not consider that any of the papers presented do in fact approach or tackle this research area. In fact, the only true reference to this requirement is a criticism of work reported by the RSPCA in 2001.

The RSPCA has proposed a basic protocol for data collection in relation to whaling operations. According to RSPCA (2001), the aim of the protocol was to encourage whalers to measure a total of 34 parameters that could be used to validate indices of sensibility, either from the deck of the ship, by using inflatable boat or by a diver in the water, and then validate these indices with the used of EEG or Ers recordings. The above proposals require information more relevant for research purposes than for regular catch, and some of the proposed procedures would endanger the safety of the hunters[5].

The reference to the RSPCA work does not reflect the aims and objectives of the RSPCA study. The results of the work resulting from the RSPCA Workshop are published (RSPCA,
Butterworth *et al* (2003) , Butterworth, Kestin & McBain 2004, Kestin, Butterworth & McBain 2003) and these studies endeavour to fulfil the second IWC Research requirement (Table 1) ;

The determination of better criteria for determining the time of onset of permanent insensibility in whales.

8.0 Over generalisation issues

On a number of occasions, Dr Knudsen summarises the findings of the separate studies. It is the view of the authors and the reviewers that the summaries of the research provided by Dr Knudsen on occasion over simplify the findings, and make short summary judgements which cannot be fully supported by the data from this research.

Example 1

Dr Knudsen indicates *"The results demonstrate that intra-body detonation of 30g of penthrite is capable of causing severe and fatal neurotrauma in minke whales.* [1]*"*

Whilst 30g of penthrite is capable of causing severe and fatal neurotrauma in <u>*some*</u> of the animals, the other possible outcomes for these animals (from the sample taken) are represented in Figure 1 of this document.

Example 2

Dr Knudsen indicates *"The results from the present study demonstrated that the .375 and .458 missiles used could fatally damage the brain and kill the animals instantaneously or very rapidly also in cases where they hit and passed as far as 20cm from the brain. In addition, in three cases examined where they had hit the spine in the neck area and in the 2nd thoracic vertebra, the animals died very fast."* [3]

'Very fast' is not a precise measure of the time taken for behavioural, or other, indicators of death to have become apparent. In an area where accuracy is required so that the implications for animal welfare can be considered with clarity, it may be of greater value to the scientific debate to make reference to recorded time intervals, as this is the basis of the TTD (time to death) used in IWC discussions on humane killing aspects of whaling. use of terms such 'very fast' are not of real value or scientific rigour.

Example 3

Dr Knudsen indicates *"When death in whales is solely determined on the basis of these (the existing IWC) criteria, which in practice is immobility, a significant proportion of animals will be recorded as being sensible or alive when they actually are unconscious or dead"* [5]

Conversely, it might be considered that lack of movement does not confidently equate to death. The welfare implications of this possibility are significant, and the application of the precautionary principle would suggest that animals which are immobile <u>may</u> still have the potential to suffer.

Example 4

With respect to the percentage of animals that lose sensibility instantaneously or very rapidly the Norwegian minke whale hunt is on a par with that achieved for several species in commercial abbatoirs. If the minke whale hunt is compared to other kinds of wildlife hunts it is perhaps only certain types of sealing that have documented similar effectiveness. The adverse characteristics that have been used to describe the hunting and killing methods used today in the Norwegian hunt for minke whales are therefore not valid or legitimate. [5]

The assertion that whaling is on a par with commercial slaughter for several species is inaccurate. Levels of 54% immediate insensibility would trigger investigation by the state veterinary examiners in all European states operating under EU Slaughter and Killing Legislation. The review by Wotton[A] makes very clear comparisons between statistics for whaling and for commercial abbatoir practice.

To compare commercial whaling favourably with other wildlife hunts implies that lower standards should be tolerated. For the individual animal, the events surrounding its death are likely to be of significance whether this occurs in a slaughter house, or in the less regulated environment of the ocean.

Example 5

If the grenade detonated in an area ranging from the mid-thorax and forward to the skull, near 100% of the whales lost sensibility immediately or very rapidly. However, sever TBI was also registered when the grenade detonated at the interface between thorax and abdomen (Knudsen & Øen 2003). Further, the study revealed that one round with the currently used rifle calibres and ammunition in the Norwegian hunt is highly efficient in causing permanent and very severe brain damage when it hits in or near the brain or in the upper cervical spine (Oen & Knudsen, 2003) [4]

This summary does not bring to the attention of the reader the following;

a) Only 67% (21 out of 63 animals were <u>not</u> impacted in this are out of Table 3) of animals in the studies[1,2,3,4] were harpooned effectively in the area bounded by the mid thorax and forward to the skull.
b) Although one round of ammunition <u>may</u> cause permanent and very severe brain damage, on average, 2.13 rounds were required for each animal on which the rifle was used (Table 4).

Summary discussion

This independent critique of the various aspect of Dr Knudsen's research, by experts in the relevant fields, demonstrate that some aspects of this research are well considered and executed, however, there remain some significant concerns with this research:

a) There is inadequate description of the sampling decisions taken during the eight months at sea over four hunting seasons. It remains unclear if:

- the 69 whales examined were taken in chronological order without any specific selection
- whether the animals used were truly representative of a random selection of hunted whales from this hunt, and if they were not meant to be a random selection, what criteria were used
- whether these animals were selected from a larger group of animals killed during the period of the study

The lack of clear description of this sampling protocol makes interpretation of the summary statistics difficult and also makes some of conclusions impossible to validate.

b) If a non-random selection was made, is it then legitimate to refer to the results of this study as a barometer of TTD for Norwegian whaling?

c) If the post mortem histological methods proposed in the studies [1,2,3,4] are to be considered as a realistic method for validating the claims of high efficiency in the percentage of whales killed immediately by the

Norwegians and the Japanese, are they practical and reliable?

d) Post mortem techniques of this type have NO effect on the welfare of the individual animal during the hunt, as they cannot influence the decisions made by the huntsmen at the time of the hunt.

e) Whilst the procedures reported in the Knudsen studies are a very positive step forward in achieving the application of science to understand the potential for animal suffering during whaling, the Knudsen studies indicate that 44% of animals were not rendered immediately insensible, and concern for the animal welfare implications of this will remain a focus for debate within the IWC working groups.

Reviewed Material

[1] Knudsen S K, Mørk S & Øen E O (2002) A novel method for in situ fixation of whale brains. *Journal of Neuroscience Methods* 120:35-44

[2] Knudsen S K & Øen E O (2003) Blast induced neurotrauma in whales. *Neuroscience Research* 46:377-386

[3] Øen E O & Knudsen S K (2003) Euthenasia of whales. Wounding effect of calibre .375 and .458 round-nosed full metal jacket rifle bullets on minke whale (*Balaenoptera acutorostrata*) central nervous system. Submitted to *Journal of Cetacean research and Management*

[4] Knudsen S K (2005) A review of the criteria used to asses insensibility and death in hunted whales compared to some other species. The Veterinary Journal 169, 1, p42-59

[5] Knudsen S K (2004) Assessment of insensibility and death in hunted whales. A study of trauma and its consequences caused by the currently used weapons and ammunition in the Norwegian hunt for minke whales, with special emphasis on the central nervous system. PhD Thesis - The Norwegian School of Veterinary Science, Dept of Arctic Veterinary Medicine.

Reviews

[A] Wotton S (2005) Comparison with scientific knowledge of slaughter in other mammals. A review of Knudsen S K - Assessment of insensibility and death in hunted whales.

[B] Knowles T G (2005) A Review of the Statistical Aspects of The PhD Thesis by Siri Kristine Knudsen; "Assessment of the insensibility and death in hunted whales".

[C] Jepson P D (2005) Review of the histological and postmortem techniques used and on the histological findings of the study. Knudsen S K, Assessment of insensibility and death in hunted whales.

[D] Love S (2005) Review of the histological and neuropathological findings of the study; Knudsen S K, Assessment of insensibility and death in hunted whales.

References

Anon - IWC (1980) Report of the Workshop on Humane Killing Techniques for Whales. *International Whaling Commission Report* IWC/33/15

Anon - IWC (2003) Use of secondary killing methods during Norwegian Commercial Whaling and Japanese JARPA hunts IWC/55/WK22

Anon - IWC (2002) Russian Federation statistics for Gray and Bowhead whale hunts. Proceeding of the International Whaling Commission IWC/55/WK 13

Anon - IWC (1980) Report of the Workshop on Humane Killing Techniques for Whales. *International Whaling Commission Report* IWC/33/15

Anon - IWC (1994) Report of the IWC Workshop on Whale Killing Methods. Puerto Vallarta, Mexico. *International Whaling Commission Report* IWC/46/18

Butterworth A (2003) AWSELVA Journal 7, 2, 16-18 ISSN13575540

Butterworth, A. Sadler, L, Knowles T. G. & Kestin S. C (2003) Evaluating Possible Indicators of Insensibility and Death in Cetacea Berlin IWC/55/WK4

Kestin S. C., Butterworth A. & McBain J (2003) A preliminary evaluation of possible indices of sensibility and vitality in captive cetacea. Berlin IWC/55/WK18

Knowles T G & Butterworth A (2006) Immediate immobilisation of a minke whale using a grenade harpoon requires
striking a restricted target area. *Animal Welfare* 15: 55-57

Butterworth A, Kestin S C & McBain J F (2004) Evaluation of baseline indices of sensibility in captive cetaceans Veterinary Record 155, 513-518

Daly C C (1987) Concussion stunning in red-meat species. Proceedings, European Conference on the protection of farm animals. Horsham England.

