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Animal Welfare in the Conduct of Whaling: A Review of the Research and Developments to Improve Animal Welfare in the Minke Whale Hunt in Norway 1981–2005

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1. Introduction

The hunting of whales along the Norwegian coast has long traditions. The first written sources of whale hunting in Norwegian waters are from the 9th century AC when the Viking Ottar visited King Alfred the great in Sussex (Gulberg 1889). Also, archeological excavations reveal remains of large whales in stone-age homesteads (Wexelsen 1987). Old Norwegian written sources like "The King's Mirror" dating from the 12th century provides accounts of whale hunting and hunting of various other marine mammals for food and other necessities. Minke whale (*Balaenoptera acutorastrata*), fin whale (*Balaenoptera physalus*), bowhead whale (*Balaena mysticetus*), North-Atlantic right whale (*Eubalena glacialis*), and humpback whale (*Megaptera novaeanglia*), killer whale (*Orcinus orca*), pilot whale (*Globicephala melas*) and dolphins seem to have been harvested at that time. According to the Kings Mirror also the giant blue whale (*Balaenoptera musculus*) might have been hunted in the early Middle ages. A unique and very old method for killing minke whales, probably dating back to the early Viking age, was to enclose it in narrow bays and use arrows infected with the spore-forming bacterium *Clostridium septicum* to weaken the whale before it was killed using spears and handheld harpoons (Nielsen 1890; Øen 1995a, 1997).

1.1 Overexploitation: Animal Welfare

Two topics have dominated the public debate regarding hunting of whales for several decades, namely (1) the hazard of overexploitation that might threaten species and populations (stocks); and (2) concerns for whale killing methods.

No whale species have so far been eradicated by men. But for some species and stocks it came very close. The industrialized overexploitation of whale populations in the North Atlantic began with right whales in the 1600s and later involved several species until the 1970s. This history demonstrates how important responsible management, regulations, monitoring, and enforcement of the regulations of whaling are. New management and monitoring principles based on science prevent repetitions and today most species and stocks of large whales that were overexploited by the industrial hunt are growing and some species and stocks are thought to have reached pre-exploitation size, with some serious exceptions such as eastern Atlantic stocks of the north Atlantic right whale (*Eubalena glacialis*) and of the blue whale (*Balaenoptera musculus*) stocks in the Antarctic oceans.

The animal welfare in whaling is still a topic for discussions in international organizations and media. Many experiments were performed in the past to develop more effective killing techniques in the industrial-type whaling. However, in bodies like the International Whaling Commission (IWC) the issue of animal welfare seems not to have been given much concern until the 1970s. In 1959 (IWC 1960), the IWC established a "Working Party on Humane and Expeditious Methods of Killing Whales" whose task was to examine the killing methods being used in whaling, and initiate any necessary research programs to improve existing methods. The working party, however, limited its discussions on improvements to electrical harpoons and harpoons with carbon dioxide (CO_2) used for the large whales. As none of these were found to be feasible alternatives to the grenade harpoon, IWC did not consider that any further work in this area was called for (Jonsgård 1992).

Also, little was done in this field with regard to the small-scale hunt of species like the minke whale, which was carried out by fishermen. They hardly had the economic resources, or interest, to carry out costly experiments or further develop whaling equipment to any degree. Any adaptation or modernization that did take place mostly consisted of local modifications performed on different pieces of equipment used for larger whales.

In 1975, however, the IWC accepted a recommendation from its Scientific Committee to "…make inquiries about possible new developments in chemicals and explosives suitable for killing whales, and examine ways of improving the efficiency of existing methods, including the killing of small whales where explosives cannot be used, and training of gunners…" (IWC 1977). In this context, drugs, carbon dioxide harpoons, and high velocity projectiles were mentioned, without any final conclusions being drawn as to their usefulness.

Killing methods were discussed in the IWC each year thereafter (IWC 1978; 1979) and it was decided to arrange a workshop on humane killing techniques for whales in 1980. This workshop, which also dealt with the minke whale was led by the former Secretary General in IWC, Ray Gambell. It took place in November the same year (IWC 1980) and became a "watershed" in IWC's work with animal welfare in whaling, and particular in minke whaling as both Japan and Norway after the workshop started to work systematically to find improvements or alternatives to the cold harpoon that was used in the minke whale hunt that time. This work initiated also similar work in other IWC member countries to improve animal welfare in the hunt and reduce losses of whales.

At this workshop, both existing whaling techniques and alternative methods were discussed without the group being able to draw any final conclusions as to which killing techniques were the best. The workshop made a working definition of "humane killing" which states: "Humane killing of an animal means causing its death without pain, stress or distress perceptible to the animal. That is the ideal. Any humane killing technique aims first to render an animal insensitive to pain as swiftly as technically possible. In practice this cannot be instantaneous in the scientific sense." (Research on whale brains described in this paper has proved that whales like other mammals can both be rendered unconscious and die instantaneously).

As there are certain practical problems connected with deciding when a whale is truly dead, the point of death was defined as "…the time taken for the mouth to slacken, the flipper to slacken and all movement to cease…" (later named "IWC criteria"). The observations were to be compared with the pathological findings made on the carcass and on animals used in controlled experiments in order to evaluate the criteria used to judge unconsciousness and death in the field.

Furthermore, recommendations were made to carry out controlled trials with drugs on stranded animals and animals killed for non-consumption. However, should post-mortem examinations of whales during the hunt and experiments have any validity or credibility it had in practice to be performed by expert personnel and not by hunters.

Japan had started experiments with whale grenades armed with the explosive penthrite in 1979 (Hasui and Kano 1981) and the workshop recommended that Japan should continue this work, and that Norway first should explore the possible use of high-velocity projectiles to kill whales.

After the workshop the Norwegian Institute of Marine Research, asked Egil O. Øen of the Norwegian School of Veterinary Science to design a plan with measures necessary to meet the request of the IWC workshop and also carry out the required research to develop and implement alternative methods to the cold-harpoon. The research program started in 1981 and continued until 2005. In 1987, the Alaska Eskimo Whaling Commission (AEWC) supported by the US Government invited E. O. Øen to plan and conduct a similar project for the Alaskan Eskimo's subsistence hunt of bowhead whales in Alaska (Øen 1995f; O´Hara et al. 1999).

2. Research and Developments to Improve the Killing Methods for Minke Whales in Norway 1981–2005

2.1 Contemporary Minke Whale Hunt in Norway

The contemporary Norwegian minke whale hunt is conducted during the summer using medium sized (ca 18–40m; 60–130 feet) fishing vessels that are rigged for whaling in the season. The vessels are equipped with calibre 50mm or 60mm deck-mounted harpoon guns firing harpoons with a detonating grenade (Whale Grenade-99) mounted in the front (Photo 1 and 2). A strong line (fore-runner) connects the harpoon to a winch that is used to haul the whale in. The harpoon has two swivel barbs behind the grenade that prevent the harpoon of being pulled out when the whale is hauled in.

The grenade is armed with 30g of the hypersonic explosive penthrite. A twin hook, trigger, is attached to the grenade with a breakable pin. It is equipped with a strong cord which is coiled up inside the grenade body and further attached to a firing pin. The pin fires the penthrite when the harpoon has hit the whale and the twin hook is released as it

Photo 1 The Norwegian minke whale vessel Draugen (1928–2008) (Photo by S. K. Knudsen)

Photo 2 50mm whaling gun loaded with harpoon and Whale Grenade-99 (Photo by Björgvin Guðmundsson)

attaches to the skin, tightening the cord when the grenade has penetrated about 70 cm inside the whale (Photo 3 and Figure 1). Rifles of calibres .375 and .458 using full jacket, round nosed bullets are used as back-up weapons. The rifle shot is directed at the brain of the whale.

The vessels search for whales at slow speed (3–5 knots/h). When a whale is spotted the vessel idles slowly up to the location where the whale is expected to blow next and starts carefully to follow after the whale to get close enough to fire the harpoon gun. Minke whales frequently approach boats and many whales are shot at very short ranges. No instruments like depth recorders or fish finders are used as they are known to scare the whale.

The hunters are recommended to shoot the whale from the side and aim the harpoon at the thorax. If the whale is fatally wounded or dies as it rises to the surface to blow it

Photo 3 Whale Grenade-99 (Photo by E. O. Øen)

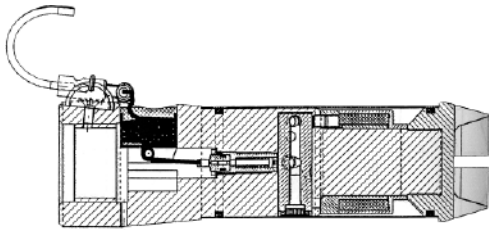


Figure 1 Whale Grenade-99 (longitudinal section view). Safety and arming mechanism in secured position.

