WELFARE ASPECTS OF THE COMMERCIAL SLAUGHTER OF WHALES

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Recently, the method by which Japanese and Norwegian whalers kill minke whales has come under scrutiny on welfare grounds. Whales are still caught with a grenade tipped harpoon fired from a cannon. The harpoon is targeted to strike the animal in the thorax, though the pattern of harpoon strikes is variable and some can even be struck in the tail. Once the whale is harpooned, it is winched to the ship and if not dead, attempts are made to kill it either by electrocution or with rifles. Some studies indicate that less than 30 per cent of animals are killed instantaneously, though best practice can achieve 50 per cent of animals killed instantaneously but with wounded animals surviving for up to one hour. To kill any wild animal humanely, immediate insensibility must be induced. Whilst in principle the methods used on whales could induce immediate insensibility, there are indications that neither harpooning nor the secondary killing processes, like electrocution or rifle bullets, are achieving this in an acceptable proportion of the animals taken. Comparison of the killing processes used on minke whales with killing processes used on other animals, indicated that there are several areas where improvements could increase the proportion of whales killed instantaneously and reduce the suffering of wounded animals. Whilst harpooning may remain the favoured method of taking whales, and some improvements have been made in the number of whales killed instantaneously, the equipment has evolved little from that originally developed by the Norwegians in the Nineteenth Century. As currently practised few people would consider the current methods employed by the whaling industry to be humane.

Keywords: *animal welfare, whales, whaling, grenade, harpoon*

Introduction

Over the last few decades, the method by which whales are killed has come under increasing international scrutiny. Responding to this, the International Whaling Commission (IWC) (the body that regulates whaling) has started to impose restrictions on the methods by which whales are killed. Commercial whaling is currently prevented by an IWC moratorium. However, some nations, principally Japan and Norway, continue to whale under scientific permit (nations can seek a derogation of the moratorium to kill whales for scientific research) and recently Norway has resumed commercial whaling. Whilst the method by which whales are captured and killed has been modified as the species hunted have changed, the equipment is still basically the same as that developed 100 years ago and concern remains that methods are still not acceptable on welfare grounds. Summarizing these concerns, Mr John Gummer, UK Minister of Agriculture said in his opening address to the 1992 IWC meeting 'We have long been concerned about the humaneness of the methods used to kill whales . . . my predecessors have spoken to you about this since the late 1970s . . . and [we] must insist upon improvements as a precondition of any lifting of the moratorium' (Ministry of Agriculture, Fisheries and Food 1992).

At an IWC workshop on humane killing held in Glasgow (Anon 1992), the progress in the development of methods for killing whales was reviewed. This was further updated during the 1993 and 1994 IWC meetings and by press releases since. This paper examines the data and arguments from an animal welfare standpoint.

Review of current whaling equipment

Hunting practices

The principal whaling nations, Norway and Japan, use very similar equipment consisting of a whaling cannon and harpoon. The cannon is a short-barrelled 50, 60 or 75mm calibre weapon mounted on the bow of a catcher vessel 4 to 6m above the waterline (Øen 1992a). Whale catchers vary in length from 16 to 30m. The cannon is mounted on gimbals, has primitive bead sights similar to a shotgun, is hand aimed and is designed for rapid action. Loaded in the muzzle of the cannon is the harpoon. This weighs from 14 to 18kg and has two or four hinged steel barbs or claws secured closed with a line (Figure 1). Screwed to the head of the harpoon is an explosive grenade which is fused to explode within the whale's body.

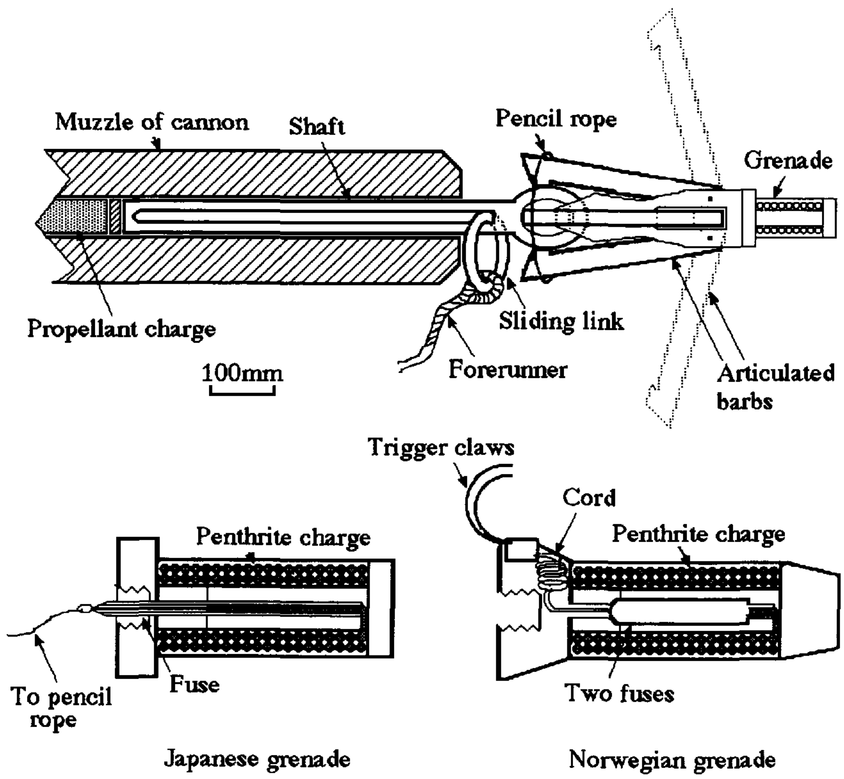

Figure 1 Simplified diagram of a whaling harpoon and grenades.