HSA (Humane Slaughter Association) (1999) Guidance Notes No.3 Humane Killing of Livestock using Firearms. HSA, Wheathampstead.

Ishikawa H (2003) Report on whale killing methods in the 2002/2003 JARPA IWWC/55/WK25

Øen E O (1995) Killing methods for minke and bowhead whales. Dissertation presented for the degree of Doctorate Medicine Veterinariae. Norwegian Veterinary School. NO-0033 Oslo

Øen E O (1999) Improvements in hunting and killing methods of minke whales in Norway. Proceeding of the International Whaling Commission. IWC/51/WK11

Øen E O (2001) Norwegian minke whaling. Proceeding of the International Whaling Commission. IWC/54/WKM & A WI 6

RSPCA 2003 Report of the First International Scientific Workshop on Sentience and Potential Suffering in hunted whales. RSPCA, Horsham, UK

Roswell H.C (1979). Assessment of Harpooning as a Humane Killing Method in Whales. A report to the International Whaling Commission. H. C. Roswell, DVM, DVPH, PhD, Professor, Department of Pathology, School of Medicine, University of Ottawa, Ottawa, Ontario.

Wotton S B (1996) New advances in stunning techniques for slaughter animals. Meat Focus International. 461-465.

Appendix A

Comparison of the Knudsen studies with scientific knowledge of slaughter in other mammals.

Thesis: Assessment of insensibility and death in hunted whales.
Author: Siri Christine Knudsen.
Reviewer: Steve Wotton - University of Bristol, Clinical Veterinary Science

The literature review and applied research, described by the author in her thesis, is well argued and well presented. However, it appears that the scientific independence of some of her claims are biased towards the Norwegian desire to maintain their traditional hunt for minke whales against opposition from many other countries. In addition, the thesis relates the trauma produced by the detonation of the penthrite grenade in the whale to diffuse traumatic brain injury in other species but does not report any research that has been undertaken to evaluate the pain produced by this level of trauma in conscious animals (Knudsen, 2004, page 51, paras 2 & 3). In section 9, Main Conclusions, para 3 it is stated that, "The International Whaling Commission (IWC) criteria of whales are not fully adequate to determine exactly when a whale loses consciousness or dies." However, measurement of brain function in controlled experiments where the immediate action of the harpoon, tipped with a penthrite grenade, on time to loss of consciousness and death (perhaps in stranded whales) were not undertaken by the author or reported from the work of other research scientists.

The harpoon is a method designed originally for capture rather than a method designed to result in the immediate loss of consciousness and death of the mammal as the target area for the harpoon is the thorax of the whale (Knudsen, 2004, page 14, para 2, lines 1 & 2) and not the head. The addition of the penthrite grenade could be considered as an adaptation that may produce an effective stun/kill rather than a method specifically designed for this purpose.

With livestock species that are processed for food, legislation (WASK, 1995) defines stunning, slaughter and killing as follows:
***stunning**, in relation to an animal, means any process which causes immediate loss of consciousness which lasts until death;*
***slaughter**, in relation to an animal, means causing the death of the animal by bleeding;*
***killing**, in relation to an animal, means causing the death of the animal by any process other than slaughter;*

Farm animals have been afforded the status of sentient beings under the Treaty of Amsterdam (FAWC, 2003); therefore we have a moral obligation to exercise a duty of care for animals under our control. As we determine when and where food animals die, there is an ethical obligation, as well as a practical opportunity, to closely control the method of death to minimise pain or suffering to individual animals (Mellor and Littin, 2004).

Pain is a subjective experience, making objective measurements and definition difficult. Webster (1994) defined it as an unpleasant sensory and emotional experience induced by sensations arising from noxious stimuli to nerve endings in tissues that are stressed or damaged mechanically, chemically or thermally. Signals are carried by sensory nerves to the central nervous system (CNS), where their nature and intensity is modulated by chemical messengers of other priorities (e.g. fear, excitement) before impacting upon the conscious mind (Weaver, 2004).

Stunning and slaughter procedures have the potential to cause fear and pain in animals, therefore stunning should produce brain dysfunction (unconsciousness) before the animal can feel any pain associated with the applied stunning method. It has been suggested that pain perception takes about 100 – 150 ms in mammals (Wotton, 1996). The two permitted methods for stunning livestock prior to slaughter, are mechanical stunning and electrical stunning (electronarcosis) (WASK, 1995). Both these methods meet the criteria for immediacy described above.

Mechanical stunning using a captive bolt stunner became commercially available in 1922 (Humane Slaughter Association, 2001) and is designed to be either a captive bolt or a concussion device (WASK, 1995). It remains the principle method of stunning adult cattle in UK abattoirs and renders an animal unconscious through concussion (Gregory, 1998). The devices work by delivering a blow to the skull, thus transferring kinetic energy and causing differential acceleration of the brain within the cranial cavity. Concussion results from the pressure changes that are set up during the oscillation of the brain within the skull. Gregory (1998) describes specific effects on the brain including torsion of the brainstem, impaction injuries, disruption of synaptic transmission, coup and contre-coup injuries and nerve transection if a penetrating bolt is used. Haemorrhaging from damaged blood vessels can cause an increase in cerebral pressure, leading to ischaemia and prolonging the period of unconsciousness (Gregory, 1998). An evaluation of the effects of the concussive device by Finnie (1995) produced the same picture of impaction damage and extensive haemorrhaging. After stunning, the animal should be slaughtered immediately as once the effects of the concussion have worn off, consciousness can be regained due to the presence of normal cardiac function.

Assessment of effective mechanical stunning is identified by the absence of rhythmic breathing movements, which indicate Stage 4 concussion. In Stage 4 concussion the subject is prostrate on the ground and there is no breathing (Gregory, 1998). In addition, following an effective captive bolt stun the animal should immediately collapse, become rigid with its forelimbs extended and hind-legs tucked under the abdomen. The eyes should have a fixed, glazed appearance. There should be no positive corneal (eye) reflex and no rhythmic breathing (FAO, 2004). Heart action, however, does not stop but continues for some time (3 - 4 min).

Electrical stunning (electronarcosis) is achieved through the passage of sufficient electrical current across the brain of an animal to produce a tonic clonic epileptic fit. This is analogous to a human being undergoing a 'tonic clonic' or “grand mal” epileptic fit. During this fit an epileptic human is always unconscious, therefore a similar brain condition in animals is analogous to a stunned state (Wotton, 1995, 1996).

Research in New Zealand (Cook, 1993) has demonstrated that epileptiform activity is generated in the brain through the over-stimulation of nerve endings by the stunning current. The "over excitation" stimulates the release of two neurotransmitters (glutamate and aspartate) which at very high levels of production result in epileptiform activity in the brain. Research has demonstrated that passing a 1.0 amp current (50 Hz, 500 V) for less than 0.2 s, through the head of a sheep does not produce a seizure-like state as evidenced by recorded electroencephalogram (Cook and others, 1995). Therefore, the production of epileptiform activity in the brain may not be immediate (<200 ms) however, the application of high amplitude alternating current (AC) to neural tissue will inhibit normal function for the duration of current application, thus bridging a possible gap between the start of current application and the initiation of epileptiform activity. The criteria for immediacy, is therefore assured.

When brain dysfunction is induced either by physical trauma, ischaemia or hypoxia a ‘quiet’ electroencephalogram is present although the carcass can display vigorous convulsions (Gregory, 1993, Wotton, 1995). The epileptiform activity following electrical stunning continues for approximately 30 to 45 seconds until the animal relaxes when epilepsy ends. Soon afterwards it will resume rhythmic breathing movements and begin the recovery process provided exsanguination has not taken place.

Assessment of effective electrical stunning (electronarcosis)
Tonic Phase (duration 10 – 12 s)

- Animal collapses and becomes rigid
- No rhythmic breathing
- Forelegs extended and hindlegs flexed into the body

Clonic Phase (duration 20 – 35 s)

- Uncontrolled kicking or paddling movements
- Eye roll or flicker and salivation

Termination of the clonic phase will lead to the return of breathing and subsequent recovery in an unbled animal. Therefore, effective stunning and slaughter can be characterised by the absence of rhythmic breathing from the initiation of the stun through to the death of the animal (FAO, 2004).

The duration of unconsciousness produced by the stunning method should last until the death of the animal (WASK, 1995). Therefore, for head-only electrical stunning of pigs, given:
(a) minimum time to recovery of rhythmic breathing = 37 s, and
(b) maximum time to loss of brain responsiveness following exsanguination = 22 s
The maximum stun start to stick (exsanguination) interval is 15 s.

The above calculation (Anil and others, 1997) is based upon controlled experiments and relies on the application of the electric current in a position that spans the brain and the severance of major vessels close to the heart by thoracic stick.

Traditionally, livestock are stunned and slaughtered (a two-stage process) or killed (a one-stage process) before processing for food. However, whatever method is employed, the target organ is the brain and a great deal of research effort has been spent refining the methodologies employed by the meat industry to ensure that a high proportion of animals are stunned and slaughtered humanely.

The use of mechanical stunning methods is governed by legislation (Schedule 1, Part 1, WASK, 1995):
5.- (1) No person shall use, or cause or permit to be used, a captive bolt instrument to stun any animal unless-
(a) subject to sub-paragraph (3) below, the instrument is positioned and applied so as to ensure that the projectile enters the cerebral cortex;
Electrical stunning methods are also directed at the brain (Schedule 1, Part 1, WASK, 1995):
8. No person shall use, or cause or permit to be used, electrodes to stun any animal unless-
(a) the electrodes are so placed that they span the brain, enabling the current to pass through it.
Therefore, the methodology described for minke whales, does not identify the brain as the primary target for the harpoon but relies on the proximity of the penetration combined with the destructive force of the grenade to produce concussion and death.