Photo 4 Automated Electronic Monitoring Box (Blue Box) for the surveillance of minke whale hunting in Norway (Photo by E. O. Øen)

normally rolls on to its back, and floats for a short time before sinking. If it is shot when it dives it often pulls out some of the line and sinks. If a whale does not die instantly it maintains its swimming position, resurfaces and blows. If the gunner has any doubt whether the whale is unconscious or dead it will immediately be hauled to the vessel and reshot in the brain with the rifle. Some gunners fire a rifle shot in the brain as a matter of routines.

The dead whale is hauled in across the deck through an open gate in the gunwale for flensing (butchering). Meat and blubber are placed on grates and cooled before being stored on ice in the hull until it is delivered to processing plants on land. The gunners are required to pass annual, obligatory shooting tests with harpoon canon and backup rifle. The vessels and hunting gear are controlled by governmental inspectors prior to the hunting season. From 2006 on the Norwegian hunt is monitored at-sea by an electronic trip recorder, "Blue Box" (Photo 4) (Øen 2005) and spot controls in harbors.

2.2 Project Planning

Hitting in a sensitive and vital area is important for a quick kill. No weapons, not even explosive grenades, are so effective that a whale will die instantly, or rapidly, regardless of where the projectile hits the body and the detonation take place. A rapid effect largely depends on which organs that are injured. The impact of the first shot will therefore always be decisive with regard to how quickly the animal collapses and dies. In whaling both the target and the boat often move and the hunt involves an inevitable risk of only wounding the animal. Marksmanship is therefore of the greatest importance.

In planning the project, it became clear that no systematic collection of data on the killing of minke whales with cold harpoon existed. Nor were there any reports from controlled experiments with alternatives. It was thus found necessary to start to gather information on the use of the cold harpoon so that a reference base for further work and comparisons could be established. Also, anatomical illustrations or charts showing locations of vital and fatal vulnerable organs systems like the central vascular system (CVS) with heart, main blood vessels, lungs and the central nervous system (CNS) with spine and brain for the minke whale were lacking. It was therefore necessary for practical use to map the gross anatomy, location and dimensions of these organs and structures relative to outer "landmarks" like dorsal fin, flippers, eyes, blowhole etc. This was made in 1981 and during the scientific whaling in 1994 an anatomical exercise to exactly locate the brain was carried out by students at the Norwegian School of Veterinary Science (Figure 2). The aim was to make an illustrated chart of the size and location of

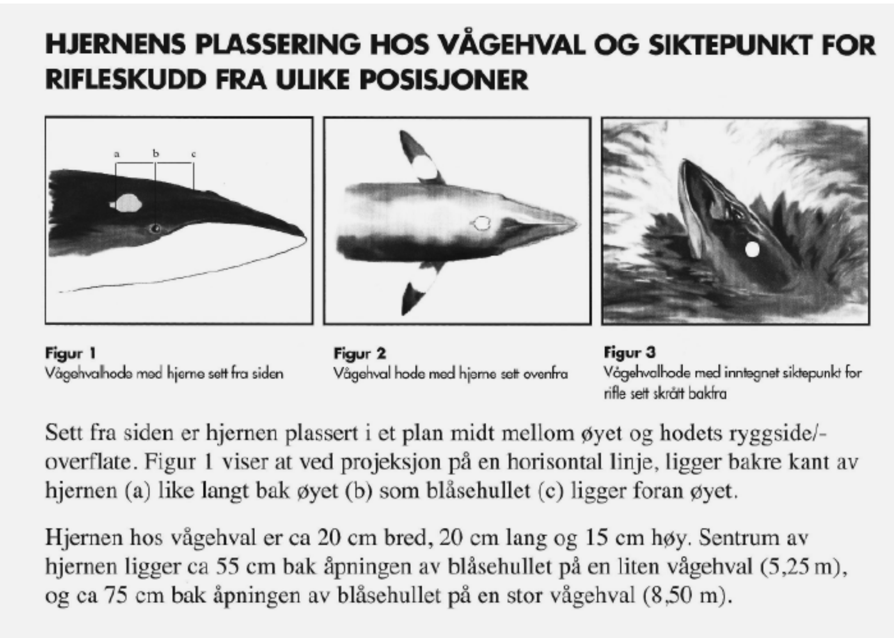


Figure 2 Chart of the position of the brain of minke whale.
(Source: Knudsen S. K., H. J. Rud, and E. O. Øen 1999)

the brain in the minke whale related to external features like blow hole, eyes and flippers to teach the gunners where to aim when the backup rifle is used. The chart has successfully been used in the training of gunners and each vessel has at least one chart hanging on the bulkhead of the steering room (Knudsen, Rud, and Øen 1999).

In planning of the project, there were several other issues which had to be taken into account: The whales had to be "hooked" before, or at the same time, they were killed; the cold harpoon had been employed in Norway for hunting minke whales as far back as the nineteen twenties and was a very familiar piece of equipment; hunting was carried out with small vessels primarily built for fishing, not hunting; the fishermen hunted whales as a side line, and were not professionals; the minke whale hunt was a dangerous enough occupation as it was, and the introduction of new methods could not be allowed to further increase the risks involved; the profitability for each vessel was limited and did not give much chance for significant economic gain, or a basis for large investments. All these factors had to be taken into consideration, although to begin with little emphasis was given to the economic consequences. The safety of the crew, and the effectiveness of the method, received the highest priority, in the above order.

There was also a large deal of uncertainty as to whether high-velocity projectiles would in fact prove to be feasible alternatives to cold harpoons. When the project was designed it was found necessary to broaden the scope to also include a wider assessment of the use of electrical harpoons, drugs, gas(air) harpoons, modified harpoons and any other method that might subsequently appear to be relevant during the course of the project. An explosive grenade adapted for use with 50mm and 60mm harpoons was also to be assessed, although the implementation of this part of the project was to wait until further results were available from the Japanese trials.

Collection of data on the cold harpoon was planned to be carried out in parallel with shooting trials and hunting trials with modified cold harpoons, testing of compressed air/gas harpoons and trials with high-velocity bullets. The first field trials with penthrite grenades started in 1983, continued through 1984, and were concluded after a comprehensive field study had been completed in 1985–1986.

3. 1981–1986: Alternative Killing Methods, Collection of Time to Death (TTD) Data, New Research, Developments and Field Trials

3.1 Electrical Harpoons and Drugs

Two of the possible alterative killing methods to cold harpoon that were dealt with in the IWC workshop in 1980 (IWC 1980) namely the use of electricity and drug to kill whales was assessed but did not result either in new equipment designs or field trials.

The first reported attempt to kill a whale using electricity seems to have been carried out in England in 1852 (Clarke 1952) and an English patent for electrical whaling was registered in 1868. More than 50 patents of electrical devises used to kill whales were accepted in Norway from 1929 to 1939 and it was carried out several experiments with electrocution of whales up to the 1960s. Electrocution had by then been used with varying but mostly poor results, for 2,500–3,000 large whales (Weber 1939; Reichert

1949; Tønnessen 1970; Hasui 1980) and basking sharks (Cetorhinus maximus) (Brøther 1968). The technical problems of breakage of the electric wires that was integrated in the harpoon line seem not to have been solved and developments of mechanical arrangements to stop or position the harpoon, the electrode, so that the current passed through the brain or heart to induce anaesthesia or cardiac arrest and not just paralysis, were not successful (Øen 1995b). Even if some of these technical problems with electric cables might have been overcome in the 1980s it was very unlikely that electrical harpoons would have improved the killing compared to the cold harpoon. The early experiments had clearly showed that the risk of hits with the harpoon outside vital areas for electrocution was overwhelming. The risk of paralysis and a slow death with painful convulsions would be considerable even with improvements. The conclusion was from an animal welfare point of view, was that electrocution could not be developed into an acceptable killing method for whales (Øen 1983b).

Also, the use of drugs would not be acceptable. Attempts to use drugs or poison to kill one whale with the cyanide compound nitroprusside are reported from 1834 (Christison 1860). Thiercelin (1866) experimented with a mixture of strychnine and curare mixed into the gunpowder of the exploding grenade. Unsuccessful experiments with curare compounds (decamethone and tubocurarine) placed in a modified shell of an explosive grenade was taken up. In Norway (1952) darts were made (Photo 5) in order to be fired with rifle and inject curare into large whales before harpooning (Tønnesen 1970). This experiment was stopped before the equipment was tried on whales.

Drugs have to be injected intramuscularly and have to fulfil very specific requirements to kill a whale rapidly. During whaling it has to be delivered using darts fired from remote positions. Therefore, they must (1) be acting effectively in relatively small amounts, (2) be rapidly absorbed from the musculature to exert a rapid effect, (3) be harmless to handle for the operator or crew and (4) non-toxic for the subsequent consumer of the whale meat. In practice, there were and still are, no known drugs which met these requirements. Another complicating factor is that an unconscious or dead minke whale will sink and be lost (Øen 1990). Consequently, drugs could only be employed together with harpooning and will not represent an independent alternative to cold harpoons (Øen 1984a).