Connected to the shaft of the harpoon by a sliding link is a strong synthetic rope called the forerunner. The link ensures that the forerunner trails from the back of the harpoon and does not disturb its flight. The end of the forerunner is connected to a power winch.

Hunting methods for the currently hunted species (the minke whale *Balaenoptera acutorostrata*) vary. The Norwegian whalers try to position their boats in approximately the place where a whale will surface to breathe, though animals can be chased for up to six hours. As the whale approaches the surface, the cannon is rapidly aimed and fired as the whale surfaces (Øen 1992a, 1993). Japanese Antarctic whalers pursue whales at moderate speed, using sonar to frighten them to the surface if necessary and fire at the whale as it swims away from the ship (Government of Japan 1993a). The harpoon travels at a velocity of 70 to 80m s^{-1} and accuracy drops considerably as ranges exceed 60m (Øen 1992b). If possible, whalers aim so that the harpoon strikes the whale obliquely, entering just behind the flipper, hoping to explode the grenade in the viscera (thought to be the best site to inflict fatal damage)(Government of Japan 1993a). On striking the whale the harpoon penetrates the animal's body. The grenade is fused to detonate approximately 0.5m inside the whale's body (Øen 1992b). Minke whales are relatively small and the harpoon often exits on the far side of the whale. When the line is tensioned the barbs open and prevent the harpoon drawing through the animal's body. Figure 2 indicates the locations of harpoon wounds on minke whales taken in the Antarctic as part of the 1978/79 Japanese commercial operation (Best 1993). Note: this figure includes all harpoon wounds (152) found on 127 minke whales caught with grenade-less (cold) harpoons in the Antarctic. It includes entry wounds and in some cases exit wounds.

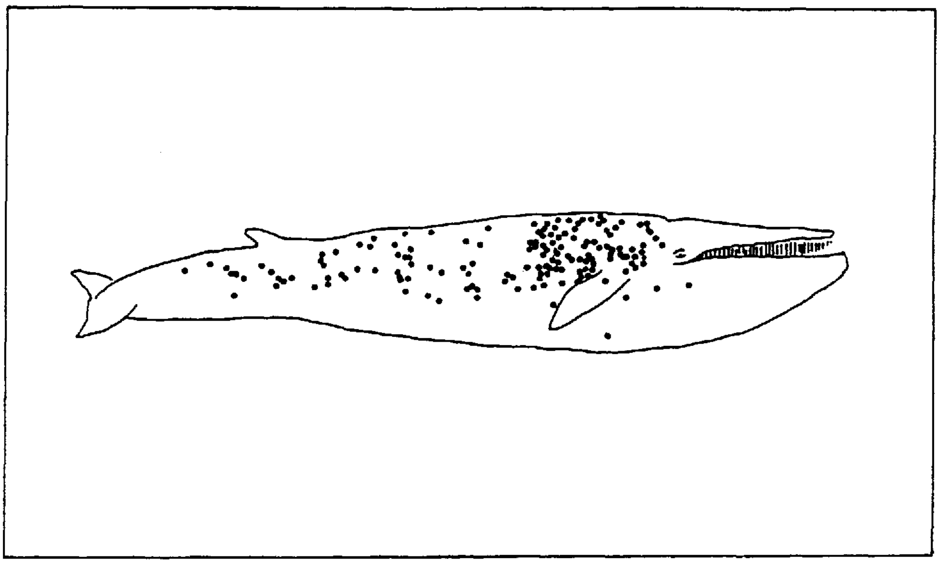

Figure 2 **Distribution of harpoon wounds on 127 minke whales caught by the Japanese in the Antarctic.**
(reprinted with kind permission of Best (1993) (1995 in press))

Since Lambertsen and Moore (1983) indicate that harpoons tend to enter the whale above the midline and travel antero-ventrally within the body, most of the wounds measured below the midline are likely to be exit wounds. Best (1993) indicates that 60.1 per cent of wounds were located on the head or thorax and that there was a significant difference in accuracy between different catcher boats. Table 1 summarizes the parts of the body damaged by grenade-less (cold) and grenade-headed (penthrite) harpoons for minke whales killed as part of the Norwegian commercial whaling operation, 1981 to 1986 (Øen 1992a, 1992c).

Table 1 Area of the body damaged by harpoons (Norwegian Commercial Whaling) and the associated survival time.

