Improvements in More Humane Killing Methods of Antarctic Minke Whales, *Balaenoptera bonaerensis*, in the Japanese Whale Research Program under Special Permit in the Antarctic Sea (JARPA)

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日本の南極海鯨類捕獲調査における クロミンククジラ *Balaenoptera bonaerensis* 捕殺方法の研究

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ABSTRACT. The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) has been conducted since the 1987/88 season and has taken an annual maximum of 440 Antarctic minke whales *Balaenoptera bonaerensis*. In order to improve whale-killing methods, we have analyzed 3,246 catch and necropsy records of Antarctic minke whales taken between the 1993/94 - 2000/2001 seasons. The average time-to-death (TTD) for each body-length class increased with body length, while the instantaneous death rate (IDR) showed no relation to body length except for whales less than 6 m. The relationship between the severity of harpoon wounds and IDR/TTD was examined. The highest IDR was observed for wounds to the brain and cervical vertebra (Central Nervous System; CNS). Wounds to the forepart of the thoracic vertebra and heart showed the next highest IDR. On the other hand, destruction of abdominal viscera as well as lumbar and caudal vertebra showed a low IDR and were less effective in reducing TTD. The average firing angle was 36.7°, and there was no significant difference in that angle between whales that died instantly and those that did not. Considering the chasing methods in the JARPA, the most efficient internal harpoon tracks (target organs) were, thorax → skull (heart and CNS), penetration of thorax (heart) as well as abdomen → thorax (heart). TTD and IDR in the JARPA have been steadily improved. The next step calls for further improvements in whaling devices.

Key words : JARPA, minke whale, whale-killing method, time-to-death, instantaneous death rate

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INTRODUCTION

JARPA has been conducted annually since the 1987/88 season. In compliance with Article VIII of the International Convention for the Regulation of Whaling, JARPA has been authorized by the Government of Japan, and planned and conducted by the Institute of Cetacean Research (ICR). The objectives of the research are as follows; 1) estimation of the biological parameters of minke whale stock, 2) elucidation of the role of whales in the Antarctic ecosystem, 3) elucidation of the effect of environmental changes on cetaceans, and 4) elucidation of the stock structure of the Southern Hemisphere minke whales to improve the stock management [1]. To

achieve these objectives, in addition to non-lethal methods such as sighting surveys and biopsy sampling, it is essential to randomly collect biological samples from a large research area encompassing the entire population [2, 3]. As a result, JARPA has taken a yearly maximum of 440 Antarctic minke whales *Balaenoptera bonaerensis*.

Lethal sampling requires careful consideration of the issue of animal welfare. Animal welfare concerns about whaling have been discussed in the International Whaling Commission (IWC) meetings since the 1960s under the headings of "Humane Killing of Whales" or "Whale Killing Method" [4]. In recent years, there have been active discussions in an IWC Working Group during their annual meetings and in occasional

Workshops. In the Japanese Whale Research Program, investigations related to whale-killing methods commenced on a regular basis from the 1993/94 season in response to an Action Plan developed at the IWC Workshop on that subject in 1992 and a resolution on humane killing adopted in 1993 [5]. Continuous efforts have been made to reduce time-to-death (TTD; the time from the first harpoon strike to death) of whales taken during the Japanese Whale Research Program.

This document reports on an analysis of the investigations into more humane whale-killing methods by determining the best firing technique in whaling operations and achieving a reduction in TTD based on that analysis.

MATERIAL AND METHODS

Data for analysis

Individual catch records including TTD were collected by gunners and mates on all sighting and sampling vessels (SSVs) that participated in the JARPA. TTD was recorded in units of 10 seconds. Death or unconsciousness of the whales was judged by gunners according to the criteria of death agreed by the IWC, i.e., cessation of movement, slackening of the jaw or flippers, or motionless harpoon line [6, 7]. Necropsies (gross anatomical observations) of sampled whales were conducted by a veterinarian or experienced biological researcher on the research base ship. The necropsy record included the strike point and internal track of the harpoon, explosive point of the harpoon, examination of harpoon wounds, and the effect of bullets used as a secondary killing method (see below). 3,246 catch and necropsy records of Antarctic minke whales taken between the 1993/94 - 2000/2001 JARPA seasons were used for the analysis. 880 catch records collected in the 2001/2002 and 2002/2003 JARPA seasons were also added for an analysis of the trends in both the TTD and instantaneous death rate (IDR).

Whale-killing-methods

The killing methods used in the Japanese Whale Research Program follows the same ones used in previous commercial whaling operations. These consist of a primary killing method by the first explosive harpoon, and a secondary killing method for animals not dispatched by the first harpoon.

Primary killing method: A whaling harpoon (75mm in diameter) with four flexible barbs is fired from a whaling cannon mounted on the forecastle of the SSV (Fig.1). The top case of the harpoon is loaded with a penthrite cartridge (30 grams of penthrite powder) and a fuse. The top case with the cartridge is called a grenade, and the harpoon with the grenade is called an explosive harpoon. When such a harpoon strikes a whale, it explodes inside its body, generating shock waves that cause a lethal wound. Since the harpoon and the SSV are connected to a whaling line, the harpooned whale is

Fig.1 A 75-mm whaling cannon with harpoon mounted on the sighting and sampling vessel.

immediately hauled in by a winch and secured to the side of the SSV. In addition to the Japanese penthrite grenades, a number of new grenades developed in Norway have been used from the 1999/2000 JARPA season to compare their performance with Japanese grenades.