Photo 5 Dart planned to be used for intramuscular injection of curare of whales 1952 (Photo by E. O. Øen)

3.2 Description and Analysis of the Use of Cold Harpoons 1981–1983

Roughly 90 vessels took part in the minke whale hunt 1981–1983 seasons sharing an annual quota of 1,690 minke whales. The whales were caught using the cold harpoons. The most commonly used cold harpoons had a welded conical, sharp-pointed tip (head) of iron with two swivel barbs fixed at the neck (Photo 6) and a shaft with two legs running from the neck into a base at the rear end of the harpoon. The overall length was about 120cm and the harpoon weighed about 12 to 18kg depending on its calibre and manufacturer. The cold harpoon, with its pointed, conical head, will function more like an arrow than a bullet (Øen 1983a; 1983c; 1995a).

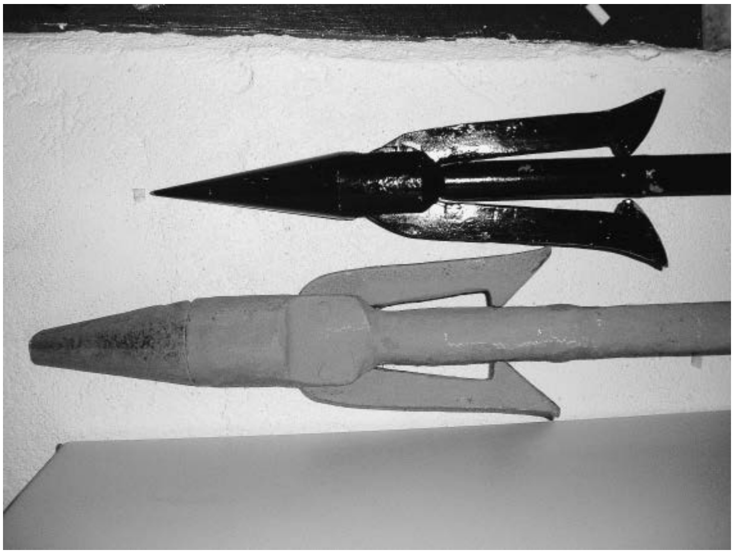


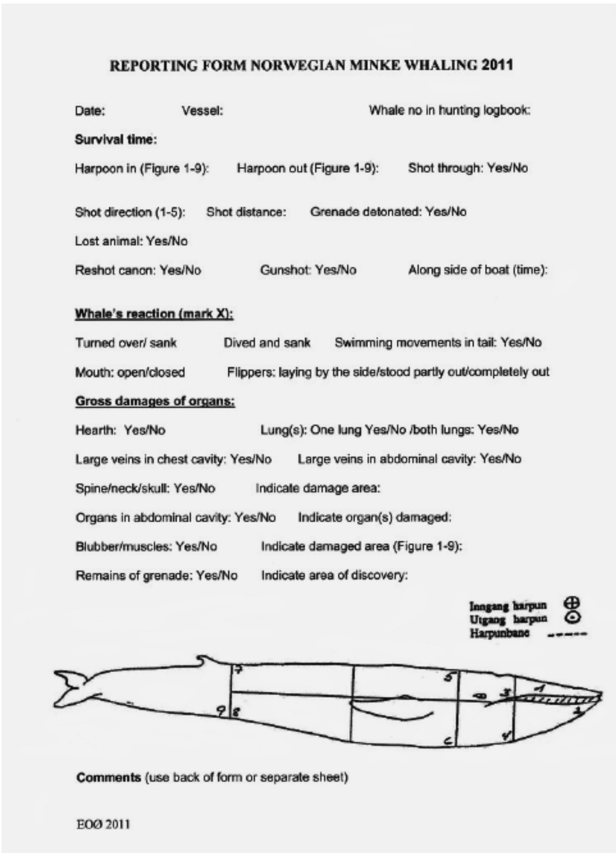
Photo 6 Heads of sharp-pointed cold harpoon (above) and older cold harpoon with butt nose-piece (Photo by E. O. Øen)

3.2.1 Data Collection and Analysis of Killing Efficiency

The collection of survival time or time to death (TTD) data for cold harpoon in 1981–1983 was carried out by personnel sampling data for the Institute of Marine Research in Norway. They were not specially trained for the sampling but recorded data on specific schemes (Figure 3). From 1984–1986 on to the last data sampling of survival time data in 2011–2012 where a gross post mortem examination of organ damages when possible, became an important part of the data sampling, veterinarians who had attended a training course sampled data on TTD data with the gross necropsy findings, the whale's reaction after being hit, whale length, estimated range at the moment of shooting, the angle between the shot direction and the whale's long axis, the impact point on the whale, the detonation site, weapons and equipment used, and whether the whale had to be reshot either with a new grenade or with a rifle. The survival time or TTD i.e. the time from a strike until the whale was declared dead according to “IWC criteria”, was recorded with a stop-watch at the moment when flipper movement ceased, relaxation of the mandible occurred, or the whale rolled over or began to sink with no active movement. From 1981 to 2012 TTD data have been sampled and analyzed for 5,524 minke whales using more or less the same form from 1984 on as shown in Figure 3.

Survival data was received for 353 whales caught using cold harpoons during the three seasons from 1981 to 1983. Instantaneous or rapid death (seconds) was reported for 17% of the whales. The median value for TTD was 9.5min, the lower quartile (Q_1) was at 3.5min and the higher quartile (Q_3) at 16min. Seventeen whales (4%) survived for 30min or longer and the longest time registered was 62min.

The median value for hits in the central nervous system (CNS) was 0. Median survival time was 30 seconds for whales injured in the heart and 7.5min in cases where the lungs but not the heart were injured. The median time for hits where main blood vessels in the thorax or abdomen had been injured was 5min. The CNS was hit in 13% and the thorax in 31% of the cases. Fifty six per cent of the whales were hit where the



REPORTING FORM NORWEGIAN MINKE WHALING 2011

Date: Vessel: Whale no in hunting logbook:

Survival time:

Harpoon in (Figure 1-9): Harpoon out (Figure 1-9): Shot through: Yes/No

Shot direction (1-5): Shot distance: Grenade detonated: Yes/No

Lost animal: Yes/No

Reshot canon: Yes/No Gunshot: Yes/No Along side of boat (time):

Whale's reaction (mark X):

Turned over/ sank Dived and sank Swimming movements in tail: Yes/No

Mouth: open/closed Flippers: laying by the side/stood partly out/completely out

Gross damages of organs:

Hearth: Yes/No Lung(s): One lung Yes/No /both lungs: Yes/No

Large veins in chest cavity: Yes/No Large veins in abdominal cavity: Yes/No

Spine/neck/skull: Yes/No Indicate damage area:

Organs in abdominal cavity: Yes/No Indicate organ(s) damaged:

Blubber/muscles: Yes/No Indicate damaged area (Figure 1-9):

Remains of grenade: Yes/No Indicate area of discovery:

Inngang harpun ⊕
Utgang harpun ⊙
Harpunbane ------

Comments (use back of form or separate sheet)

EOØ 2011

Figure 3 Scheme used for TTD data collection in Norway.

injury was unlikely to cause rapid death, e.g. in the abdomen or musculature. The median survival times for hits in these regions were 11.5 and 14.5min, respectively.

Seventeen per cent of the whales were reshot with harpoons, and rifle shots were used in 56% of the cases. Complete penetration of the body by the harpoon was seen in 87% of the cases. The whales varied in size from 4.9m to 9.2m with a median length of 6.7m. The shooting range varied from estimated 5 to 100m, with a median value of 30m. Four per cent were shot in front (directly in front, 0° to 45° to the animal's long axis), 60% from the side (45°–135°) and 36% were shot from behind (135°–180° – directly from behind).

The range, the size of the whale and the angle of the shot relative to the animal's long axis all strongly influenced survival time. The influence of shooting range and whale size on killing time was studied by Cox regression (proportional hazard) and by a combination of logistic regression for the whales killed instantaneously and Cox regression for whales that was recorded instantly dead. The time to death was significantly dependent on both covariates in the Cox regression. Analyses based on a combination of logistic regression and Cox regression gave similar results. However, the fraction of the whales killed instantaneously was only dependent on shooting range and not significantly on animal size. Shots fired from in front or behind produced poorer results than shots from the side. The effect was quite clear both on the median and mean survival times.

Twenty-three per cent of the whales were shot with 50mm and 77% were shot with 60mm harpoons. The results showed that there was no significant difference between the two harpoons in survival times or frequency of total penetration.

In general, the lethality of non-explosive and non-expanding projectiles such as the traditional sharp pointed cold harpoon is directly related to the damage caused by the projectile itself to the organs and tissues it passes through. It must therefore hit vital organs like the brain, heart or major blood vessels to kill the animal rapidly (Øen 1994). When such vital organs are injured by large projectiles like 50mm and 60mm harpoons, the whale would die very rapidly regardless of the harpoon calibre or the animal's size. As long as a whale was alive, however, the hunters would be careful not to haul it in too fast because they were anxious not to lose whales alive, and the larger the whale the more time this process took, thus prolonging the time to death.