Area of body	Cold Harpoon (%)	Mean Survival Time (min)	Penthrite Harpoon (%)	Mean Survival Time (min)
Lungs	22.50	9.1	26.20	2.6
Heart	7.70	1.8	18.70	0.46
Blood vessels (thorax/abdomen)	14.20	?	20.70	?
CNS	15.60	3.4	26.90	0.65
Abdomen	50	12	50	≥1.25
Musculature		19		
Source	Øen 1992a		Øen 1992c	

Recent developments

The grenade developed in the Nineteenth century for large whales was powered by black powder and on detonation was designed to propel fragments of shrapnel through the whale. The whale was thought to be killed by a combination of damage to vital organs caused by the shrapnel and by the large volume of gas liberated on detonation which compressed vital organs, like the heart, until they could no longer function (Lambertsen & Moore 1983). Since minke whales are relatively small and are hunted for their meat, the excessively large quantities of flesh condemned by shrapnel damage caused whalers to use cold harpoons. Using this equipment, instantaneous or rapid kills were rare (Table 2 and 3, Figure 3). The harpoon was used to secure the whale which was then killed by a variety of other means, such as rifles, further harpoons or electrocution.

Table 2 **Whale killing statistics.**

	Japanese Antarctic Whaling	Japanese Coastal Whaling	Norwegian Commercial Whaling	Norwegian Commercial Whaling	Norwegian Scientific Whaling	Norwegian Scientific & Commercial Whaling
Years	1983/84	1984 to 1987	1981, 1982, 1983	1984, 1985, 1986	1992	1993
Type of harpoon	Penthrite grenade	Penthrite grenade	Cold	Penthrite grenade	Penthrite grenade	Penthrite grenade
n	2758	1309	357	264	95	226
Mean harpooning range (m)	?	?	30	25	30	25.8
Whales struck and lost (%)	?	?	1.10	2.70	3.10	3.98
Intra-body detonation mean time to death	47.50% 1.45min	? ?	0 0	94.30% ?	90.70% ?	100% ?
Extra-body detonation mean time to death	52.50% 3.3min	? ?	100% 11.1min	5.70% ?	9.30% ?	0% ? ?
Secondary killing method	Electrocution	Additional harpoons	9mm rifle bullets	9mm rifle bullets	9mm rifle bullets	9mm rifle bullets
Source	Government of Japan 1992	Government of Japan 1993b	Øen 1992a	Øen 1992c	Øen 1993	Government of Norway 1993

Table 3 **Whale survival times.**

	Japanese Antarctic Whaling	Japanese Coastal Whaling	Norwegian Commercial Whaling	Norwegian Commercial Whaling	Norwegian Scientific Whaling	Norwegian Scientific & Commercial Whaling
Years	1983/84	1984 to 1987	1981, 1982, 1983	1984, 1985, 1986	1992	1993
Type of harpoon	Penthrite grenade	Penthrite grenade	Cold	Penthrite grenade	Penthrite grenade	Penthrite grenade
Instantaneous kills (%)	28	?	16	45	50	54
Whales surviving after 1 minute (%)	61	?	82	50	47	
Whales surviving after 5 minutes (%)	9		72	38	34	
Whales surviving after 10 minutes (%)	2		50	23	9	9
Whales surviving after 15 minutes (%)	0		25	16	2	6
Whales surviving after 30 minutes (%)	0		5	3	1	
Longest survival time (min)	14	?	62	57	32	55
Mean time to death for all whales (min)	2.4	1.1	11.1	6.6	3.7	3.5
Source	Government of Japan 1992	Government of Japan 1993b	Øen 1992a	Øen 1992c	Øen 1993	Government of Norway 1993