The references that were quoted for the effectiveness of stunning methods in abattoir surveys (page 75 lines 3-5) gave comparable results to the 80% success rate claimed within this study. However, the reference to the survey of cattle bolt stunning in British abattoirs by Daly and Whittington (1992) produced results that 6.6% of animals were shot more than once. In response to these results, action was initiated by the UK government to improve the accuracy and effectiveness of captive bolt stunning of cattle, which led to a change in the legislation (5th July 1992). The compulsory use of head restraint was introduced in the UK, in order to enhance the welfare of cattle at slaughter by improving the accuracy of stunning. (Schedule 4, WASK, 1995): *3. Without prejudice to the generality of paragraph 2 above, no person shall. . . . stun, or cause or permit to be stunned, any adult bovine animal, unless at the time it is stunned it is either confined in a stunning pen which is in good working order or its head is securely fastened in such a position as to enable it to be stunned without the infliction of avoidable excitement, pain or suffering;* In a report on head restraint at slaughter, the Humane Slaughter Association (HSA) (1995) demonstrated that passive head restraint systems (those with no moving parts) improve the accuracy of stunning without increasing the length of time spent in the stunning box without causing the animals increased stress. Therefore, proactive action was taken which has been demonstrated to improve the accuracy of captive bolt stunning of cattle rather than simply accepting the results of the survey.

The unacceptably poor practice that was highlighted by Anil and McKinstry (1993) in pig abattoirs (page 75 lines 4-5) also produced immediate corrective treatment. They reported that 36% of pigs were stunned with less than optimal electrode positions and in 15% of animals a second application of the tong electrodes was required to ensure an effective stun. Additionally, the average applied electrical current was less than the minimum recommended current of 1.3 amps for pigs. As a result of this survey MAFF issued a new set of guidelines for the industry (MAFF, 1993) to address the problems of poor practice and amended legislation to include the following clause: Regulation 14 (b) (ii) of the Slaughter of Animals (Humane Conditions) Regulations (1990) states:
(b) any electrical equipment used for stunning an animal in the slaughterhouse or knacker's yard –
(ii)contains a device which will prevent it from delivering a current below that which it has been set to deliver.
This clause was incorporated in the Council Directive 93/119/EC of 22 December 1993 and formed part of Schedule 5 Part II of WASK (1995) as follows:
9. No person shall use, or cause or permit to be used, electrodes to stun any animal individually unless the apparatus-
(a) incorporates a device which-
(i) measures the impedance of the load; and
(ii) prevents operation of the apparatus unless a current can be passed which is sufficient to
render an animal of the species being stunned unconscious until it is dead;
This legislative requirement has been referred to as providing 'fail-safe' operation (Wotton and Whittington, 1994). However, no equipment manufacturer has been able to meet this legislative requirement because research has shown that for live pigs, no significant correlation could be determined between the pre-stun low voltage sensed impedance

and the actual, higher voltage stun impedance. They also showed that the impedance of a live pig's head was predominantly a function of the stunning voltage and it decreased non-linearly with increasing voltage (Wotton and O'Callaghan, 2000). They concluded that 'fail-safe' devices based on low voltage pre-stun sensing are unlikely to meet the current legislative requirements.

Exsanguination is the process of bleeding a stunned animal to produce death. The majority of stunning systems do not kill, e.g. head only electrical stunning, and simply render the animal unconscious for a sufficient period to allow the animal to die following the severance of major blood vessels. Death can be defined as the irreversible breakdown of the central nervous system (CNS). Brain failure or death, can be diagnosed objectively through the production of an isoelectric EEG or, through the irreversible failure of specific neural pathways. The visual pathway is a basic one that links the retina with the visual cortex. The evoked response to photic stimulation of the retina can be measured in the visual cortex with implanted electrodes. Signal averaging techniques provide accurate and consistent estimation of brain failure and through the use of a system of moving averages, the time to loss of brain responsiveness to visual stimuli can be identified (Gregory and Wotton, 1984).

Killing is defined in the WASK regulations (1995) as "causing the death of an animal by any process other than slaughter." This can be achieved with livestock species by the use of a free bullet, electrocution, and in pigs and poultry, exposure to gas mixtures. Electrocution is a method that induces an effective stun and ventricular fibrillation (cardiac arrest) simultaneously or sequentially. The induction of an effective stun is important because the cardiac arrest caused by the passage of electrical current through the animal and in particular, cardiac muscle is very painful (Cook and others, 1991). Some systems employ a stun/kill process, where the animal is first electrically stunned and then immediately killed by an electrically induced cardiac arrest. This has the effect of promoting the start of the death process to the stunning point, which has advantages for both animal welfare and operator safety. The use of an irreversible, head-to-body electrical stun incorporating cardiac fibrillation and spinal discharge, can be used for cattle. Jarvis Equipment (N.Z.) Ltd. produce a Beef Stunner which is in commercial use in the UK. It is programmed to run three cycles sequentially; (i) a head only cycle, to stun the animal, (ii) a cardiac cycle, to induce ventricular fibrillation (cardiac arrest), and (iii) a spinal discharge cycle, employed to reduce post kill convulsions. However advantageous the use of automated electrical systems, post-stun responses are difficult to categorise and therefore commercial welfare assessment of the Beef Stunner is difficult. Recent research (Moreno, 2004, Weaver, 2004) together with personal experience has produced the following welfare assessment for cattle that have been processed using a Jarvis Beef Stunner:
Where cattle have been hoisted for slaughter, look for:

- Correct thoracic stick
- Decreasing muscle tone in fore limbs
- Decreasing muscle tone in free hind leg (dropping)
- Ears lowering slowly
- Tongue extending from mouth
- Fixed glazed expression of eyes (no corneal reflex)

Where there is any doubt, slaughtermen are advised to shoot with a captive bolt gun. (www.AWTraining.com, Jarvis Masterclass)

The use of a rifle as a back-up weapon (Knudsen, 2004, page 13, para 3, lines 2 & 3) is to be commended however, in a livestock abattoir, the back-up system is applied immediately after a failure of the primary system, whereas with whaling there is a significant delay whilst the whale is brought alongside the boat (Knudsen, 2004, page 15, para 1).

The IWC workshop (1980b) recognised that it was difficult to decide exactly the moment of death of a whale (Knudsen, 2004, page 23, para 1, lines 4 & 5). However, they failed to promote research to link physiological/neurological indices with behavioural symptoms that may have validated their criteria.[*]

The argument against the possible research and development of alternative methods that may be more humane was focused on the opinion that the hunting of whales was a sideline activity and the profitability of each vessel was limited (Knudsen, 2004, page 24, para 1, lines 3 - 11). The decision about the possible adoption of new technology can only be based upon the available evidence and further research should be encouraged to provide this evidence. The trials that were carried out did suggest that 18 g penthrite was sufficient to kill a minke whale instantaneously if the detonation occurred centrally in the thorax near the spine (Knudsen, 2004, page 25, para 2, lines 7 & 8). If we

were to accept the methodology for identifying brain death behind this claim, the logical next step is to determine how we can guarantee the accuracy of the detonation. Training and equipment maintenance improved the percentage of 'instantaneous deaths' to 45% between 1984 and 1986 (Knudsen, 2004, page 26, para 1, lines 1 - 8), a success rate that was acceptable to the IWC. This level of effective killing would not be acceptable with livestock species. However, the adoption of mandatory training (Knudsen, 2004, page 29, para 1, line 5) and improved weapon maintenance, resulted in an improvement in the incidence of instantaneous death from 54% in 1993 to 59% in 1994 (Knudsen, 2004, page 29, para 1, lines 19 - 22).
[*Editorial note - This issue was addressed by the IWC in the Action Plan on Whale Killing Methods and then the Revised Action Plan on Whale Killing Methods – which states under point 5 of the current Revised Action Plan adopted in 2003 (IWC/55 Rep 5, Appendix 4):
'Develop better criteria for determining the onset of permanent insensibility in whales, using physiological and behavioural observations'
The IWC identified this as a priority as far back as 1995, but, to date research has not adequately addressed this issue.

The IWC workshop agreed to recommend that further research should be undertaken to investigate the basis of agreed criteria for assessment of loss of sensibility and time to death (TTD) in whales under controlled conditions to establish baselines (Knudsen, 2004, page 28, para 2, lines 8 - 13). However they recommended the use of *post mortem* examinations as a way of retrospectively assessing the induction of unconsciousness and death. Research with mechanical stunning of cattle has emphasised the importance of observations made at the time of stunning and slaughter rather than retrospective assessment of the trauma produced (Whittington, personal communication). In addition, neurophysiological techniques have been used to assess stunning, slaughter and killing methods in other species (Wotton and Gregory, 1986, Gregory and Wotton, 1989) including fish (Robb and others, 2000, Robb and others, 2002).