Another factor that prolonged killing times for some whales was outdated hunting techniques inherited from earlier days with poorer equipment and ropes, which were still in use in 1981 and 1982. These vessels had no winch which meant that the harpoon line could only be connected to an air-filled buoy that was thrown out after the harpoon had hit. In the case of a non-lethal hit, a long time could elapse before the whale could be killed either by a second harpoon or by rifle shots. This hunting method was forbidden from 1983 on.

The shooting range influenced the results, which were poorer for ranges exceeding about 30m. The reduction of accuracy at longer ranges is also a well-known phenomenon in other types of hunting using projectiles, but the accuracy of the relatively heavy, slow harpoons (v_0=80m/s) will decrease substantially at longer ranges. In addition, the sharp-nosed harpoons which were used in 1981–1983 had tendency to ricochet or turn upwards under water (Øen 1995a; 1995c). Shots from directly in front or behind the animal gave poorer results than shots from the side because the likelihood of hitting the animal in the most vital organs was considerably lower at such angles.

More accurate shooting and hits in the most vital body areas would undoubtedly improve results with the cold harpoon. However, even if accuracy were to be improved by optimizing weapons, sighting implements, harpoons and training of gunners, this would probably not be sufficient reason for accepting cold harpoons used in the Norwegian minke whale hunt.

3.3 Field Trials 1981–1984

Field trials with high-velocity projectiles, testing of cold harpoons with different head designs and air-filled harpoon/containers were carried out in parallel with pilot studies and preliminary field trials with Japanese penthrite grenades and modified harpoons with stoppers to prevent full penetration through the whale.

3.3.1 Compressed Air (gas) Harpoons

Attempts to kill whales with harpoons filled with carbon dioxide were carried out from 1920 to 1961 (Tønnesen 1970). The results were not promising. However, at the IWC workshop in 1980 this method was still focused on. During the field trials in 1983, two harpoons/containers with compressed air at 200kg pressure of 200 litres and 400 litres, respectively, and with a servo-operated valves which emptied all the air almost instantaneously at a predetermined depth after penetration, were constructed and tested on one dead minke whale on the boat deck.

When the air was released the body of the whale made a "jump". However, if this "shock" would have killed the whale is not known. Such information seems not to exist. But, it was easy to conclude that such harpoons/containers were useless for hunting. Even though only moderate amounts of gas were involved in this trial, the harpoons/containers were so voluminous that the harpoons would scarcely have hit the whale at shooting ranges over 10–15 meters. Further trials with air/gas harpoons were therefore discontinued (Øen 1995a).

3.3.2 High-velocity Bullets

High-velocity bullets are described as projectiles with a muzzle velocity of over 750m/s or 2500ft/s (Berlin et al. 1976). Such projectiles are known to create shock and pressure waves by compression of the tissues at the impact site and projectile path. The region of compression ahead of the projectile moves away as a shock wave, whose velocity is slightly higher than the speed of sound in water (1,450–1,500m/s). It generates complex pressure changes at a level of several hundred atmospheres and radiate outwards spherically from the projectile path (Berlin et al. 1976), expanding the missile tract into a pulsating temporary cavity, disorganizing the musculature and blood vessels and nerves along the path (Harvey et al. 1962; Rybeck 1974; Charters and Charters 1976). The damage caused by high-velocity projectiles in organs and tissues is very similar to and has therefore led various workers to compare high-velocity projectiles with explosives (Øen 1995a; 1995d). Although speed is the most important factor, also the shape of the projectile will also determine the characteristic changes in the organs and tissues caused by high-velocity projectiles (Berlin et al. 1976).

Field trials with 3 different 20mm high-velocity hollow point projectiles weighing 115g with estimated muzzle velocity (v_0) of 1058m/s and impact energy at 100m (E_{100}) of about 60kJ were conducted in 1982–1983. To investigate the terminal effect, the target ballistics and the effect of water, shots were fired both above and below the waterline at two dead whales. These were kept afloat with part of the back above the water by fastening air-filled buoys to the rostrum, flippers and body behind the dorsal fin. The projectiles were first fired into the sea. They ricocheted if they hit the water at ranges between 200m and 400m.

During the trials on the dead whales it was observed that projectiles that went through water about one meter or more before it hit the whale often stopped in the blubber due to the braking effect of the water. Examination of the carcasses of the two whales and post-mortem examination of whales killed in the hunting trials revealed that only direct hits caused wounds more than 30cm deep. The cavity made by projectile that hit in the musculature without being slowed down by water varied in size from 3cm to 12–15cm in diameter and along the projectile path, injured muscles could be transformed into a granular mass. Bleeding and patches could be seen up to 30cm from the center of the wound. Blubber and muscle tissue at the projectile path were jelly-like in consistency. Bones struck by the projectiles were splintered. A hit in the dorsal spines of the vertebra completely split the vertebral body, revealing the spinal cord (Øen 1995d). The conclusion from these trials was that the most solid of the three 20mm high-velocity projectiles that were tested could kill minke whales instantly or rapidly if the bullets hit the skull, thoracic/neck part of the spine or in the thorax when these parts of the body were over the water (Photo 7). If it went into the water before it passed into the whale the effect was more doubtful.

However, since a dead minke whale would sink high velocity projectiles could only

Photo 7 20mm, 15g high-velocity bullet used in hunting trials of minke whale (Photo by E. O. Øen)

be used in conjunction with harpooning, and not be an independent method. Another important disadvantage was that the harpoon line could be shot away. This happened in one of the cases. This whale was rescued from sinking, but the high risk of losses, the long range of the projectiles (7,000m) and the danger of ricochets that could hit people on land and crew on other boats on the same hunting grounds, disqualified the method from whale hunting. The large calibre rifle, which already had been introduced in the hunt, was a faster and more effective method to dispatch wounded whales compared to a separate gun with 20mm high-velocity projectiles (Øen 1995a; 1995d).

3.3.3 Traditional Sharp Pointed Versus Blunt Cold Harpoons

Observations in 1981 from the hunt with traditional sharp-pointed 50mm and 60mm cold harpoons revealed that at longer ranges (60–100m), the harpoons sometimes nearly ricocheted out off the water and that many of the shots hit the whale high in the back muscle, often well above (60cm) the point on the animal at which the gunners normally aimed. This occurred even if the harpoon hit the water several meters from the whale. Hirata (1951) made similar observations during experiments using sharp-pointed and blunt 90mm harpoons. Older minke whale hunters could tell that the most successful harpoons they had used were made by a blacksmith who produced harpoons where the shape of the head was blunt. To examine whether high shots and ricochets could be related to the shape of the harpoon head, prototypes with blunt heads of different diameter were made for ballistic testing in 1982.

The harpoons were shot from a 60mm harpoon gun mounted 5m above the water at a floating target at a range of 70m. The targets consisted of seven wooden frames measuring 3 × 2.5m, weighted at the bottom and covered with chicken wires. These were placed at one meter intervals across a floating wooden frame measuring 3 × 6m and with a red buoy as target 1m in front of the frame. The weights kept the target frames vertical in the water. The harpoon passed through the nets and the projectile path could be registered by measuring the distance from the water surface down to the harpoon line in the nets with a dipstick. For each shot the impact point of the harpoon relative to the buoy was registered from a boat lying on the side of the target.

Twenty-two shots were fired. After striking the water surface, the trajectory of the traditional sharp-pointed harpoons lost height at an average rate of 10–12cm per metre water for the first five metres, and in one case it deflected upwards towards the surface again. No ricochets over water were registered. The trajectory through water for blunt harpoons went almost straight forward the first 3–5m and lost an average of 20–30cm per metre depending on the diameter of the nose before they went steeper down and sank. The harpoons with the widest nosepiece (7 and 9cm) lost height at a rate of up to 50cm per metre after the first 3 meters. The nose of the harpoon with the straightest trajectory was 4.5–5cm in diameter.

Using floating underwater targets gave a good picture of the underwater ballistic characteristics of harpoons. The ballistic trials indicated that harpoons with blunt noses up to 50mm were ballistically more suitable for the hunting of minke whales than those with sharp points if the aim is to kill the whale fast. The trajectory of the cold harpoon made it well fitted to hook the whale rather than to kill the whale. Therefore, the hunters liked to fire at the whale slightly from behind to make the target as "long" as possible and thereby get a better chance to hook it. A harpoon which may rise in the water is more likely to strike too high up on the body than one that continues more straight ahead, especially at longer ranges (> 50m) and in particular if the whale has started to dive when the harpoon hits. The design of nose of the blunt harpoon that had the best trajectory through the water was with some modifications used to design the nose-piece of the penthrite grenades developed in 1984 and 1999 (Photo 3) (Øen 1995a; 1995c; 2003b).

Hunting trials on one boat in 1983 indicated that the harpoons with blunt nose also killed the whales more rapidly than sharp-pointed harpoons as the median time to death (TTD) for this harpoon was somewhat reduced compared to the traditional sharp-pointed harpoon. However, this was not enough to recommend continued use of cold harpoons in the Norwegian minke whale hunt (Øen 1995a).