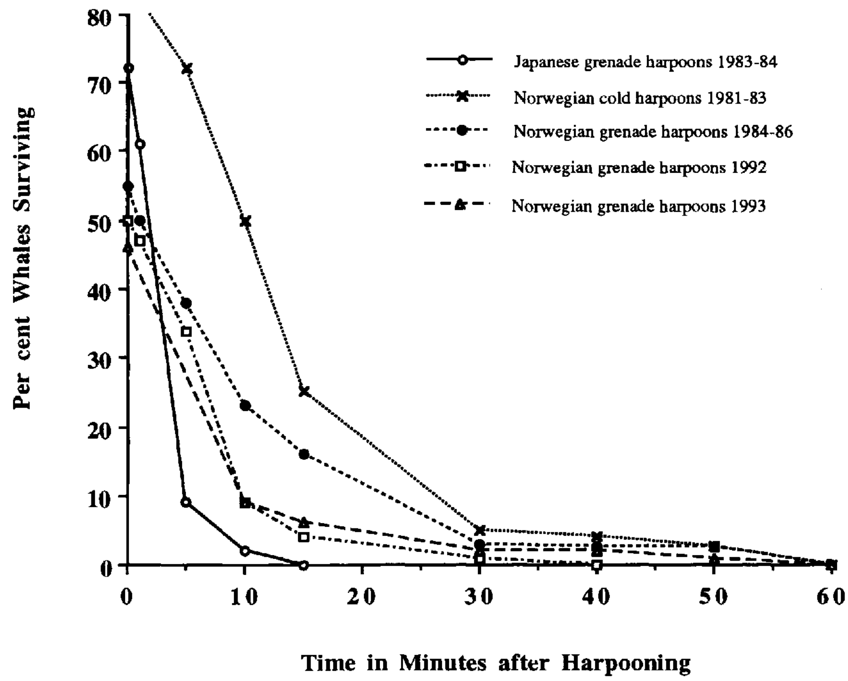

Figure 3 **Whales surviving post-harpooning.**

Concern that whales harpooned with cold harpoons were taking a long time to die, stimulated the Japanese and subsequently the Norwegians to develop shrapnel-less grenades. To encourage this development the IWC proposed a ban in 1981 on the use of cold harpoons for minke whaling, which was introduced in 1982/83. The current grenades are shrapnel-less and are powered by a relatively fast-burning explosive, pentaerythritol tetranitrite (penthrite). It has been proposed that this fast-burning explosive can stun a whale with shock waves, and can also rapidly induce fatal blast injuries from tissue damage also caused by the shock waves (Øen 1992c). Hunting methods and preferred targets remain the same as those for cold harpoons (Øen 1993). Both Japan and Norway now use penthrite powered shrapnel-less grenades of their own design.

The Japanese penthrite grenade (Figure 1) is a development of the original black powder grenade (Kano & Hasui 1982; Government of Japan 1984). A 30g charge of penthrite explosive is wrapped around a central metal core and is protected by an aluminium or cardboard sleeve. Detonation is achieved by a friction fuse. The fuse, which is situated in the centre of the grenade, is connected by a line or wire to a rope holding the harpoon barbs closed. After firing, and as the harpoon passes into the whale's body, the rope is pulled off, pulling in turn the wire attached to the fuse and igniting it. The explosives in the fuse are designed to delay detonation until the grenade is in the optimum position inside the whale to maximize damage. Should the grenade fail to detonate for any reason the fuse explosive is flooded by sea water or body fluids, thus rendering it inoperative. Japanese development of the grenade ceased in 1984.

The Norwegian penthrite grenade, described in Øen (1992b) and illustrated in Figure 1, was developed after the Japanese weapon and is similar in principle but includes several modifications to ensure greater efficiency and operator safety. The grenade contains two fusing mechanisms and 22g of penthrite wrapped round a central metal core. The first fuse is designed to detonate the grenade 0.50 to 0.70m inside the whale and consists of two small steel claws that protrude from the side of the grenade, connected by a length of string (about 0.35m long) to an ignition fuse. The claws dig into the blubber as the harpoon strikes the whale and pull out the string as the harpoon travels through the whale, which in turn ignites the fuse and grenade. The second fuse is slow burning and is automatically activated on firing the harpoon. It is designed to detonate the explosive 5s after firing in the event of failure of the first fuse or a missed shot. This is to ensure that no live unexploded grenades are recovered.

Times to death in whales killed by Japanese and Norwegian whalers

The recommended criteria used by whalers to assess death in harpooned whales were established at the first IWC workshop on humane killing (Anon 1980). Summarized, these indicate that, in the absence of obvious vital signs such as respiration or swimming, a whale could be pronounced dead when flipper movement had ceased, the lower jaw had relaxed open or the whale had sunk without any active movement. Clearly, the assessment of some of these stages could be quite difficult at sea and, if the information is diligently collected, there will be cases where the time to death is overestimated. Conversely, there is a strong possibility that whales that receive damage to the heart or great vessels, or are paralysed by damage to the spinal cord, will lie motionless and die of blood loss or drowning whilst being winched to the ship. These animals could be classified as instantaneous kills but actually took several seconds from harpooning to loss of consciousness, which is the important end-point from an animal welfare view. In practice, it will take a few seconds to observe the behaviour of a whale after harpooning, and instantaneous death is likely to mean animals which show none of the IWC criteria after 10 seconds. In a detailed study of the harpooning of 19 fin whales (*Balaenoptera physalus*) Lambertsen and Moore (1983) compared, the time to cessation of active movement or jaw relaxation with estimates of the time to onset of terminal unconsciousness, from correlations between behavioural records and post-mortem findings. They judged that cessation of movement produces a consistent, but variable, overestimate of killing time. Whilst in the field it is difficult to estimate unconsciousness based solely on behavioural evidence, Lambertsen and Moore (1983) have shown that it is possible if supported by post-mortem examination. However, this approach has not been applied to any minke whaling study.

Whilst the IWC criteria do have some weaknesses and are different to those used extensively in abattoirs to assess the efficiency of farm animal slaughter, they may be treated as adequate for comparative purposes to assess how quickly different harpoons and secondary killing methods kill whales.

Data on the times to death in whales, caught as part of the commercial catches of both Japan and Norway and scientific catches of Norway, have been collected. These were recorded primarily to monitor improvements in killing times during the development of the penthrite grenade and are published in many forms. Data from several sources are summarized in a standard format in Tables 2 and 3 for comparison.