The significant problem that is faced by veterinarians and hunters in assessing the effectiveness of the killing method at sea is that the animal may sink or dive after impact and that it may take several minutes before the criteria can be checked. (Knudsen, 2004, page 30, para 1, lines 11 - 13). Thus a greater emphasis must be placed on the effectiveness of the killing methodology employed when in certain circumstances the effect on the animal cannot be assessed immediately. With livestock species, the physical responses that can be displayed post-stun can, in the absence of rhythmic breathing, be associated with effective stunning. Similarly, animals that are shot with a free bullet can after a short delay display physical activity or convulsions (HSA, 1999). These symptoms are accepted evidence of an effective stun/kill because they are supported by peer-reviewed evidence. The suggestion (Knudsen, 2004, page 48, para 2, lines 1 - 4) that electroencephalographic methods are subjective is not supported by recent publications (Robb and others 2000, Raj and O'Callaghan, 2004) where quantitative changes can be used to identify effective stunning. The two key research needs that were identified by the IWC (1995) includes:- 2. The determination of better criteria for assessing the time to onset of permanent insensibility in whales (Knudsen, 2004, page 32, para 1, lines 5 - 13). However, it is an area that has been largely ignored by the author.

The examination of trauma and its consequences is well presented and detailed however, the effect of the trauma on whale welfare should the animal remain conscious was not discussed. Throughout the thesis, when welfare issues are discussed, the author does not allow the whale any benefit of doubt when assessing the effectiveness of the methodology employed e.g. as neuropathology has not been possible to conduct in a majority of cases the real percentage of instantaneous death is probably somewhat higher than the reported 80% (Knudsen, 2004, page 72, para 2, lines 16 & 17). However, the progress that has been made within the last 20 years when the percentage of instantaneous death has risen from 17% to 80% (Knudsen, 2004, page 73, para 1, lines 5 - 7) should be recognised but the drive for further improvement must be continued. The problem that may arise is that the current method of choice relies too heavily on the ability of a marksman to hit a moving target from a moving vessel and that the percentage of instantaneous death may never reach an acceptable level. Therefore it is important that alternative methods should be considered and research instigated to determine whether a high percentage of whales can be killed without pain and distress.

The conclusions of Knudsen and Øen (2003) which state that depending on the detonation site, 30 g of penthrite inside the body of a minke whale induces neurotrauma similar to either severe TBI associated with a direct impact to the head or acceleration-induced dTBI, in which the cardinal symptoms are immediate loss of consciousness without any lucid interval and very high mortality rate, conflicts with the description that the final model that went into production contained 22 g penthrite (Knudsen, 2004, page 25, para 2, lines 7 - 9).

Øen E.O. and Knudsen, S. Euthanasia of whales: Wounding effect of rifle calibre .375 and .458 round nosed full metal-jacketed bullets on minke whale central nervous system.
Øen and Knudsen in their introduction (pages 3 – 5) compare the effectiveness of hunting whales with other species. Personal observations by Professor L. Hoffman (Department of Animal Sciences, University of Stellenbosch, RSA) of large scale hunting of springbok in RSA, have shown that the success rate is less than 52 shots to kill 50 animals. As the meat can only be exported if head or high neck shots are fired, of these 50 animals, at least 48 would be clean kills. Professor Hoffman reported that the number of successful shots also depends on various factors, e.g. accuracy and experience of the marksman, wind velocity and direction, etc. and that is not uncommon for a well-trained marksman to shoot more than 50 animals in one evening. These observations would suggest that with hunting game, the expected percentage of instantaneous deaths would be in excess of 95%, which is significantly higher that the 80% quoted for minke whales. It is interesting to note that the experimental use of different ammunition with rifles for the destruction of minke whales (Øen and Knudsen, *) showed that when soft point bullets were used, none penetrated the skull. The advice given when a firearm is used for the humane killing of livestock (HSA, 1999), is to use soft point bullets, because jacketed rounds will fail to distort sufficiently on penetration to cause the requisite amount of physical damage to the brain

Knudsen, S.[†] A review of the criteria used to assess insensibility and death in hunted whales compared to some other species.
The criticism raised against the use of evoked responses (Knudsen [†] page 7, para 2) is valid when scalp electrodes are used in human studies. Their use to identify the loss of residual consciousness in livestock species and fish, where electrocorticograms can be recorded using implanted electrodes is well recognised (Daly and others, 1986, Gregory and Wotton, 1983, Mouchoniere and others, 2000, Robb and others 2000, Raj and O'Callaghan, 2004).

The reduced effectiveness of the application of a captive bolt when applied in the poll position (Knudsen [†] page 12, para 2, lines 14 & 15) for horned sheep and goats is recognised in UK legislation (WASK, 1995) by the caveat that animals must be bled within 15 s of the shot. It is important (Knudsen [†] page 15 & 16) that two approaches are used to determine the effectiveness of electrical stunning, firstly to test the efficiency of the equipment and secondly, to evaluate the animals physical behaviour (Gregory, 1991). However, these criteria were chosen based on published scientific evidence that for example, assessed the physiological basis for effective electrical stunning (Cook and others, 1995), assessed the minimum current required to produce an effective stun (Hoenderken, 1978) assessed the optimum electrode positions (Anil and McKinstry, 1998), etc., evidence that was not available when the IWC selected their criteria. In addition, the key research needs outlined on page 22, para 1 (Knudsen [†]), should include studies to determine the effect of such trauma on brain function and consciousness in controlled experiments. Nevertheless, it must be noted that if the detonation of a 22 g penthrite grenade in a known position of a minke whale will produce a humane kill, research can be directed at ways to improve the accuracy of the strike. The report that the IWC made in 1992 (Knudsen [†] page 32, para 2) that EEG recording should be made in either controlled experiments or in countries where whales commonly strand should in my opinion, have been conducted initially to form a basis for the neuropathological and the observed behaviour studies.

References

Anil, M.H. and McKinstry, J.L. 1993. Results of a survey of pig abattoirs in England and Wales. Ministry of Agriculture, Fisheries and Foods, Tolworth, UK.

Anil, M.H. and McKinstry, J.L. 1998. Variations in electrical stunning tong placements and relative consequences in slaughter pigs. The Veterinary Journal. 155, 85-90.

Anil, M.H., McKinstry, J.L. and Wotton, S.B. 1997. Electrical stunning and slaughter of pigs. Fleischwirtschaft 77 (5) 473-476.

Cook, C.J., Devine, C.E., Gilbert, K.V., Tavener, A. and Day, A.M. (1991) Electroencephalograms and electrocardiograms in young bulls following upper cervical vertebrae-to-brisket stunning. New Zealand Veterinary Journal. **39**, 121-125

Cook, C.J. 1993. A guide to better electrical stunning. Meat Focus International. March 128-131.

Cook C.J., Devine C.E., Gilbert K.V., Smith D.D., Maasland S.A. 1995. The effect of electrical head-only stun duration on electroencephalographic-measured seizure and brain amino-acid neurotransmitter release. Meat Science 40 (2): 137-147.

Daly, C.C., Gregory, N.G., Wotton, S.B. and Whittington, P.E. 1986. Concussive methods of pre-slaughter stunning in sheep: assessment of brain function using cortical evoked responses. Research in Veterinary Science. 41, 349-352.

Daly, C.C. and Whittington, P.E. 1989. Investigations into the principal determinants of effective captive bolt stunning of sheep. Research in Veterinary Science. 46, 406-408.

Daly, C.C. and Whittington, P.E. 1992. Survey of captive bolt stunning in British abattoirs. RSPCA, Horsham, UK.

FAO Animal Production and Health. Rome 2004. Good practices for the Meat Industry. Manual. ISBN 92-5-105146-1. Section 7 pp 6.

Farm Animal Welfare Council. (2003). Report on the Welfare of Farmed Animals at Slaughter or Killing. Part 1: Red Meat Animals. London.

Finnie, J.W. (1995). Neuropathological changes produced by non-penetrating percussive captive bolt stunning of cattle. New Zealand Veterinary Journal, **43**, 183-185.

Gregory, N.G. 1991. Humane slaughter. Outlook on Agriculture. 20, 95-101.

Gregory, N.G. 1998. Animal Welfare and Meat Science. CABI Publishing, Wallingford, Oxon OX10 8DE, UK.

Gregory, N.G. and Wotton, S.B. 1983. Studies on the central nervous system: visually evoked cortical responses in sheep. Research in Veterinary Science. 34, 315-319.

Gregory, N.G. and Wotton, S.B. 1984. Sheep slaughtering procedures. 2. Time to loss of brain responsiveness after exsanguination or cardiac arrest. British Veterinary Journal. 140, 354-360.

Gregory, N.G. and Wotton, S.B. 1989. Effect of electrical stunning on somatosensory evoked potentials in chickens. British Veterinary Journal. 145, 159-164.

Gregory, N.G. and Wotton, S.B. 1985. Sheep Slaughtering Procedures. IV. Responsiveness of the Brain Following Electrical Stunning. British Veterinary Journal 141, 74.

Hoenderken, R. 1978. PhD thesis. University of Utrecht.

Humane Slaughter Association. 1995. Head restraint at slaughter. HSA, The Old School, Brewhouse Hill, Wheathampstead, Herts. EL4 8AN.

Humane Slaughter Association. 1999. Guidance Notes No.3 Humane Killing of Livestock using Firearms. HSA, Wheathampstead.

Humane Slaughter Association. 2001. Guidance Notes No.2 Captive Bolt Stunning of Livestock 3rd Edition. HSA, Wheathampstead.

Knudsen, S. and Øen E.O. 2003. Blast-induced neurotrauma in whales. Neuroscience Research 46, 377-386.

Knudsen, S.[†] A review of the criteria used to assess insensibility and death in hunted whales compared to some other species. (note: has this been published)

MAFF. 1993. Guidance for slaughterhouse operators - Manual Electrical Stunning of Pigs. Meat Hygiene Division, Tolworth, London.

Mellor, D.J. and Littin, K.E. 2004. Using science to support ethical decisions promoting humane livestock slaughter and vertebrate pest control. *Animal Welfare*, **13**, S127-S132.