3.3.4 Development and Testing of Penthrite Grenades

After the pilot studies and trials with high-velocity projectiles had been concluded in 1983, a thorough assessment of and hunting trials with the Japanese penthrite grenade was carried out. The conclusion was that the security system could not be accepted on Norwegian vessels where the gunners are fishermen with whaling as a side income and not professional gunners. Also, the triggering system would not function properly on Norwegian harpoons without major modifications of the harpoons. It was therefore decided to start development of a Norwegian grenade with penthrite in cooperation with Raufoss Ammunition Factory, Raufoss (RA) and Henriksen Mek. Verksted, Tønsberg, (HM Henriksen) a grenade that attended the specific safety and technical demands that were important for the hunter's safety and hunting efficiency (Øen 1984b).

Two prototypes with penthrite as explosive, one with a built-in trigger mechanism for detonation at 50–70cm depth, and one with a time-delayed fuse to be used on harpoons with mechanisms that were designed to prevent the harpoons from completely penetrating through the whale, were tested in field trials in 1983. The trials confirmed the previous assumption with respect to the Japanese grenade that the Norwegian grenade with the prefabricated safety mechanism and triggering system proved to be best suited for the Norwegian type of hunting operations (Øen 1984b; 1995a).

Efforts to further develop the Norwegian grenade continued, and two new prototypes were tested in an extensive field trial in 1984. These grenades were armed with 22g of penthrite fuse. The trigger mechanism was principally the same as described for the Whale Grenade-99 where a twin hook attached to the grenade with a breakable pin, triggered the detonation when the grenade had penetrated about 70cm inside the whale. The grenades were armed by the acceleration forces when the harpoon gun was fired and could not be re-secured. To avoid armed grenades from being hauled on board if the harpoon failed to hit the whale the grenade was equipped with a self-destructive element that detonated the grenade in the sea after five seconds.

The grenade body was made of steel. It was 25cm long and weighted 2.5kg. It was equipped with an outer jacket made of 1mm thick steel to protect the penthrite fuse. After preliminary hunting trials in 1983 the steel jacket was replaced with a 0.7mm thick aluminium jacket like the jacket later used for Whale Grenade-99 (Øen 1995e; 2003b).

The collection of data for the penthrite grenade started in 1984 and continued through 1985 and 1986. The statistical analyses of the data were from now on to 2012 carried out by professor Lars Walløe at the University of Oslo, Norway. TTD data collected for 259 minke whales killed in 1984–1986 showed that the percentage of whales that were killed instantly had increased from 17% using cold harpoon to 44.8% using penthrite grenades, about 2.7 times higher than the results obtained with cold harpoon (Table 1). The median survival time was reduced to 72s. The lower quartile was 0s and the upper quartile at 9min. Seven whales (2.7%) survived 30min. Four per cent of the whales were re-shot with grenades.

Autopsy established that detonation in or near the thoracic cavity damaged the lungs, heart and larger vessels, and that there was massive intrathoracic, sub-pleural haemorrhaging. For animals in which the main damage was recorded in the central nervous system (CNS), heart, lungs or major blood vessels in the thorax or abdomen, the percentage of instantaneous deaths recorded was 92.6%, 78.7%, 62.7% and 52.8% respectively. Detonation in the musculature caused massive injuries to muscle tissue which was transformed into a granular, pulped, jelly-like mass without normal tissue structure up to 20–30cm from the detonation site. Bleeding and rib damage could be seen up to 50cm from the centre. Hits in the region of the head or neck caused crushing of the cranium. The harpoon went completely through the whales in 85% of the cases.

Range, whale size and the angle of the shot relative to the animal's long axis all influenced survival time. However, the fraction of the whales killed instantaneously was only dependent on shooting range and not significantly on animal size. Shots fired from in front (directly in front 0° to 45° to the animal's long axis) and behind (135°–180° directly from behind) produced significantly poorer results than shots from the side (45°–135°) (Øen 1995a; 1995e).

As data on survival times from the hunt in 1984 showed that a substantially higher

Table 1 Year and percentage of minke whales killed instantly and median survival times for whales killed with cold harpoons (1981–1983), penthrite grenades with 22g penthrite fuse (1984–1993), and penthrite grenades with 30g pressed penthrite (Whale Grenade-99) (2000–2012).

Type of catch	Year	No. of whales	Instant death %	Survival time (s) Median
Cold harpoon	1981–1983	353	17,1	570
Penthrite 22g fuse	1984–1986	259	44.8	72
Penthrite 22g fuse	1993	157	54.1	0
Penthrite 30g Pressed in wax	2000–2002	1667	79.7	0
Penthrite 30g Pressed in wax	2011–2012	271	81.9	0

percentage of instantaneous deaths was recorded for penthrite grenades than for cold harpoon, use of the cold harpoon was banned from the 1985 season on, and the penthrite grenade together with high powered rifle as backup became the only permitted killing devices in the minke whale hunt in Norway.

4. Scientific and Traditional Whaling 1992–1994

The traditional minke whale hunt was temporarily halted from 1987 to 1993 to carry out a comprehensive assessment of the minke whale stock in the Northeast Atlantic. In 1992 whales were only caught for scientific reasons.

About 10% of the grenades produced in 1992 misfired. As these grenades could not be re-secured the undetonated grenades implied considerable safety risks for the hunters and scientists. The manufacturer (RA) started in cooperation with Øen a comprehensive fault-finding program to find the causes for the misfire. The problem was located to the arming mechanism and the remaining grenades produced in 1992 were rebuilt prior to the 1993 seasons. However, some grenades continued to malfunction but in lower scale until they were replaced with the Whale Grenade-99 in 2000.

Reanalysis of the data from the hunt with cold harpoon and penthrite grenade used in 1984–1986 verified that although whale size (length) and the range and angle of the shot relative to the animal's long axis all influenced survival time, whale size was only a statistically significant factor when the whale did not die instantaneously. It also showed that marksmanship, technical and functional reliability of equipment, and hunting techniques, were all crucial for a good result. This implied that improved training of gunners, more effective weapons and hunting equipment, and more rapid re-shooting of wounded animals, would reduce the proportion of long survival times.

Prior to the traditional hunt in 1993, the hunters therefore had to undergo obligatory training courses and shooting tests, the hunting equipment was made stronger, and hunting procedures were changed. The collection of data on killing was carried out by trained veterinarians as in 1984–1986. In the scientific catch, data were collected by scientists who had received special instructions.

The survival plot for the 157 whales caught in the traditional hunt in 1993 showed that instantaneous death was recorded for 54% of the whales. The mean survival time was 228s. Signs of life were seen for more than 15min after harpooning in eight per cent. The size of the whale did not significantly influence survival time in 1993 as it had done earlier as the whalers were instructed to haul the whales in for possible reshooting as soon as possible after they were hit.

Training courses for hunters and inspectors were also held in 1994. The shooting tests were made more stringent and the hunting equipment further improved. To improve marksmanship only harpoons that were consistent in weight were permitted used. The required tensile strength of harpoons, fore-runners, wires, winches and braking devices was further increased from 1,500kg to 5,000kg to avoid breakages and losses. Specific instructions were given the gunners on shooting and catching routines. The recommended range for harpoon shots was set to 30m and whenever possible the animals were to be shot from the side aiming at the thorax/neck area and hauled to the boat immediately to determine whether re-shooting with rifle was needed. During the hunt the rifle had to be kept in a closet beside the gunner at all times.

In 1994 the instantaneous death rate went up from 54% to 59% and the mean survival time was reduced from 228s to 185s. Signs of life seen for more than 15min was reduced from 8% to 4%. The results from the scientific catch in 1992, 1993, and 1994 (Øen and Walløe 1995) were not so good as those from the traditional hunt, a situation which probably was due to both misfire of grenades in 1992 and differences in hunting techniques.

5. 1997–2004: Development and Implementation of the Contemporary Penthrite Grenade (Whale Grenade-99)

Some cases of misfire of grenades continued the following years and created an unacceptable situation regarding safety and animal welfare. The manufacturer could not guarantee better quality in future productions and a more reliable and secure penthrite grenade had to be developed for a safe continuation of the hunt. Invention and development of a new grenade became therefore an integrated part of a project for a wider study on improvements of hunting and killing methods for whales, seals and large wild terrestrial mammals at the Norwegian School of Veterinary Science, starting in 1997 (Øen 1999). The study was partly funded by the Norwegian Research Council.

The development and field trials of the grenade started in 1997 in cooperation with Norwegian Defence Research Establishment (NDRE). The development of the grenade was concluded in 1999 and the new grenade, Whale Grenade-99, was fully implemented in the hunt in 2000. Data on killing efficiency (TTD) were sampled by trained veterinary inspectors in three hunting seasons of 2000–2002 (Øen 2003a; 2006; 2010).