The most recent Japanese data available, collected from Antarctic commercial whaling in 1983/84 and presented in 1992 (Government of Japan 1992), relate to 2,758 whales harpooned in the Southern Ocean. Summary data are also available from 1984 to 1987 for Japanese coastal whaling (Government of Japan 1993b) and Antarctic scientific whaling for 1984 to 1987 (Government of Japan 1993c). Up-to-date data from the current Japanese Antarctic scientific whaling programme are not yet available.

Comparable Norwegian data are for whales killed as part of the commercial hunts in 1984, 1985 and 1986 and relate to 264 whales harpooned off the coast of Norway (Øen 1992c). Data from the Norwegian scientific catch of 1992 have also been collected (Øen 1993) and recently the Norwegian Government has published some summary information for the scientific and commercial catches of 1993 (Government of Norway 1993). These hunts were said to have been conducted more carefully than previously, with harpooners and riflemen attending a training course (Øen 1993). For comparative purposes, it is also interesting to examine the times to death for whales harpooned with cold harpoons. These Norwegian data are from 1981 to 1983.

Of the whales killed by the Japanese within which a grenade did explode 46 per cent died instantaneously, a figure similar to the Norwegian record. Of the Japanese whales within which a grenade did not explode 12 per cent died instantaneously, a figure similar to the record for cold harpoons. It is therefore probable that the differences in the proportion of animals killed instantaneously can be largely attributed to the lack of efficiency of the Japanese grenade.

Data relating to struck and lost whales are not presented for any Japanese hunts. It is probable that a struck and lost rate of approximately 3 per cent indicated by the Norwegian statistics also applies to Japanese whaling. If this is the case, approximately 80 animals are not accounted for in the 1983 Japanese Antarctic data set. This is an important omission as wounded whales are likely to die a lingering and painful death.

Secondary killing methods

Ignoring those animals that are killed instantaneously, there are obvious differences between the Japanese and Norwegian commercial figures in the time wounded whales survive post-harpooning (Figure 3). This could reflect differences in the practice or the execution of the secondary killing methods employed. Interestingly, despite the much more efficient Norwegian grenade, the time taken to kill wounded whales is considerably longer than for wounded whales killed by the Japanese. This difference is still present but reduced when the comparison is made between Japanese commercial whaling and the Norwegian scientific catch.

The Japanese and Norwegians use different techniques for dispatching wounded whales. The Japanese whalers winch the whale to the ship, implant electrodes through the blubber (positioned either side of the heart) and then attempt to cause a cardiac arrest by passing a 110 volt, 5 ampere (60Hz, a.c.) current between the electrodes (Hasui 1980; Hayashi 1980). The most recent data available (Hayashi 1980) indicate that after the first application of current 45 per cent of whales showed some indications of vitality, 29 per cent of animals required electrocution a second time, and 5 per cent required four applications. Application times were up to 8min.

Until 1992 Norwegian whalers on the other hand would 'play' the wounded whale to exhaust it and then attempt to kill it with a 9mm (or larger) calibre rifle (Øen 1992c). Protracted killing times are inevitable if wounded whales are played to exhaustion before dispatch. This practice, originally adopted to reduce the risk of losing the whale due to gear failure, may explain some of the differences in the survival time between the early Norwegian and Japanese data. The practice is now actively discouraged, but substantial differences between the time wounded whales survive still remain. The practice makes comparison between the two secondary killing methods difficult. This is complicated by the limited published data relating to the use of rifles. Metveit (1992), citing Norwegian whaling inspectors' reports, indicates that of five whales killed by rifle shots, one was apparently killed by the first shot, two required four shots, one required eight shots and one required nine shots. In a brief review of Japanese experiments with explosive bullets, Hasui (1980) mentions that due to problems with the motion of the boat, several bullets are needed to hit the vital organs and that times to death were not shortened much.

Discussion

The most effective way to kill any species of vertebrate humanely is to render it insensible instantaneously. It is also obviously important that the insensibility should last until the brain dies. (The only non-instantaneous method that could be considered humane is to induce insensibility with an anaesthetic.) Laboratory studies in cattle (Daly C C 1995 in preparation) and pigs (Anil 1991) have shown that instantaneous unconsciousness can be achieved if sufficient energy is delivered to the brain with sufficient accuracy. To some extent power and accuracy are interchangeable (Anil 1991). Since such a large proportion of whales are not killed instantaneously, it is evident that either the harpoon or the grenade does not contain enough energy or that it is not being delivered close enough to the brain. It is not clear whether the accuracy of shooting minke whales with the currently used grenade-headed harpoons is similar to that recorded for cold (grenade-less) harpoons by Best (1993). However, assuming this is the case, two important conclusions can be drawn. First, nearly half of shots that hit the whale strike it in a region that is not likely to lead to rapid death. This would indicate an urgent need to improve the accuracy of the equipment used and/or the hunting practices. It is not clear whether inaccurately placed shots are caused by inaccurate equipment or by inaccurate shooting. Improvement in the accuracy with which the harpoon can be delivered to the whale could play an important role in reducing the number of wounded whales.