Moreno, R.L. 2004. Monitoring the operation of a Jarvis Beef Stunner. MSc Dissertation, University of Bristol.

Mouchoniere, M., Le Pottier, G. and Fernandez, X. 2000. Effect of current frequency during electrical stunning in a water bath on somatosensory evoked responses on turkey's brain. Research in Veterinary Science. 69: 53-55.

Øen E.O. and Knudsen, S. * Euthanasia of whales: Wounding effect of rifle calibre .375 and .458 round nosed full metal-jacketed bullets on minke whale central nervous system. (note: has this been published)

Raj, A.B.M. and O'Callaghan, M. 2004. Effects of electrical waterbath stunning current frequencies on the spontaneous electroencephalogram and somatosensory evoked potentials in hens. British Poultry Science. 45, 230-236.

Robb, D.H.F., Wotton, S.B., McKinstry, J.L., Sorensen, N.K. and Kestin, S.C. 2000. Commercial slaughter methods used on Atlantic Salmon: determination of the onset of brain failure by electroencephalography. Veterinary Record. 147, 298-303.

Robb, D.H.F., Wotton, S.B. and van de Vis, J.W. 2002. Preslaughter electrical stunning of eels. Aquaculture Research. 33, 1-6.

The Welfare of Animals (Slaughter or Killing) Regulations. 1995 Statutory Instrument No. 731 (London HMSO).

Weaver, A.L. 2004. Jarvis Beef Stunner: The effect of electrode position on the cardiac arrest cycle and post stun/kill movement. MSc Dissertation, University of Bristol.

Webster, J. 1994. Animal Welfare: A cool eye towards Eden. Blackwell Science Ltd, London. 273pp.

Wotton, S.B., O'Callaghan, M. 2002. Electrical stunning of pigs: the effect of applied voltage on impedance to current flow and the operation of a fail-safe device. Meat Science. Vol 60/2, 203-208

Wotton, S.B. and Whittington, P.E. 1994. Measured resistance. Meat Trades Journal. July, 21, 8-9.

Wotton, S.B. and Gregory, N.G. 1986. Pig slaughtering procedures: time to loss of brain responsiveness after exsanguination or cardiac arrest. Research in Veterinary Science. 40, 148-151.

Wotton, S. 1995. Stunning in pigs. Meat Focus International. 4 (3), 105-108.

Wotton, S.B. 1996. New advances in stunning techniques for slaughter animals. Meat Focus International. 461-465.

Appendix B

A Review of the Statistical Aspects of The PhD Thesis by Siri Kristine Knudsen; "Assessment of the insensibility and death in hunted whales"

By

Dr Toby Knowles

Carried out on behalf of

WSPA

February 2005

Qualifications

I am astatistician at the University of Bristol, School of Veterinary Science. In addition I am a member of the Animal Welfare and Behaviour group within the School with my own programme of research. I have published book chapters and over 100 scientific papers on aspects of animal welfare. I regularly referee scientific papers for a number of veterinary, animal production and animal welfare journals.

I hold the following academic and professional qualifications:-

BSc (Hons) (Agric.)	1986
MSc (Appl. Stats.)	1998
PhD (Cantab.)	1990
CStat Royal Statistical Society	2002
CBiol Institute of Biology	2001

Introduction

I was asked to provide a critique of the statistical aspects of the PhD thesis by Siri Kristine Knudsen; "Assessment of insensibility and death in hunted whales". The thesis contains an Appendix of four paper upon which the study is based. I have limited my review to the papers alone as they provide the scientific basis for the conclusions drawn in the thesis. Paper I is a description of methodology and no statistical questions arise therefore I have no comments to make on this paper. Paper IV is a review paper and again no statistical questions arise, thus I have limited my critique to papers II and III alone.

General

It is necessary to comment that I felt that the thesis (including appendices) was not written at the usual level of objectivity found in the majority of scientific papers. Throughout, the reader gains the impression that the author is pro-whaling. Few researchers are able to retain complete objectivity, however, the work reviewed here is unusual in the strength with which the author's stance was conveyed. When carrying out research, and with the best of will, it is always difficult not to introduce some selection and bias, often subconsciously, into a study. However, my comment is only a qualification and should not detract from what appears to me to be useful science and interesting results. What it does mean is that the reader should more carefully consider how the samples for the study were selected and if the conclusions that are drawn are justified by the results.

The thesis describes a time-consuming study carried out, under what would be difficult conditions, whilst working on commercial whaling boats. The work is relatively well described and reported and the study appears to have been carried out with a good level of practical competency and with the assistance of experts in the field. The thesis is certainly to a level expected for the award of PhD.

The work takes the form of a series of observational studies (as distinct from controlled experiment) in which sixty-six whales were used. Thirty-seven of the whales were documented to have been killed by a single penthrite grenade, and are the subject of paper II, the remaining 29 were hit by the harpoon but required re-shooting with a rifle, and are the subject of paper III. The overall design of the study is heavily constrained by the practicalities of commercial whaling and considerations of animal welfare.

There are some problems with the overall design which are not addressed in the text of the papers nor in the thesis. These inadequacies mean that the conclusions drawn from the results should be considered with a greater degree of qualification than is given by the author in her conclusions. They are described in more detail below. Briefly, the practical constraints on the study affected the way in which whales were sampled, a) for the overall work and b) for inclusion in either the study for paper II or the study for paper III. These limit the types of conclusions which may be drawn from the studies.

<u>Source of material for the papers</u>

The source of material for the study is not adequately described. In order to be able to draw general conclusions about a population as a whole it is necessary to obtain a representative sample from the population. Ideally, in this type of study, a random sample would be taken. However, in this particular case it was impractical to obtain a random sample and only a limited number of boats (two), harpoon guns, their operators and local populations of whales could have been included in the study. Given that the sample could not be representative, the authors need to more carefully describe their sample, its selection and to discuss to what extent it is likely to be representative of what would occur in the population (whaling for Minke) as a whole and to what extent their sample is likely to be unrepresentative. For example, to what extent is their study representative of the accuracy with which animals would be shot, and require re-shooting, by the whole fleet. Were the vessels chosen out of convenience or because of the past record of their crew? To what extent would between-crew hunting style affect the variability of the trajectory of the harpoon through the whale? More detail is required in order to weigh the value of the results and to put them in context.

<u>Paper II – Blast induced neurotrauma in whales</u>

In this study the main conclusion, as stated by the authors in the Abstract, is that "even if several vital organs were fatally injured in most whales [in the present study], the neurotrauma induced by the blast-generated pressure waves were the primary cause for the immediate or very rapid loss of consciousness and death". This conclusion is justified from the results because the authors are referring to the animals in the study. But the conclusions are only justified for the animals in the study – and these animals were chosen, in the first place, because they were observed to demonstrate 'immediate or very rapid loss of consciousness and death' after the impact of the harpoon.

The conclusion cannot be carried over to the wider population as the authors have done in the section 5 (Conclusions) of the paper where they write, " The present study has demonstrated that depending on the detonation site, 30g of penthrite inside the body of a minke whale induces neurotrauma similar to either severe TBI [traumatic brain injury] associated with a direct impact to the head or acceleration-induced dTBI, in which the cardinal symptoms are immediate loss of consciousness without any lucid interval and very high mortality rate." The animals reported in paper II were chosen <u>because</u> they did appear to lose consciousness immediately or very soon after impact. Twenty-nine out of the 66 whales demonstrated that 30g of penthrite inside the body of a minke whale DOES NOT induce neurotrauma similar to either severe TBI associated with a direct impact to the head or acceleration-induced dTBI, in which the cardinal symptoms are immediate loss of consciousness without any lucid interval and very high mortality rate.

The limitations of the conclusions that can be drawn from the study have not been recognised by the authors. The conclusions as stated in the paper are not logically based on their sample and from their results.

The real conclusion that can be drawn from the study is of the nature that 'on some occasions the detonation of the penthrite grenade appears to cause immediate loss of consciousness, and that this may even occur (but at a lesser frequency) when the impact is some distance from the brain'.

Paper III – Euthanasia of whales: Wounding effect of rifle calibre .375 and .458 round nosed full metal-jacketed bullets on minke whale central nervous system.

Paper III describes the examination of the 29 whales judged as “not being instantly dead after the grenade detonation” and describes the rifle shots used in re-shooting. This is essentially a descriptive paper primarily concluding that both types of round are, in some circumstances, capable of penetrating the skull and spine of the whale. This conclusion is fully justified from the results.

The number of shots and the trajectories are reported. My comments above about the representativity of the samples (whales, boats, etc which form the study) applies to these results. For example, the (statistical) distribution of the number of shots required may not be representative of the Norwegian whalers as a whole.

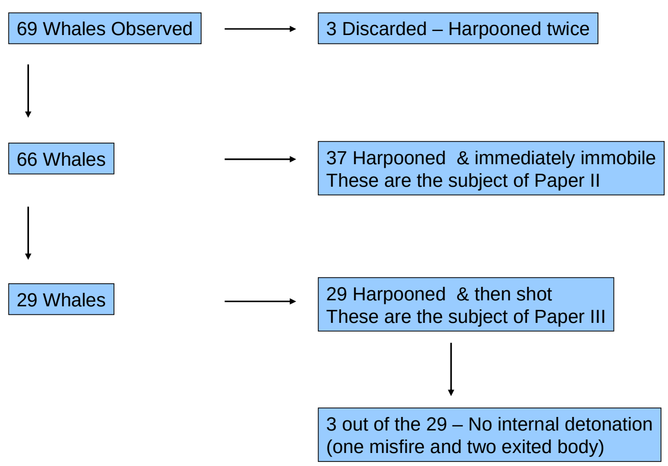
The other consideration is that the ‘treatment’ was not ‘being shot using a rifle’ but was ‘being shot with a harpoon, grenade detonation (in most cases) and then being shot with a rifle’. Thus, for some types of shot the results should certainly not be extrapolated to ‘the use of a rifle shot alone’.