Secondary killing method: When the harpooned whale does not die instantly, a large caliber rifle (0.375 inch) with solid bullets and/or a second harpoon without a penthrite cartridge is immediately used to kill the whale. Although electric lances were used as the secondary killing method in previous research seasons, they were replaced with the rifle starting with the 1997/98 JARPA season.

Results

Body length of whales and TTD

Table 1 shows the relationship of the body length of whales taken to both TTD and IDR. Average TTD by each body-length class rose with an increase in body length ($r = 0.981$). Total average TTD was 230 seconds (s.d. = 224) except for whales that were pursued again after the first harpoon was dislodged

Table 1 Relation of body length to average time-to-death (TTD) and instantaneous death rate (IDR). Cases of continued pursuit after dislodgement of the first harpoon were excluded from the data.

Body length	TTD $\pm$ S.D. (sec.)	IDR	N
<6 m	124 $\pm$ 152.5	0.50	368
6m - 7m	193 $\pm$ 200.1	0.35	286
7m - 8m	222 $\pm$ 199.6	0.28	410
8m - 9m	249 $\pm$ 225.4	0.30	1703
9m $\leq$	287 $\pm$ 276.6	0.31	374
Total	230 $\pm$ 224.1	0.33	3141

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Table 2 Relation of damage from the first harpoon to TTD and IDR.

Damage site	TTD $\pm$ S.D. (sec)	IDR	N
Brain	16 $\pm$ 66.9	0.94	107
Cervical vertebra	11 $\pm$ 49.0	0.89	65
Thoracic vertebra (T1-T5)	23 $\pm$ 78.8	0.89	70
Heart	39 $\pm$ 86.8	0.77	341
Lung	104 $\pm$ 153.3	0.59	516
Thoracic large vessels	74 $\pm$ 93.5	0.57	21
Thoracic vertebra (T6-T12)	160 $\pm$ 321.4	0.51	61
Brain (hemorrhage)	177 $\pm$ 144.1	0.35	17
Thorax	212 $\pm$ 175.4	0.27	410
Skull	233 $\pm$ 196.9	0.24	85
Lumbar vertebra	267 $\pm$ 145.9	0.08	242
Abdominal viscera	333 $\pm$ 183.6	0.06	116

or the harpoon line broke. IDR for whales less than 6 m in body length was 50.3%, while those less than 5 m showed a much higher IDR of 81.8% ($n = 11$). However, IDR of whales over 6 m in body length was about 30% in each body length class, thus showing no relationship with body length.

Harpoon wounds and TTD

Table 2 shows the relationship of the wound caused by the first harpoon to both TTD and IDR (data from whales where a second harpoon was used were excluded). The highest IDR of 94% was observed in cases where the brain was wounded followed by wounds to the cervical vertebra (both positions are referred to as the Central Nervous System (CNS) in this study). Wound to the forepart of the thoracic vertebra also resulted in a high IDR and short TTD. The IDR and TTD in the case of a heart injury were lower than those for wounds to the CNS and the forepart of the thoracic vertebra. Other thoracic viscera and vertebra destruction resulted in a high IDR of more than 50%,

though TTD was more than 1 minute.

On the other hand, the destruction of abdominal viscera such as the liver, kidney and digestive tract resulted in a low IDR and was less effective in reducing TTD, as was also the case in the destruction of the lumbar and caudal vertebra. Skull damage also resulted in a low IDR and relatively long TTD. Brain damage with skull destruction was categorized simply as brain damage because skulls of baleen whales are large (nearly one third of body length) compared with the cranium, therefore skull destruction did not always result in brain damage. Although the number of observations was small, a cerebral hemorrhage resulted in an IDR of 35% and TTD of 177 seconds when the harpoon strike the skull without cranium destruction. Although injury to the thoracic cavity without damage to the vertebrae, lung or heart resulted in a low IDR, when a large hemorrhage was observed (indicating vascular destruction), the IDR reached 57%. Figure 3 shows the position of the vital organs resulting in a high IDR when struck by a harpoon.

Trajectory of harpoon before and after strike, and resulting TTD

Shooting angles with the body axis were estimated from harpoon wounds in 422 individuals. The average firing angle was 36.7° (s.d. 21.4°). There was no significant difference in the average firing angle between whales that died instantly and those that did not (t-test, $p = 0.80$).