The second conclusion is that since the centre of sensibility of the animal is in the brain, some increase in the proportions of whales killed instantaneously could probably be achieved if the gunners aimed at the head of the animal rather than the thorax. Whilst some shots are hitting the target (the thorax), because this is some distance from the brain there is doubt that even these shots will induce instantaneous insensibility.

It is interesting to compare the energy carried by the projectile used to kill other species with that carried by a harpoon. Since more energy is required to induce insensibility in large animals than in small animals, to allow comparison the energy delivered by a projectile to an animal is expressed as a proportion of the animal's body-weight. Under ideal experimental conditions the minimum energy required to stun a bullock with an accurately placed captive bolt gun or percussion stunner is at least 1.6 joules per kilogram liveweight (Daly C C 1995 in preparation). Experimental studies have also shown that it is the kinetic energy delivered to the brain that is more important in the induction of insensibility than the direct physical trauma caused by the passage of the projectile. At these relatively low energies the direction from which the energy is delivered to the brain is also important (Daly & Whittington 1986). Similarly, a 0.223 calibre high velocity rifle bullet delivers 13.6J kg^{-1} liveweight to the head of an impala, and observations of the animal's behaviour and the damage inflicted indicate that this is ample to cause instantaneous insensibility. Lewis, A (pers comm 1993) also indicates that it is possible to kill more than 90 per cent of wild impala instantly with this equipment. Assuming that a harpoon is not slowed by travel through water before striking the whale, the maximum kinetic energy available in the harpoon on impact to induce insensibility is 13.7J kg^{-1} liveweight for a 2500kg whale. This comparison could indicate that a cold harpoon may contain sufficient kinetic energy to stun a minke whale instantaneously provided it strikes the animal in the brain, a view supported by the 12 per cent of whales killed instantaneously by cold harpoons. However since the head of the whale is not the preferred target, it is not surprising that few whales are killed instantaneously with these harpoons. Figure 2 indicates the relative infrequency of harpoon damage to the head region.

The grenade is incorporated in the harpoon to increase the stunning and lethal range within the whale. Two effects of the penthrite grenade have been proposed. First, the shock of detonation is said to produce a concussion-like stunning effect on the central nervous system. Second, an increase in physical trauma caused by pressure and rarefication waves radiating from the point of detonation and damaging tissue remote from the wound canal (Øen 1992c). In the event of only wounding a whale, this secondary damage increases the chance of seriously disabling a vital organ and thus hastening the death of the whale.

There is some debate about the concussive effects of underwater or intra-body explosions (see Jordan 1992; Øen 1992c), detailed laboratory studies are lacking and there is a clear need for more details of this process. However, two concussive effects of the grenade are probable depending on the distance separating the explosion and the brain. First, when the grenade detonates relatively close to the brain sufficient traumatic damage may be caused by displacement of parts of the skull, and by the pressure and rarefication waves as they pass through neural tissue to cause irrecoverable damage to the brain and instantaneous insensibility. Post-mortem inspection should reveal extensive subdural haemorrhage and damage to the skull similar to that reported by Lambertsen and Moore (1983). In this case, loss of sensibility may be expected to be instant and permanent. Whales that suffer this type of damage should be recorded as instantaneous kills.

Second, since the energy in the pressure waves caused by an explosion reduces as a function of the cube root of the distance from the focus (Øen 1992c), detonations that occur more than a relatively short distance from the brain will not deliver sufficient energy to cause irrecoverable traumatic damage to the brain. At distances a little greater than this threshold, the pressure waves will probably induce a state of recoverable insensibility similar to that of a concussive blow to the head. In these cases, loss of sensibility will be instant but not permanent. Unless a vital organ such as the heart or a great vessel has also been seriously damaged by the wound canal or explosion, these whales will recover sensibility. Øen (1992c) indicates that some whales do behave in an apparently concussed fashion immediately post-detonation, and furthermore that some of these animals recover before dispatch. Similarly, beyond a further threshold distance between the brain and detonation, pressure waves from the explosion will not possess sufficient energy to concuss the animal. The tissue in which the grenade detonates will affect the threshold distances somewhat, depending on their energy propagating characteristics. For example, detonations in the lungs are likely to have less concussive effect than detonations elsewhere.

From the data presented it is not clear what the effective stunning range of a grenade detonating within the whale is. Before this can be deduced, accurate behavioural details coupled with detailed post-mortem reports will be required.