5.1 Development and Testing

The grenade was designed to accommodate a reversible safe and arming mechanism (SAM) invented in 1996 (NO-Patent 310796) that combined the security and arming functions of the grenade and made the earlier self-destruction element unnecessary. The SAM keeps the grenade in a secured and safe state during transport and handling. The grenade will not be armed until it has been fully mounted on the harpoon. The reversible function means that the arming immediately will be turned off and re-secure the grenade the same moment dismounting of the grenade from the harpoon starts. But, even when armed it cannot detonate unless the firing pin is cocked and released by a force of ca 70kg. This happens when the grenade has penetrated 60–70cm inside the whale. If the shot misses the whale the grenade is dismounted and re-secured and can be re-used later. The grenades are individually marked and can be identified after they have been used.

The weight of the former grenade with steel body made some problems with the balance of some harpoon guns and thereby reduced marksmanship. To reduce the weight the body of the new grenade is made of aluminium with a nose piece of steel (Photo 3). The explosive of 22g penthrite fuse in the steel grenade was replaced with a ring of 30g penthrite charge pressed in bees wax and located around the body under the aluminium tube. This charge needed much smaller space than penthrite fuse. Aluminium body together with a shorter body reduced the weight of the grenade compared to the steel grenade by 40%. Shooting trials showed that this grenade considerably improved the ballistics and marksmanship.

After laboratory testing and shooting trials on land-based proving grounds a prototype of the grenade was used for the hunt of 14 minke whales from one vessel in 1997. Seven of the 14 whales were registered dead instantly. The average survival time was 125s. After some modifications a second prototype was produced for a larger field trial in 1998. Report was received for 625 whales of which 64% were registered instantly dead. The 75% fractile (Q_3) of the median survival time was 5min. However, some grenades failed to detonate. The reason for misfire was that a strong spring in the arming mechanism had been replaced with a weaker one (Øen 1999). In 1999 the third prototype was used for 129 minke whales and 72% were recorded instantly dead. The 75% fractile (Q_3) of the median survival time was 140s. Again a few grenades failed because the trigger hooks were too weak and bent and some trigger ropes were torn off when the grenade went through bones.

After the 1999 season, the trigger hooks, trigger ropes and some pyrotechnical elements were replaced and improved before the grenade was re-tested and presented for approval by competent authorities, the Norwegian Directorate of Fire and Explosion Prevention, to obtain authorization for use on whaling (fishing) vessels and UN authorization for transport under the name "Whale Grenade-99". Authorization was obtained and the former steel grenade that had been used since 1984 was banned.

5.2 Implementation and Killing Efficiency of Whale Grenade-99

Prior to the hunt in 2000 weapon workshops were arranged for the gunners and licence holders like in 1998. Detailed instructions were given on function and use of the grenade. Like in earlier seasons trained veterinarians and biologists collected data on the killing of the whales.

In 2000, 481 minke whales were recorded killed with Whale Grenade-99. Instant death was recorded in 78.3% of the whales. In 2001 the corresponding figures were 552 whales with an instant death rate of 79.7%. In 2002, 634 whales had been recorded and 80.7% of the whales died instantly. The longest TTD was recorded in 2001 and 2002 where two whales broke free and had to be retrieved and re-shot with grenades. Altogether, 1,667 minke whales were caught during the three seasons. There was no statistically significant difference between the three seasons. When the data were pooled, 79.7% of the whales had died instantly (Figure 4). This result is 20% higher than the best result obtained with the former grenade (59%).

Like in earlier seasons (1984–1986) it was found that the whales die instantaneously or very quickly (seconds) if the grenade hits and detonates in the thorax or near the central nervous system. Also, detonation in the cranial part of the abdomen or in musculature dorsal to the thorax can result in instantaneous or very rapid death, but the effect of such hits is less reliable.

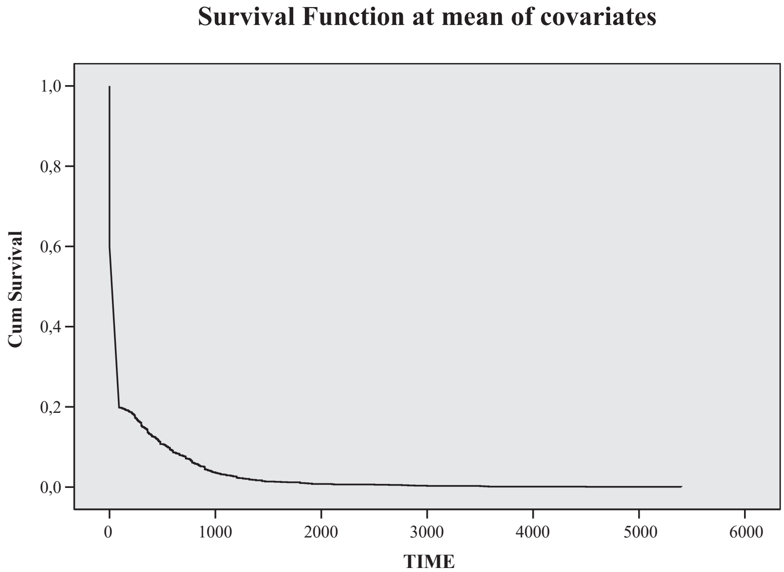


Figure 4 Survival plot for 1,667 minke whales shot in 2000–2002 with Whale Grenade-99. Horizontal axis: time in seconds. Vertical axis: proportion of whales showing signs of life.

Like earlier the TTD data showed how the angle of the shot relative to the animal's long axis influenced survival time. Shots from directly in front (0°–10°) or behind (170°–180°) gave poorer results than shots directed from the side (45°–135°) because the likelihood of hitting the animal so that detonation would take place in the most vital organs is considerably lower in such cases. However, if a whale was injured in the central nervous system, heart, lungs or major blood vessels (aorta, vena cava) it generally lost consciousness and died rapidly regardless of the angle of the shot (Øen 2003b).

5.3 TTD Data Sampled in 2011 and 2012

In 2010 an Expert Group Meeting arranged by The North Atlantic Marine Mammal Commission (NAMMCO) to assess TTD data from whaling in member and associated member countries, recommended new sampling of TTD data from the Norwegian minke whale hunt in order to check the status of the hunt (NAMMCO 2010).

To follow up these recommendations the Directorate of Fisheries in Norway engaged E. O. Øen to organize sampling, processing and analysis of TTD data. The sampling took place during the hunting seasons of 2011 and 2012 by trained veterinarians like in earlier years.

A training course for hunters and inspectors were arranged prior to the 2011 hunting season. As in earlier seasons hunters were recommended to shoot the whales from a side position (45°–135° – relative to the animal's long axis) and aim at the chest.

TTD data were received for 271 minke whales, 180 whales in 2011 and 91 whales in 2012. The results of the survival plot for the 271 minke whales are shown in Table 1 and shows that instantaneous death was recorded for 222 whales (81.9%) with an average TTD of 60s. The median TTD for the 49 whales not registered instantly dead was 300s. One whale that had only been wounded was reshot after 20–25 minutes. No whales were lost alive.

The angle of shot is registered for 254 (94%) of the 271 whales. Of these were 62% shot from the recommended side position, 22% in a narrower angle from behind (135°–180°), 16% were shot from the front or from behind. About 92% of the whales shot from the recommended side position (45°–135°) were registered instantly dead while only 70% of whales shot in the narrower angles either from front or behind positions (0°–45° and 135°–180°) died instantly. The results for the other 16% of whales shot from the front (0°) or from behind (180°) were about 63%.

The shooting distance varied from 20 to 60 meters. Whales shot from the shortest distance were registered dead in average little faster than whales shot from the longer distances. However, the differences were not statistically significant. No misfire of grenades due to technical errors was reported during the two seasons (Øen 2015).

6. Criteria of Death in Whales - Immobility vs Agonal Reflexes

The criteria used in IWC (1980) to decide the point of death to the moment total immobility is practical for the whalers like it is for hunters of terrestrial mammals. However, Øen (1995a; IWC 1992) had observed whales that rolled over on its back soon after the detonation of the grenade and started sinking sometimes continued to have its flippers partly erected and sometimes showed movements of the tail. He also had observed whales with violent tail thrashing after they had been hauled close to the vessel. Post mortem examination of these whales had, however, revealed massive bleedings in the brain *cortex* and also injuries of vital organs in thorax, injuries that strongly indicated that the whales must have lost consciousness and died instantly or very rapidly. Cases where the brain was completely crushed (Øen 1994; 1995a) but where the whale continued to move its tail were also observed. It was therefore reasonable to expect that such movements were caused by agonal reflexes i.e. uncoordinated reflexive movements that occur when the motoric control of the spinal cord has been lost due to damage of the *cerebral cortex* and not by life.

At slaughter of livestock it is well known that complete immobility during the first few minutes after stunning rarely is achieved (Blackmore and Delany 1988) and serious doubts have therefore been raised about the value of using total immobility as a criterion to determine when an animal is dead. Yet, on the contrary, the above authors and others consider the occurrence of agonal convulsions and seizures to be reliable indicators that the animal has been satisfactorily stunned (Gregory 1987; Blackmore 1987; Blackmore and Delany 1988).