Additionally, the paper does not appear to fully address any possible confounding effect of the result of the harpoon hit and grenade detonation and the additive/different effect of the bullet.

Additional Analysis by TGK

If it is assumed that the data collected by Siri Knudsen are indeed representative of the Norwegian Minke whalers as a whole then it is possible to use her estimates as estimates of what happens in general. It is also possible to obtain confidence intervals for these estimates.

The Figure below summarises what happened to the 66 whales that were observed in the study. The Table below summarises the percentage of whales in each category together with a 95% confidence interval for the estimate (calculated using Wilsons’ method (see Statistics with Confidence (2000) Altman, Machin, Bryant & Gardner BMJ Publications ISBN 07279 13751)).



Group	Proportion	Est. Percentage	Lower 95% CI	Upper 95% CI
Immediately immobile	37/69	54	42	68
Required reshooting	32/69	46	35	58
Reshot with rifle	29/69	42	31	54
Reshot with harpoon	3/69	4.3	1.5	12.0
No internal detonation	3/69	4.3	1.5	12.0

The estimate of the percentage immediately immobile is in good agreement with that of 60 per cent reported by Kestin (Veterinary Record (2001) 148, 304-307).

Appendix C

ZSL Institute of Zoology

LIVING CONSERVATION

Review of papers on neurotrauma and death in hunted whales
Commissioned by the World Society for the Protection of Animals

Paul D. Jepson BVMS PhD MRCVS

Thesis: Assessment of insensibility and death in hunted whales.

Author: Siri Christine Knudsen.

Remit: Review of the histological and postmortem techniques used and on the histological findings of the study.

Papers reviewed

1. Knudsen SK, Mørk S, Øen EO. (2002) A novel method for *in situ* fixation of whale brains. *Journal of Neuroscience Methods* 120: 35-44.

2. Knudsen SK, Øen EO. (2003) Blast-induced neurotrauma in whales. *Neuroscience Research* 46: 377-386.

3. Øen EO, Knudsen SK. Euthanasia of whales: wounding effect of rifle calibre .375 and .458 round nosed metal-jacketed bullets on minke whale central nervous system. PhD thesis.

4. Knudsen SK. (2005) A review of the criteria used to assess insensibility and death in hunted whales compared to some other species. *The Veterinary Journal* 169: 42-59

The four papers formed the basis of Dr Siri Knudsen's thesis for the degree of Doctor Medicinae Veterinariae in The Norwegian School of Veterinary Science: 'Assessment of insensibility and death in hunted whales. A study of trauma and its consequences caused by the currently used weapons and ammunition in the Norwegian hunt for minke whales, with special emphasis on the central nervous system.'

The four papers involved in this review involve the description and interpretation of gross and histopathological lesions in the brain and spinal cord of minke whales hunted as part of the Norwegian whaling industry. Although my research background as the scientific co-ordinator of a national marine mammal research programme incorporates 11 years of experience in marine mammal pathology, neuropathology is a very specialized field in both human and animal studies. I would therefore recommend a specialist in human or animal neuropathology is consulted as part of the review of these papers.

1. Knudsen SK, Mørk S, Øen EO. A novel method for in situ fixation of whale brains. Journal of Neuroscience Methods 2002; 120: 35-44.

In this paper, the authors report on a novel *in situ* technique for the formalin-fixation of the whole brain of 38 minke whales hunted during the Norwegian whaling operations. The technique basically involved the removal of the head (at the atlanto-occipital joint), the mandible, and a triangular section in the back of the skull near the foramen magnum. Fixative, 8% neutral formalin in seawater, was then poured into the cranial cavity and topped up every 4 hours as required for 72 hours until the tissue was sufficiently firm to be successfully removed from the cranial cavity. Immersing the brain in formalin for another 2 months or longer completed fixation. The brain was subsequently sliced coronally, at 1cm intervals, and a standardised suite of brain sections (cerebrum, cerebellum, brainstem and spinal cord) were embedded in paraffin wax, sectioned at 5µm, and stained with haematoxylin and eosin (H&E) (all individuals/sections) and luxol fast blue-Cresyl violet (brainstem and spinal cord of 10 individuals) for histological analysis.

The technique was undoubtedly successful, and 37/38 brains exhibited good or excellent preservation of tissue sections. This method also had advantages in this study over the conventional approach of formalin-fixation (which involves the removal of the brain from the cranial cavity before immersion in formalin), because it avoided the risk of damaging the brain during its removal and overcame the practical difficulties involved when performing this procedure on board a whaling boat. Having personally examined a number of cetacean brains (including two stranded minke whales) using conventional methods of brain removal and formalin-fixation, I was impressed by the tissue quality reported in this paper.

In summary, this paper describes a novel and practical approach to formalin fixation of whale brains that permits a good standard of neuropathological examination with few postmortem artefacts. The methods, sample size and interpretation of results appear appropriate. The authors, quite reasonably, attributed a large proportion of the success to the relatively short interval between death and onset of formalin fixation permitted by this novel technique.

2. Knudsen SK, Øen EO. Blast-induced neurotrauma in whales. Neuroscience Research 2003; 46: 377-386.

Using the methods of brain and spinal cord fixation and tissue examination in the first paper (Paper 1), this paper reports the gross and histological findings in the brain of 37 minke whales killed by a single 30g penthrite grenade harpoon. The study aims to compare the pathological changes in the CNS with the location of impact of the grenade harpoon in order to assess the role of grenade/blast-induced neurotrauma on loss of consciousness and death. The brainstem and spinal cord from the first three whales were examined with a myelin stain (Luxol-fast-blue/Creysl violet) and all sections (brainstem, spinal cord, cerebrum and cerebellum) from all individuals were also examined after staining with haematoxylin and eosin. As in paper 1, the histological methods appear appropriate and the preservation of tissue quality was generally good, again assisted by the relatively short period between death and onset of formalin-fixation.

In order to remove potential bias in interpretation of neuropathological findings, the examination of the brains was conducted blind to the individual whale's behaviour at and immediately after detonation, and also to the impact location in the animal's body of the harpoon. Table 1 provides a summary of the principal gross and histopathological findings (scored on a scale of I-V, with I being the most severe) and these are tabulated alongside details of the proximity of the impact of the harpoon to the cranial cavity (listed as regions A-E, with A closest to the brain; see Fig. 1).

In general, there appears to be a good correlation between the severity of the neuropathological injuries and the proximity of the impact site of the grenade harpoon to the brain. Seven of the 10 whales struck just behind the region of the cranial cavity showed large or multiple skull fractures with severe brain disruption or disintegration, or a combination of severe epidural, dural, subdural and subarachnoid haemorrhage and multiple smaller haemorrhages in other brain regions. A further 28 whales struck in the thorax or abdomen (including the spinal cord in some cases) had severe gross and microscopic lesions in multiple brain regions, many of them centrally located (e.g. brainstem and spinal cord). Epidural, dural, subdural and subarachnoid haemorrhage, typically involving the base of the brain, was also seen in 11 of these cases. In a further two whales in which detonation of the grenade occurred within the lungs, small macroscopic foci of dural and subdural haemorrhage were found over the cerebrum and a few microscopic haemorrhages were found near the aqueduct in the thalamus, in the brainstem (deep to the fourth ventricle) and in the white matter of the cerebellar vermis. The microscopic findings of these final two whales were described as "inconclusive" in the table summarizing the injuries (Table 1).

In my opinion both the methods used and the interpretation of the pathological findings are sound scientifically. Knowledge of the relevant literature, including the pathogenic mechanisms involved in traumatic brain injury (TBI) and diffuse traumatic brain injury (dTBI) in human and experimental animal studies, also appear comprehensive. Although only vascular haemorrhages in the absence of specific neuronal (parenchymal) injuries were demonstrated in most cases, diffuse axonal injury is difficult to detect by histopathology if death occurs within 1-2hrs after injury (as was the case with all of these whales). Furthermore, the scale and pattern of the haemorrhages described, particularly those deep in the brain tissue, are consistent with those associated with widespread traumatic axonal injury (i.e. major brain injury) resulting in rapid loss of consciousness and death in human and experimental animal studies of traumatic brain injury including blast trauma.

To summarize, the main conclusion of this paper that, depending on grenade harpoon location, neurotrauma consistent with TBI or dTBI in human and experimental animal studies occurs in minke whales killed with a single 30g penthrite grenade harpoon appear soundly based. It also appears likely that most, if not all, whales selected for this study* probably sustained traumatic brain injuries from the harpoon grenade sufficient to have induced a rapid loss of consciousness and death.

* Editorial note – In the paper reviewed here (**Knudsen SK, Øen EO. Blast-induced neurotrauma in whales. Neuroscience Research 2003; 46: 377-386** by Dr Jepson, the animals were selected as a sub set (37 out of a larger group of 69) on the basis of having been immediately disabled by the harpoon and grenade. The remaining 32 animals were subjected to rifle shooting in addition to harpoon grenade and do not form the subject of the paper described in this section.

3 Øen EO, Knudsen SK. Euthanasia of whales: wounding effect of rifle caliber .375 and .458 round nosed metal-jacketed bullets on minke whale central nervous system.