However, it is possible to arrive at an estimate of the concussive range of current grenades. For animal welfare reasons it is important that there is no capacity for recovery, consequently it is the irrecoverable concussive range that is important. Therefore if it is assumed that: 1) the centre of the currently preferred target (the thorax, just behind the flipper) is 1m from the brain, 2) 50 per cent of shots fall at this distance or less from the brain, and 3) there are no other fatal effects other than irrecoverable concussive damage to the brain. If the grenade did have an irrecoverable concussive range of 1m, then 50 per cent of whales would be recorded as instantaneously killed. However, the third assumption is clearly not valid. There are many other fatal effects of the blast which, whilst not causing instantaneous irrecoverable insensibility, will so severely damage the whale that the kill could easily be recorded as instantaneous. These include damage to the spinal column which could cause paralysis, and whales recoverably stunned but which die from blood loss before recovery of sensibility. Since the best that current practice can achieve is approximately 50 per cent of kills recorded as instantaneous, this indicates that the irrecoverable concussive range of the current grenades is less than 1m, and probably nearer 0.5m. A grenade containing enough explosive to render 90 per cent of harpooned whales irrecoverably insensible (ie those whales harpooned in the head, thorax, abdomen or musculature forward of the dorsal fin (Figure 2)) would require a stunning range of at least 4m (approximately the distance from the dorsal fin to the head in relatively small minke whales).

The object in humane killing of any species is to induce an immediate insensibility that must persist until the brain of the animal is dead. In farm animals this can be a two stage process. For example, a bullock is stunned by captive bolt (step 1), and whilst insensible is exsanguinated (step 2). Loss of blood flow to the brain causes brain death before recovery from the stunning insult. Occasionally step one and step two are combined, for example by passing an adequate electric current through the brain and heart of a pig it will be stunned and a cardiac arrest induced simultaneously. Brain death from cerebral ischaemia will then occur before recovery of sensibility.

To kill a wild animal humanely, since killing is taking place under poorly controlled conditions and the opportunity for applying two procedures is not certain, step one and step two must be combined. The most effective and reliable way to do this is to shoot the animal in the head with a projectile that carries adequate energy. A shot placed in the thorax will not cause instantaneous insensibility. Whilst it could damage the heart, the brain is capable of functioning without a blood supply for a number of seconds. Lambertsen and Moore (1983) estimate that fin whales that sustained very severe harpoon or grenade damage to the heart or great vessels, lost consciousness after 10s; whilst whales with less severe damage to the heart or great vessels remained conscious for up to 2min. However, Lambertsen and Moore (1983) based their estimates on information from terrestrial mammals. The time between loss of blood flow to the brain and insensibility could be longer than Lambertsen and Moore's estimates as it is possible that the diving physiology of the whale may allow its brain to survive and function longer under conditions of anoxia than would the brain of a terrestrial mammal.

To kill whales reliably and humanely the harpoon and grenade combination must induce immediate insensibility, and if the brain has not been damaged irrecoverably, it must cause sufficient damage to vital organs to achieve death from cerebral ischaemia before recovery from the stun. This is not happening in 50 per cent of whales killed by the best available method. There are two possible reasons for this. Either these whales are not being concussed by the harpoon or grenade (highly likely in whales harpooned in the abdomen); or they are concussed but the harpoon and grenade are not inflicting sufficient damage to vital organs to cause brain death from loss of blood before recovery of sensibility. It is evident from the most recent data available that with good training and adequate supervision, the best current minke whaling practice can achieve is approximately 50 per cent of whales killed instantaneously and, provided no gear failure occurs, the maximum time a wounded whale survives is approximately 30min. Failure of either the grenade or any of the ship's gear reduces the percentage of whales killed instantaneously and/or increases the survival time up to one hour.

No primary killing method can be expected to be 100 per cent reliable, therefore some form of secondary killing method is required. Several methods have been tried in the past (Hasui 1980) and those that are currently in use by Japan and Norway are designed to minimize damage to the edible parts of the whale. In principle both electrocution, as used by Japan, and rifle bullets, favoured by Norway, could kill a whale humanely as they are modifications of common and demonstrably humane abattoir practice. However, there is evidence that as currently practised these methods may not be humane.

Electrocution can instantaneously stun an animal by inducing an epileptic fit (sometimes called an electroplectic fit) and simultaneously induce a cardiac arrest, which will rapidly lead to brain death from cerebral ischaemia. The important criterion is that sufficient current is passed simultaneously through the brain and heart. Failure to deliver adequate current, or failure to pass it through the brain, can be expected to cause excruciating pain.

When whales caught by the Japanese are electrocuted, because the electrodes do not span the brain (Government of Japan 1984) the animals will not be rendered insensible. As experimental work on pigs has shown, most current flows more or less directly between the electrodes and if the brain is not directly spanned by these electrodes insufficient current flows through the brain to induce epilepsy (Anil 1991). Since such a high proportion of animals require electrocuting a second time, there are also indications that either the whale's heart spontaneously reverts to a normal rhythm after electrocution or the current delivered is not sufficient to reliably induce a cardiac arrest. Recent experimental work in New Zealand indicates that insufficient current is probably delivered (Blackmore *et al* 1994). As currently practised, electrocution of whales cannot be considered humane.