Using total immobility as sign of death were challenged by Øen in several meetings and workshops in IWC (1992; 1995; 1999) and this view was also supported by Blackmore (IWC 1995). However, the majority of the animal welfare and anti-whaling coalition in IWC disagreed. Some simply declared that whales did not have the character to show reflexive movements and accordingly, any movement was a true sign of that the animal was still conscious and felt pain. Doubt was also frequently expressed whether the rifles and ammunition used for backup in Norway were strong enough to penetrate the scull and kill a minke whale effectively (IWC 1992; 1994; 1995; 1999).

After the discussions in the IWC Workshop in 1992 (IWC 1992), Øen found that a more systematic investigation of brain damages caused by the detonation of the penthrite grenade and the use of backup rifle became necessary to find (1) if whales were different from terrestrial mammals and seals with regard to agonal reflexes, and (2) if the recommended ammunition for backup was effective to kill minke whales rapidly.

7. Development of a Method for *in Situ* Fixation of Whale Brains

The first brain studies were carried out during a scientific catch of minke whales in 1992. The aim was to undertake gross and histological examination of brains of whales and relate, if possible, the findings to observed behaveour and movements of limbs after detonation of the grenade and/or rifle shots. As the whale brain is well protected deep inside the skull and under solid bones, attempts to remove fresh brains caused injuries of the brain tissue that would create artefacts that would disturb the histological examination. A way to fixate the brain *in situ* before the excision therefore had to be developed to retrieve the brains undamaged and reduce the risk for artifacts.

Fixation trials and excision of the brains on board the vessel was carried out by EO Øen of the Norwegian School of Veterinary Science and further gross and histological examination was carried out by brain pathologist S. Mørk of the University of Bergen, Department of Pathology, the Gade Institute. Four fixated brains were sent to the University for histological examination in 1992. No information was given to the pathologist of the behaviour of the whales or the TTD.

To prepare for the brain fixation the whale's head was cut from the body in the *atlanto-occipital* joint as soon as possible (usually 2–3 hours) after the whale was dead. Skin, blubber and muscles on the scalp was removed from the bones using knives. A triangular opening about 10 × 10 × 10cm in the bone over the brain was carefully cut through using an electric bone saw. The saw blade could be regulated to prevent it from cutting deep and into the brain. Chisels were carefully used to finish the cutting where necessary. It was important to avoid damage of the meninges (*Dura mater*). When the triangular bone had been removed *Dura* was cut open using scalpel and forceps to expose the dorsal part of the brain for inspection in fresh state. *Foramen magnum* was clogged using paper and a fixative of a mixture of 2 litre of 36% ($^{w}/_{w}$) formaldehyde in 9 litres of sea water, was poured into the scull and frequently refilled. After 36, 48 and 60 hours, respectively the whole scalp over the brain was removed using saw and chisel so the brain with its meninges could be lifted out and grossly examined before being transferred to containers with fixative.

The four brains in 1992 were subjected to gross and light microscopy examination. Two of the brains were from whales which had shown movements of the tail for 133s and 143s, respectively. One of these had been tradring violently with the tail thrashing for about 30–40s after it had been hauled aside of the vessel. The two others were from whales that did not show any movements and had been recorded instantly dead using the "IWC criteria".

The histological examination revealed, however, same type of changes in all four brains. There were extravascular haemorrhages in the brainstem, the base of the fourth *ventricle*, and in the white matter of the *cerebellum*. There were no signs of intravital reactions in the tissues surrounding the blood accumulations which according to the pathologist, indicated that the changes had been hyper-acute and that all four whales had lost consciousness and died instantly (Mørk S. J. pers. comm).

Fifteen brains were sampled during scientific catches in 1993 (Øen and Mørk 1999). Five of these had not been re-shot with rifle. The brains had haemorrhages of the brain surface from less than $1cm^2$ to those covering most of the brain. Four had been recorded instantly dead and one lived for 280s using IWC criteria.

The post mortem examinations showed endocardial haemorrhages at the base of the heart valves, particularly the atrioventricular valves in five whales. Four of these had been registered dead instantly and one after 280s. Air bubbles were found in the coronary arteries of one whale that had died instantly. Haemorrhaging and damage of varying extent was found in the lungs where the grenade had detonated in the thorax. Intrapulmonary haematomas were also found on five whales where the grenades had detonated extrathoracically. Haemorrhaging in both lungs, heart and brain were observed in instantly dead whales (Øen and Mørk1999).

Ten of the 15 whales had been reshot with 9.3mm full-jacketed blunt nose rifle bullets. Six of these were registered as instantly dead, but were reshot by the gunner as a matter of routine. In all cases the bullets were found to have passed completely through the skull. There was tissue damage and bleeding along the wound canal, and large haematomas covering most of the brain surface. Apart from the damage along the path of the bullet, it was not possible to distinguish between pathological changes caused by the bullets and those caused by detonation of the grenade.

The conclusion from the *in situ* fixation trials was that agonal reflexive movements can be present in whales as it has been documented in terrestrial mammals (Blackmore and Delany 1988). However, neither these results nor the conclusions were accepted by the anti-whaling lobby in IWC (1995). In 1997 therefore, a major study of trauma and its consequences caused on minke whales by the use of penthrite grenade was launched as a veterinary doctoral study at the Norwegian School of Veterinary Science. The *in situ* fixation trials in 1992–1993 laid the ground for the studies of 66 minke whale brains from 1997 to 2002 (Knudsen, Mørk, and Øen 2002; Knudsen and Øen 2003; Knudsen 2004, 2005).

8. 1997–2004: Assessment of Insensibility and Death in Hunted Minke Whales; Study of Trauma and Its Consequences Caused by the Currently Used Weapons in the Norwegian Minke Whale Hunt

This part of the animal welfare studies at Norwegian School of Veterinary Science funded by the Norwegian Research Council was to examine the trauma and its consequences caused by the weapons and ammunitions used in the Norwegian minke whale hunt. The project was designed as a 4 years veterinary doctoral study conducted by Siri K. Knudsen. The field work started in 1997 and Knudsen was conferred her veterinary doctor's degree in 2004 with the thesis "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" (Knudsen 2004).

The major aims of these studies were to investigate: (1) pathological lesions caused by penthrite grenade detonation in minke whales, with special emphasis on the central nervous system (CNS); (2) based on the findings under point one confirm whether or not the so called "IWC criteria" developed in 1980 (IWC 1980) are valid to determine time to death (TTD) in whale; and (3) confirm whether or not the currently used rifle ammunitions (.375 and .458) in the Norwegian hunt are capable of penetrating the skull of minke whales and cause sufficient damage to the CNS to account for an instantaneous loss of sensibility.

The materials in these studies were collected from 66 minke whales during regular minke whaling on two vessels during four hunting seasons (1997–2000). The behaviour of the whales was noted and all whales were examined in the field for gross pathological damages after detonation of the penthrite grenade and rifle shots into the brain. The subsequent histological analyses took place in cooperation with professor S. Mørk at the University of Bergen, and focused in particular on damages inflicted on the brain.

Material collected in the field work in 1997–2000 from 37 animals killed with a single penthrite grenade showed that the intra-body detonation of 30g of penthrite was capable of causing massive multi-organ damage in the animals, including severe and fatal neurotrauma.

The whales were decapitated and the brains were fixed *in situ* using principally the same method described in chapter 7 (p. 310) and the paper of Knudsen, Mørk, and Øen (2002). The results showed that detonation of the grenade in near vicinity of the brain resulted in trauma similar to severe traumatic brain injury (TBI) associated with a direct blow to the head. Detonation in more distant areas from the skull resulted in injuries resembling acceleration-induced diffuse TBI (dTBI). Depending on detonation site the neuropathological changes varied from very severe brain tissue laceration with concomitant skull fractures and regular decapitation to histological intracerebral haemorrhages in central brain areas (Knudsen and Øen 2003).

Although the majority of the whales also had fatal damage to several other vital organs/organ systems, it was concluded that the neurotrauma significantly contributed to instantaneous or very rapidly loss of consciousness and death without any lucid intervals

(Knudsen and Øen 2003; Knudsen 2004, 2005). The brain studies confirmed the conclusions drawn by Øen (1995a) from his observations of the whale's behaviour and gross post mortem examination of whales killed with 22g of penthrite that instantaneous or very rapid lethal detonating area for the penthrite grenade ranged from the dorsal skull to the rostral abdomen.

The results obtained in Knudsen's study of brains (Knudsen 2004; 2005) confirmed that whales can show agonal reflex movements after they are dead and that the "IWC-criteria" are not fully adequate to determine exactly when a whale loses consciousness or dies.

The study further concluded that when TTD are solely determined on the basis of these criteria a significant proportion of animals will be recorded as being sensible or alive when they most likely are unconscious or dead. If the IWC criteria are used in conjunction with a post mortem examination, however, the estimated TTD will be closer to the real TTD for a majority of the whales. Consequently, this method can be used to compare different hunting techniques and methods provided that competent personnel collect the data and the same protocol are used for the data collection and analyzing. However, if the pathological examination does not include investigations of neurotrauma, it is likely that the TTD of some animals will still be overestimated (Knudsen 2005).