This paper reports the neuropathological findings in 29 whales deemed not to have been killed by the harpoon-mounted penthrite grenade and were subsequently shot by a .375 or .458 calibre rifle. Of these, 8 had been shot with a .375 calibre rifle and 21 with a .458 calibre rifle. Fifteen had received a single shot, 10 received two shots, three whales received three bullets and one whale received six bullets. The results were categorized in terms of the track of the bullet (divided into seven separate categories including a group of five animals where no bullet track could be found) and these categories were compared with the behavioural observations of each whale after rifle impact and with the gross and histological findings on neuropathological examination of the brain, brainstem and spinal cord using the same methods as described in Paper 1.

In the 19 whales where the bullet had penetrated the cranium, the most severe disruption and haemorrhage was found in 10 whales that had penetrating brain damage (i.e. the bullet had directly entered the braincase and directly damaged the brain) and in seven whales in which the cranium had been penetrated by the bullet within 20cm of the brain resulting in multiple foci of haemorrhage in parts of the brain that maintain vital functions, notably the brain stem and deep nuclei of the cerebrum.

Of the 10 whales that did not have bullet entrance holes in the cranium, three had been hit in the upper cervical cord and one in the second thoracic vertebra. The latter was not assessed by fixation and histological examination, which was a pity considering the location of the bullet in the second thoracic vertebra (where spinal but not brain injury may have occurred), although marked haemorrhage was grossly visible within the spinal canal and all movements of the whale were observed to have ceased immediately after impact. Neuropathological examination of the other nine whales that did not have bullet entrance holes in the cranium revealed multiple foci of haemorrhage in the brain stem and deep nuclei of the cerebrum and, in some cases, haemorrhages in the dura, the subarachnoid space, the cerebellum or spinal cord.

In five cases the bullet tracks were not identified but extensive brain haemorrhage in four of these whales suggested that the bullet had passed quite close to the cranium or that marked brain damage had been caused by the detonation of the grenade. In one case the bullet track had passed over the top of the skull with gross haemorrhages in the dura and and microscopic haemorrhages in the brainstem, thalamus and upper cervical spinal cord. The final case was interesting because the grenade had failed to detonate and so the brain injuries (including multiple haemorrhages in the deep cerebrum and brainstem) could only have been caused by the passage of the rifle bullet.

In conclusion, the authors report severe traumatic brain injury in most if not all of the 29 whales shot with a .375 or .458 calibre rifle following the suspected failure of a harpoon grenade to kill the whale. In this study, almost all the whales re-shot with a rifle after apparent failure of the grenade harpoon appeared to die instantly based on behavioural observation*.

*Editorial note – the behavioural observations are the existing IWC criteria for determination of death (IWC - 1980 Report of the Workshop on Humane Killing Techniques for Whales. *International Whaling Commission Report* IWC/33/15): Relaxation of the lower jaw OR No flipper movement OR Sinking without active movement. These criteria have been the focus of critical scrutiny by observers both within and outside of the IWC and are at present the focus of other studies.

Of the 28 whales that had a detailed neuropathological examination, the findings were considered of sufficient severity to induce loss of conscious brain function after impact, even though several of the whales showed body movements after they had been shot. Although this assessment is largely based on experience and inference from neuropathological studies in human beings, and with the caveat that I am not an expert neuropathologist, the author's interpretation of the results and subsequent conclusions appear rational and consistent with studies of similar injuries in other species.

4. Knudsen SK. (2005) A review of the criteria used to assess insensibility and death in hunted whales compared to some other species. The Veterinary Journal 169: 42-59

The author reviews the findings derived from the studies reported in Paper 2 and Paper 3. These findings are also assessed in relation to knowledge of the criteria used to establish death or 'brain death' in humans, the effectiveness of methods used to stun and slaughter captive animals, techniques used for hunting terrestrial wildlife, and the IWC criteria for determining death in whales. The knowledge of this literature demonstrated by the author is undoubtedly extensive and extends beyond my own area of expertise.

The author discusses a number of issues derived from this research pertinent to the debate on the humane and welfare aspects of commercial whaling. Given that motor activity can occur after brain death, and that whales selected for examination in these studies had severe traumatic brain damage likely to cause virtually immediate loss of consciousness and death (despite movements of the body being observed after impact with the grenade), the author argues that the existing IWC criteria are inadequate (at least in some cases) for diagnosing death in whales and may overestimate time-to-death (TTD). I would agree with this line of argument based on the evidence presented in these papers, although one could imagine circumstances where TTD in individual whales was also underestimated using these same criteria. Based on existing IWC criteria for determining TTD, recent data presented from Norwegian whaling operations suggests that the 30g penthrite grenade now achieves around 80% instant kill. If true, this is undoubtedly a considerable improvement from years gone by. Nonetheless, major welfare concerns persist for an unknown proportion of the remaining 20% of hunted whales before loss of consciousness and death occurs.

<u>Conclusion</u>

In summary, the pathological aspects of this research are robust and comprehensive a and resulted in Dr Knudsen's PhD thesis and a number of scientific papers published in respected peer-reviewed neuroscience journals. The authors demonstrate a broad and comprehensive knowledge of literature including those pertaining to established criteria for determination of death in humans, food animals and whales. In all research papers, appropriate techniques for gross and histopathological investigations are deployed, including an excellent and novel technique for *in situ* brain fixation. With the caveat that I am not an expert neuropathologist, I also found the interpretation of the results to be consistent and scientifically objective in general.

Throughout the thesis and papers the authors refer to, and discuss, the implications of their research on the debate relating to the welfare aspects of the Norwegian commercial whaling industry. Given the paucity of good scientific studies conducted on the welfare aspects of whaling, including the scientifically valid estimation or determination of time to death (TTD), the research of Dr Knudsen and colleagues reported in these papers is of undoubted merit and will be scrutinised widely. It is therefore critical to this debate that the 66 cases presented in these papers are representative of the Norwegian whaling industry as a whole, and that no whales were excluded from this study if they met the relevant criteria of being either killed by a single grenade, or being killed by grenade impact followed by deployment of the back-up rifle. If any whales were excluded, despite satisfying these criteria, a full explanation for these exclusions should be provided in order to have complete confidence that these studies are entirely representative of the Norwegian whaling industry as a whole.

Paul Jepson
London, 22/02/05.

Appendix D

Review of papers on neurotrauma and death in hunted whales

Commissioned by the World Society for the Protection of Animals

Seth Love, 6 February 2005

Qualifications

I am a practising Consultant Neuropathologist at Frenchay Hospital, North Bristol NHS Trust, and hold a Chair in Neuropathology in the University of Bristol. I have published papers and chapters on many aspects of neuropathology and have edited several neuropathology reference books.

My qualifications are:

MB BCh 1978, University of the Witwatersrand

PhD 1984, University of London

FRCP 1996, MRCP 1980, Royal College of Physicians, United Kingdom

FRCPath 1996, MRCPath 1985, Royal College of Pathologists, United Kingdom

Papers reviewed

1. Knudsen SK, Mørk S, Øen EO. A novel method for in situ fixation of whale brains. Journal of Neuroscience Methods 2002; 120: 35-44.
2. Knudsen SK, Øen EO. Blast-induced neurotrauma in whales. Neuroscience Research 2003; 46: 377-386.
3. Øen EO, Knudsen SK. Euthanasia of whales: wounding effect of rifle calibre .375 and .458 round nosed metal-jacketed bullets on minke whale central nervous system.
4. Knudsen SK. A review of the criteria used to assess insensibility and death in hunted whales compared to some other species.

In addition, I was provided with Dr Knudsen's thesis for the degree of Doctor Medicinae Veterinariae in The Norwegian School of Veterinary Science: 'Assessment of insensibility and death in hunted whales. A study of trauma and its consequences caused by the currently used weapons and ammunition in the Norwegian hunt for minke whales,with special emphasis on the central nervous system.'

I shall confine most of my comments to the neuropathological findings and their interpretation.

1. Knudsen SK, Mørk S, Øen EO. A novel method for in situ fixation of whale brains. Journal of Neuroscience Methods 2002; 120: 35-44.

The conventional approach to the fixation of the brain in large mammals is to remove it intact from the cranial cavity and then suspend it in formalin for several weeks. There are several problems in applying this approach to the fixation of the brain of whales killed at sea. These include the relative inaccessibility and large size of the whale brain and hence the risk of causing damage to the brain during its removal. In addition, the limited space and other practical difficulties faced in performing this procedure on board a whaling boat may necessitate considerable delay between the death of the whale and the commencement of fixation. During this time the brain is undergoing autolysis and is at risk of post-mortem colonisation and damage by micro-organisms such as gas-forming bacteria.

In the study reported in this paper, whose authors include an experienced neuropathologist, Sverre Mørk, the brains of 38 whales killed at sea during traditional whale hunts were fixed *in situ* after the head was separated from the body, the mandible removed and a triangular opening made in the back of the skull close to the foramen magnum. This allowed formalin fixative, usually 8% neutral formalin in sea water, be poured into the cranial cavity where it was left, with 4-hourly topping up as required, for 72 hours. By this time the fixative had produced sufficient firming of the brain to allow its removal without damage. To complete the fixation, the brain was then left immersed in formalin for a further 2 months or longer. At this stage, the brain was sliced coronally, at 1cm intervals, and sampled comprehensively for embedding in paraffin wax and histological assessment.