The destruction of harpooned and disabled whales with rifle bullets also gives cause for concern on animal welfare grounds. The limited evidence available suggests that it is difficult to reliably kill these animals with one bullet. The tracks of rifle bullets, even relatively large calibre ones, are unpredictable when travelling through water and flesh. Unequal forces can cause them to tumble, yaw and ricochet. Blackmore (1992) indicates that a high velocity bullet can be more than 30mm off target after only 150mm of penetration. Øen (1992d) reports attempts to kill whales using 20mm projectiles from a naval gun with a velocity of 1058m s^{-1}. Only direct hits resulted in penetration of more than 30cm and after penetration of one metre of water the projectile was stopped by the blubber. It is not obvious from the published studies whether the 9mm bullets used commercially have sufficient energy to reliably penetrate through salt water (in some cases), then the flesh to the brain of the whale, and still deliver sufficient energy to the skull or brain to induce insensibility. The energy 9mm high-velocity bullets deliver to a whale is only 80 per cent of the minimum energy that has been found necessary to stun a bullock with an accurately placed captive bolt pistol (Daly 1995 in preparation).

Whatever secondary killing method is chosen it should be capable of being rapidly deployed to dispatch a wounded whale. When terrestrial game animals are shot, wounded animals are rapidly dispatched with a second shot from the rifle. Indeed rifles are often semi-automatic or double barrelled to allow rapid refiring to cope with such woundings. In a similar manner, whalers could fire a second or even a third harpoon into their injured animals. There are several reasons why this may be the most humane secondary killing method. A harpoon can be fired into the head of the animal quickly and accurately once the whale has been winched to the ship. There is little chance of missing the target and the harpoon is directionally stable and carries sufficient energy to ensure instantaneous insensibility. There is good evidence that this practice, common when large whales were hunted, is highly successful in rendering a whale insensible. In their study, Lambertsen and Moore (1983) indicate that every animal that suffered harpoon or grenade damage to the brain (in one case it was from the first harpoon, and in six others from the second or third) was estimated to have lost sensibility immediately on detonation of the grenade. There are also indications from the Japanese coastal fishery, where injured minke whales are killed with a second harpoon, that this is a rapid method for dispatching whales (Table 3). If this practice is adopted for all whaling, it will be important to ensure that the cannon can be reloaded rapidly or to have a second cannon permanently loaded for dispatching wounded animals.

It should be possible to improve the percentage of whales killed instantaneously and also to reduce the time wounded whales survive if several parts of the harpooning and killing sequence are modified. Since increasing the quantity of explosive in the grenade to the levels required is probably unrealistic, the greatest increase in instantaneous kills could come from re-targeting the harpoon on the head. This should have the beneficial effect of delivering the harpoon and explosive charge nearer the brain. Using the existing and rather inaccurate cannon, it may reduce the number of whales struck in non-fatal parts of the body such as the musculature or abdomen (though more may be hit in the jaw), probably at the expense of increasing the number of whales that are missed completely. However, a further important area for development would be to improve the accuracy of the harpoon and cannon. The use of current weapons could also be limited to shots that have a high probability of success. This could be done by limiting the range and/or the conditions under which shots are taken. Criteria such as angle of presentation of the whale to the gun, and maximum permissible range at which shots are taken would be important. Such simple measures, often outlined in codes of practice, are commonplace within farm animal abattoirs. Another improvement would be to incorporate shrapnel in the grenade; this might be unpopular with whalers because of damage to saleable meat, but would probably reduce the time wounded whales survive. From post-mortem reports of whales killed with old black powder/shrapnel grenades (Lambertsen & Moore 1983) it is evident that fragments of shrapnel are highly effective at increasing the severity of damage to vital organs (Lambertsen & Moore 1983). It is therefore probable that shrapnel would also increase the effectiveness of the modern penthrite grenade.

Current whaling equipment and practice for dispatching wounded whales appear at best to be unreliable and are often likely to cause the animal considerable further pain and suffering before death. Whatever secondary killing process is used, it is essential that the brain of the injured whale is rendered insensible as rapidly as possible. Using existing technology this is probably best achieved by firing a secondary harpoon into the animal's head.

Since the number of whales killed instantaneously together with the time taken to dispatch the wounded animals is central to the debate about whaling, it is important that credible data are collected on a reliable and consistent basis and presented in a format that enables detailed analysis. With the notable exception of the papers by Lambertsen and Moore (1983) and Hayashi (1980), few of the published papers contain sufficient information for detailed analyses of the effect of different procedures. The media have also claimed that some published studies may not be accurate and that survival times can be longer than indicated. To add to the credibility of future studies there is a need for independent verification of some of the data collected, such as independent observers on each whaling vessel.

It is felt by many that those who kill animals for food have an obligation to ensure the animal is killed in a humane fashion. This implies that it should suffer no pain or distress as it dies. Wild species can be humanely killed if weapons and killing practices are appropriate for the species involved. Harpooning may remain the favoured method for taking whales, however, the methods and equipment used have evolved little since originally developed by the Norwegians in the Nineteenth Century. Whilst some improvements have been made in the number of whales killed instantaneously by adopting better hunting practices and modifying equipment, few people would consider the current methods of the whaling industry to be humane. There are indications from the most recent data available that further improvements will not be easily achieved.

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