In 1981 rifle calibre .30–06 with full jacket, pointed or soft pointed ammunition was used as back-up for the cold harpoon catch of minke whales. Observations in the field showed that calibre .30–06 ammunition often needed several bullets to kill the whale (Øen EO: Letter to the Directorate of Fisheries 1982). In 1983–1984 rifles of minimum calibre 9.3 using full jacket, round nosed bullets therefore replaced the calibre .30–06. When the efficiency of 9.3 bullets to kill minke whale was investigated in 1992–1993 in connection with the *in situ* fixation trials of whale brains, the conclusion was that this calibre and ammunition functioned well for euthanasia of minke whales (Øen 1995a). However, from the middle of the 1990s this ammunition was no longer commercially available in Norway except for people that had knowledge of handloading. Accordingly, the hunters were recommended to change to calibre .375 and .458 of which ammunition was commercially available in shops. An investigation of the efficiency of these calibres therefore became an integrated part of the brain study in 1997–2000.

Materials collected in the field period 1997–1999 by Knudsen (Knudsen 2004; Øen and Knudsen 2007) from a total of 29 minke whales re-shot with rifles showed that a round nosed full-jacketed projectile of calibres .375 or .458 is fully capable of penetrating the skull of a minke whale and cause severe and massive damage to the CNS. Direct hits in the brain caused skull fractures, very severe brain *parenchyma* laceration and in-driven bone fragments. When the projectile penetrated the cranium near the brain (< 20 cm) or in the upper cervical spine, extensive gross intracranial haemorrhages were generally produced as well as displaced skull fractures in some cases. The brainstem and central areas of *cerebrum* were frequent sites of haemorrhages. It was concluded that when rifles of calibres .375 or .458 are used with round nosed full metal-jacketed ammunition, minke whales hit with one single round in the brain, in the near vicinity to the brain (< 20 cm) and in the upper spinal cord will immediately lose consciousness and die (Knudsen and

Øen 2003; Knudsen 2004; Øen and Knudsen 2007). In 2002 a 12.5 meters stranded sperm whale was also successfully killed using rifle .458 and the recommended round nosed ammunition (Øen 2003a).

9. Summary and Conclusions

The current management principles used for whales and whaling prevent from overexploitation. Today the populations of many whale species are thought to have reached pre-exploitation size. Concern for the killing methods is, however, still a topic in IWC and elsewhere and much of this concern is built on emotions. For many it is natural to identify themselves with the animal that are to be killed and relate the situation to one own's knowledge about death and its consequences. This fact has to be taken seriously even if the rationale behind the reactions sometimes can be doubted.

Compared to the huge number of animals that are killed in slaughterhouses and at big terrestrial game hunting, only a very small number of whales are killed annually. Nevertheless, hunting and killing methods for whales have often been criticized and variously described with outspoken adverse characteristics. Comparisons with stunning and killing of livestock in abattoirs are often used to justify critics of whale killing methods.

It is generally accepted that most animals are humanely killed in slaughterhouses. But, unfortunately that does not mean that all will lose consciousness and die instantly. When slaughtered, sometimes after a long transport, the animals are restrained before the killing take place, but despite this, inadequate stunning attempts occur. A result with 95% instant loss of consciousness at the first stunning attempt satisfies regulations in most countries (Knudsen 2005). However, in practice the actual per cent may be much lower for some methods in use. There are also other factors that may delay the killing process. Not only animal welfare considerations influence the killing methods, economic factors play an important role and the killing procedures are not permitted to delay the process (throughput of animals) or to damage the carcase or products (Øen 1995b). For the big game hunting of moose (*Alces alces*) it has been registered that only 21% of the animals lost consciousness and died instantly or in the course of few seconds (Øen 1995a).

However, no activity can be defended merely on the basis that other corresponding activities are just as "bad". But on the other hand, whaling cannot be judged in isolation from all other activities where animals are killed according to generally accepted standards.

The methods suitable for the stunning and killing in slaughterhouses are not applicable to free living mammals. Killing of whales must take place according to the same principles as those applied for wild terrestrial mammals. The animal must be rendered unconscious and bled-out more or less in one and the same operation using projectiles fired from remote positions and where the aim is to inflict so much damage to vital organs that the animal dies quickly as a result.

In the contemporary Norwegian minke whaling most whales are shot instantly dead without any previous chase. The instant death rate of about 82% of whales hunted is based on survival data using the "IWC criteria". According to Knudsen (2005) the use of these criteria for deciding when the whales are unconscious or dead means that a significant proportion of the remaining animals will be recorded as being sensible or alive when they most likely are unconscious or dead.

The weapons and ammunitions used in the contemporary Norwegian minke whale hunt are when applied as recommended, highly effective in causing instantaneous or very rapid deaths of the whales. The harpoon grenade has a much wider lethal area compared to conventional weapons used in other forms of big game hunts. The results from the studies support the already established recommendation that the whales for welfare reasons should be shot from the side in the thorax area, and that all animals should be hauled in as fast as possible for control. In the 2011–2012 Norwegian minke whale hunt 92% of the whales shot from the side position, using the "IWC criteria", died instantly. Shooting from all other positions were less effective. This knowledge is now well known for the whalers.

However, shooting whales from behind, which was the most common earlier, is still used in minke whaling in other countries even if such shooting considerably increases the risk of only wounding the whales with the first shot and also with re-shooting as a wounded whale will try to avoid and swim away from the vessel. Data from whales shot from behind and from the front positions have proved that many whales will survive longer than necessary and are re-shot or hauled to the boat alive. Films of such cases displayed on TV and social media help to feed much of the resistance against whaling in the world and are actively used for discrediting whaling worldwide. Both the whales, the hunters and not the least the judgement of whaling would benefit if such less efficient and less humane methods and hunting practices were phased out and replaced with methods that have proven to be more efficient and humane.

Implementation of new technology or improved "modern" weapons are sometimes met by the argument that it violates traditions of hunters and aboriginal people. This is no real argument against more humane killing methods, rather an excuse. New technology and improvements of hunting weapons do not threaten any tradition or people's right to hunt. Hunting weapons have changed and been replaced by better weapons as long as hunting has been practiced. Metal replaced sharp stones or bones as heads of arrows, spears and harpoons. Firearms replaced bow and arrow for hunting birds and terrestrial mammals. And hunters use it because it makes the hunt safer and more effective as the animals die faster and losses are reduced. The tradition in this context is the workmanship of hunting for food and/or an important part of one's or the societies' way of life, together with the utilization, sharing, trading or sale of the products derived from the hunt. A good example of this view is the Alaskan Eskimo's support to improve the killing methods in their subsistence hunt of bowhead whales where the losses that were substantial (50%) have been reduced considerably to 15–20% (Øen 1995f; O'Hara et al. 1999).

When the research to improve hunting and killing in whaling began in Norway and Japan it was natural to expect that the animal welfare and anti-whaling groups in IWC that spoke against whaling on the grounds that the killing methods were inhumane, would support and encourage the research, in particular when the results and "know-how" from the Norwegian research were transferred to the hunts in Alaska (USA), Greenland, Iceland and also Chukotka (Russia). Remarkably not, this was not the case and some continued to criticize Norway for lack of information even when Norway had submitted IWC with more than 25 reports and publications in scientific journals with data from more the 5,000 minke whales and defended two veterinary doctoral degrees on the issue (Øen 1995a; Knudsen 2004; IWC 2003, 2005, 2006). However, the opinion of the majority of IWC gradually changed and it advised other whaling countries to seek advice in Norway to improve the hunts. In 2007 the Commission unanimously supported Norway's recommendation to conduct a workshop on euthanasia and disentanglement of entangled and stranded whales (IWC 2007). Today, this initiative has become the IWC's "Global Whale Entanglement Response Network" that provides training and have arranged several workshops on how to manage strandings, disentanglements and good animal welfare standards of euthanasia of such helpless creatures.

The demand is sometimes made that humane killing should involve a guarantee that all animals should lose consciousness or die instantaneously, without having been subjected to pain or experiencing fear. Although this may be an ideal goal, it is hardly expedient to include in official regulations, as it will, in practice, be a provision with which it is impossible to comply and thus respect and does not seem to be interpreted in an absolute sense by legislating authorities, in connection with slaughtering of livestock, ritual slaughter, or the hunting of wild animals. In connection with both slaughtering and hunting, and even at euthanasia, there will always be some animals which survive the killing attempt, no matter the method employed or the prior precautions taken. The aim should, nevertheless, be to reduce the likelihood of this occurring to an absolute minimum. The fastest method for killing an animal will always be the most humane method. Therefore, when several hunting and killing methods are available, the method available that kills the animal fastest should always be chosen.

Emotions have played and will continue to play the principal role of many people's scepticism towards whaling as well as hunting of wild animals in general. Therefore, the animal welfare associated with the hunt must never be neglected. Respect for the animal welfare and considerate behaviour during hunting are keys to a wider acceptance of whaling and hunting.

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