The authors describe good or excellent histological preservation of the cerebrum, cerebellum and brainstem/upper spinal cord in 37 of 38 whale brains examined, and acceptable preservation in the 1 other brain. Apart from flattening of some of the brains where they had rested against the bottom of the container in which they were fixed, the only artefactual abnormalities of note were a small amount of traumatic damage related to the initial opening of the cranial cavity and a mild degree of 'Swiss cheese' artefact, due to limited post-mortem growth of gas forming bacteria. On the whole, preservation was of a high standard, as illustrated in several photomicrographs.

In summary, this paper describes a practical approach to ensuring that whale brains can be subjected to a reasonably high standard of neuropathological examination.

2. Knudsen SK, Øen EO. Blast-induced neurotrauma in whales. Neuroscience Research 2003; 46: 377-386.

The authors report the gross and histological appearances of the brain in 37 minke whales that were killed by a single harpoon with a 30g penthrite grenade. The brains were fixed and examined by the methods described in paper 1. The neuropathological assessment was blinded with respect to the clinical observations such as the site of impact of the harpoon and the behaviour of the whales immediately after detonation (see paper 4). The neuropathological findings were subsequently analysed with respect to the proximity of the impact of the harpoon to the cranial cavity.

The 7 whales that had been struck by the harpoon in or just behind the region of the cranial cavity showed either severe disruption and disintegration of the brain, or a combination of severe epidural, dural, subdural and subarachnoid haemorrhage and numerous smaller foci of haemorrhage in multiple regions within the brain. In a further 28 whales that had been struck by the harpoon in the thoracic or abdominal region (the site of detonation in some cases also involving the spinal cord), neuropathology revealed multiple foci of gross or microscopic haemorrhage in several parts of the brain, including the deep grey nuclei and brain stem. In addition, 11 of these whales had severe extradural, dural, subdural and subarachnoid haemorrhage, particularly over the base of the brain.

In a further 2 whales, in which detonation of the grenade occurred within the lungs, macroscopically visible haemorrhage was confined to small foci within, and deep to, the dura over the cerebrum. This dural and subdural haemorrhage would not, of itself, be expected to produce significant brain dysfunction. However, the authors also describe microscopic haemorrhages in the thalamus, deep to the fourth ventricle in the brain stem and in the white matter of the cerebellar vermis. One of these 2 brains had been compressed on the side of the left cerebral hemisphere, presumably during fixation, and it is not altogether clear from the account whether deep brain haemorrhages were found in both of the whales in which detonation of the grenade had occurred within the lungs or only one of them. In the table that summarises the injuries to the head and brain in these 2 whales, the findings on microscopy are described as "inconclusive".

The whales with extensive disruption of the brain or gross brain haemorrhage had clearly sustained injuries that were incompatible with continued conscious brain function. In addition, the presence of multiple microscopic deep brain haemorrhages in most if not all of the other whales in this series strongly suggests that these whales too had sustained severe brain damage. In humans with non-penetrating traumatic brain damage, deep parenchymal haemorrhages almost invariably occur only in association with widespread traumatic axonal injury and reflect the tearing of small blood vessels within the substance of the brain, typically after its abrupt exposure to severe acceleration- or deceleration-inducing forces (e.g. on impact of the head with the dashboard in a motor vehicle collision). The converse is not the case, i.e. widespread traumatic axonal injury can often be demonstrated even if there are no associated deep parenchymal brain haemorrhages. At least in man, therefore, axons are more susceptible than small parenchymal blood vessels to acute, non-penetrating brain trauma. Although the axonal damage is not usually histologically demonstrable until some hours later (when one can begin to detect the build-up within the axon of molecules that are normally transported rapidly along it), the patient is typically comatose (and unresponsive to pain) from the time of the initial injury and fails to recover consciousness.

The precise mechanisms of brain trauma after detonation of a grenade within the body of a whale are, of course, different from those in a patient with acceleration-deceleration-type head injury but the relatively greater susceptibility of axons than small blood vessels to acute traumatic distortion is likely to apply in both situations and, if so, the presence of multiple small parenchymal haemorrhages in the whale brain would signify widespread traumatic axonal injury. The authors might have tried to demonstrate axonal injury histologically; however, in view of the short survival time it is unlikely that this would have been informative.

My interpretation of the findings reported in this paper are therefore that most if not all of the whales in this study* that were killed by the detonation of a single penthrite grenade probably sustained, almost immediately after the detonation, severe brain damage that was incompatible with sensibility to pain or other higher brain function.

* Editorial note – In the paper reviewed here (**Knudsen SK, Øen EO. Blast-induced neurotrauma in whales. Neuroscience Research 2003; 46: 377-386)** by Professor Love, the animals were selected as a sub set (37 out of a larger group of 69) on the basis of having been immediately disabled by the harpoon and grenade. The remaining 32 animals were subjected to rifle shooting in addition to harpoon grenade and do not form the subject of the paper described in this section.

3 Øen EO, Knudsen SK. Euthanasia of whales: wounding effect of rifle calibre .375 and .458 round nosed metal-jacketed bullets on minke whale central nervous system.

This paper reports the clinical and neuropathological findings in 29 whales shot by one or more bullets from a .375 or .458 calibre rifle after the whale hunters had judged the whales not to have been killed by the detonation by a harpoon-mounted penthrite grenade. Of these 29 whales, 8 had been shot with a .375 calibre rifle and 21 with a .458 calibre rifle; 15 had received a single shot and 14 had received two or more bullets.

The authors subdivide the results according to the sites of impact and penetration of the bullets. In all of the 19 whales with penetration of the cranium, examination of the brain revealed multiple foci of haemorrhage in those parts of the brain that maintain vital functions (i.e. the brain stem and deep nuclei of the cerebrum). In addition, more extensive disruption and haemorrhage was noted on examination of 10 whales that had penetrating brain damage and 7 in which the cranium had been penetrated by the bullet within 20cm of the brain.

Of the 10 whales that did not have bullet entrance holes in the cranium, 3 had been hit in the upper cervical cord and 1 in the second thoracic vertebra, 1 had a bullet track that passed over the top of the skull and in 5 cases the entrance wounds and bullet tracks were not identified. In 1 of the 10 whales the extent of brain damage was not assessed by fixation and histological examination, although marked haemorrhage was grossly visible within the spinal canal. In the other 9 whales that did not have bullet entrance holes in the cranium, neuropathological examination revealed multiple foci of haemorrhage in the brain stem and deep nuclei of the cerebrum and, in some cases, haemorrhages in the dura, the subarachnoid space, the cerebellum and/or spinal cord. The extensive brain haemorrhage in 4 of the 5 whales without a detectable bullet track suggests either that the bullet had passed quite close to the cranium or that the marked brain damage had been caused by detonation of the grenade, even though at the time this had not been thought to kill the whale. In 1 case the grenade had failed to detonate and the brain damage could only have been caused by the passage of the bullet.

In conclusion, the authors report the induction of severe brain damage in most if not all of 29 whales shot with a .375 or .458 calibre rifle after the suspected failure of a harpoon grenade to kill the whale. In my opinion, the brain damage reported in the 28 whales that had an adequate neuropathological examination was probably of a severity that was, almost immediately after the impact of the rifle-shot that caused the damage, not consistent with continued conscious brain function, even though several of the whales showed body movements after they had been shot. As in relation to the harpoon gun-induced brain damage, this assessment is based on an unproven (albeit, I suggest, reasonable) extrapolation from human neuropathological studies: that widespread damage to small parenchymal blood vessels within the brain signifies that it has been subjected to forces in excess of those known to cause extensive traumatic axonal injury. I would also note that the study does not inform as to whether or not the whales are likely to have had conscious brain function in the period between the impact of the harpoon and the subsequent shooting, except in relation to the one whale that was struck by a harpoon that failed to detonate and did not therefore sustain significant brain injury until it was shot.

4 Knudsen SK. A review of the criteria used to assess insensibility and death in hunted whales compared to some other species.

The author reviews the findings in papers 2 and 3 in relation to the criteria used to establish death or 'brain death' in man, the IWC criteria for diagnosing death in whales, the effectiveness of methods used to stun and slaughter captive animals, and the techniques used for hunting terrestrial wildlife. Some of the points made by the author on the basis of previous studies as well as those described above are that (i) motor activity can occur after brain death, (ii) the IWC criteria are therefore inadequate for diagnosing death in whales, (iii) whales with spinal impact and detonation have severe traumatic brain damage and are not at risk of paralysis while still conscious, and (iv) the effectiveness of the harpoon gun and rifle in causing immediate fatal brain damage of whales in the above studies approaches that of methods used for the stunning and slaughter of animals in captivity* and exceeds those used for the hunting of terrestrial wildlife.

*Editorial note – for more detailed comparison between cetacean hunts and commercial farmed animal slaughter practice, please see the associated review by Wotton in this publication.

In general I found this to be a reasonably argued review. However, it is for others to judge what constitutes acceptable effectiveness when it comes to methods of killing animals, and I should note that much of the information on slaughter and hunting methods and their effectiveness in causing death or brain death is outside my field of experience and expertise.

Knudsen SK. Assessment of insensibility and death in hunted whales. A study of trauma and its consequences caused by the currently used weapons and ammunition in the Norwegian hunt for minke whales, with special emphasis on the central nervous system. Thesis for the degree of Doctor Medicinae Veterinariae. The Norwegian School of Veterinary Science.

This thesis comprises an extensive review of the literature on the techniques used to kill whales and a detailed account and discussion of the studies published in the separate papers above. The thesis includes a slightly more detailed analysis of the distribution of injuries induced by harpoon grenade or rifle shot in the 66 whales included in the above studies, and of their behaviour immediately after having been harpooned or shot, but the results and conclusions are otherwise as already described.