Figure 4 shows the body of a whale divided into numbered areas. Internal track of the harpoon was recorded as the entrance area number $\rightarrow$ the exit area number or the number of the area where the harpoon stopped. Table 3 shows internal tracks observed as well as TTD and IDR. The highest IDR and shortest TTD were recorded for whales when the harpoon internal track went from area 5 $\rightarrow$ area 1 (abdomen $\rightarrow$ thorax $\rightarrow$ head). The internal tracks from area 5 $\rightarrow$ area 3 (abdomen $\rightarrow$ thorax), area 3 $\rightarrow$ area 1 (thorax $\rightarrow$ head), and area 3 $\rightarrow$ area 3 (penetration of thorax) showed a relatively high IDR and short TTD with a high frequency of cases. The tracks from area 7 $\rightarrow$ area 1 (rear abdomen $\rightarrow$ head) and from area 2 $\rightarrow$ area

Fig. 2 Structure of the explosive harpoon. When the harpoon strikes and penetrates the body, the pencil rope holding the barbs is pushed back. This pulls the twine connecting the friction wire of the fuze and the pencil rope which then pulls the friction wire, causing ignition of the fuze and detonation of the penthrite cartridge [9].

Fig. 3 Anatomical chart of a minke whale. Shaded area represents thorax. CNS, central nervous system; H, heart; Lu, lungs; Li, liver; S1, fore stomach; S2, second stomach; K, kidney; ey, eye; ea, ear; um, umbilicus; an, anus.

3 (front dorsal muscle → thorax) showed a high IDR and low TTD due to possible destruction of CNS, however, such cases were rare. On the other hand, internal tracks with entrance areas 4, 6 (dorsal area) and 8 (caudal area) showed a low IDR and long TTD.

Yearly changes in TTD and IDR

Table 4 and Figures 5 and 6 show average TTD and IDR by each research season. Regression analysis revealed that TTD and IDR have been successfully and significantly improved (TTD; $p = 0.0078$, IDR; $p = 0.0168$) between the 1993/94 (7th) to 2002/2003 (16th) seasons.

Discussion

Improvements in whale-killing methods require various approaches. The Action Plan on Whale Killing Methods adopted by the IWC recommended selection and improvement

Fig. 4 Target division for firing. Each part number approximately represents (1) head, (2) fore-back, (3) thorax, (4) middle-back, (5) fore-abdomen, (6) rear-back, (7) rear-abdomen and (8) peduncle. um, umbilicus; an, anus.

of whaling devices, assessments of death in relation to TTD, collection and provision of information on TTD, and behavioral and physiological studies [5, 8]. IWC members have taken initiatives especially in the selection and improvement of whaling devices with the result that the explosive harpoon with penthrate grenade was found to be the most effective and humane killing device for whales [6]. The penthrate grenade was developed by Japanese and Norwegian specialists and has also been used by some aboriginal subsistence whaling countries such as the United States (Alaska) and Denmark (Greenland) [6, 8-10].

On the other hand, there are relatively few studies on the assessment of death in relation to TTD, especially those examining the internal track of the explosive harpoon and resulting damage to the whales. This is due to the difficulty of measuring TTD and conducting necropsies systematically during whaling operations. Rowsell [11] examined three fin whales *Balaenoptera physalus* and 16 sperm whales *Physeter macrocephalus* and reported that effective harpoon damage to whales included 1) brain hemorrhage or destruction, 2) heart destruction, 3) rapid massive hemorrhage by cutting major vessels in the thoracic cavity, or 4) cervical dislocation. He noted that rapid unconsciousness without recovery was produced by CNS destruction, and that a rapid lowering of the blood supply to the brain subsequent to heart destruction. However, he could not collect TTD information since there was then no approved criterion for judging whale deaths. Øen [12, 13] examined body length, firing range and angle, and the results of necropsies with IDR and TTD data for North Atlantic

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Table 3 Relation of internal track of the first harpoon to TTD and IDR. Internal track is represented as the strike area → exit area (commonly opposite to the strike area) or the internal position of the penetrating harpoon. Data are presented in decreasing order of IDR. Cases comprising less than 32 samples (1% of total number) were excluded.

Internal track	TTD ± S.D. (sec)	IDR	N
5 → 1	50 ± 112.4	78 %	159
7 → 1	75 ± 154.7	71 %	34
2 → 3	149 ± 182.0	53 %	55
3 → 1	159 ± 218.1	51 %	228
3 → 3	154 ± 189.9	49 %	235
4 → 3	145 ± 170.6	48 %	128
5 → 3	155 ± 191.5	47 %	411
4 → 1	185 ± 208.8	45 %	86
2 → 1	220 ± 250.4	38 %	186
7 → 3	186 ± 187.3	37 %	145
5 → 2	173 ± 164.7	36 %	80
6 → 3	225 ± 214.3	28 %	74
1 → 1	330 ± 261.0	22 %	78
4 → 2	281 ± 197.3	13 %	213
2 → 2	340 ± 241.9	12 %	111
5 → 5	353 ± 225.1	10 %	114
7 → 5	337 ± 197.5	8 %	120
6 → 5	330 ± 167.0	3 %	72
6 → 2	364 ± 199.8	3 %	88
4 → 4	340 ± 170.2	2 %	48
7 → 7	343 ± 192.5	2 %	120

Table 4 Total TTD (average and median) and IDR in each research season and area.

Research season	Research Area	TTD (Average)	TTD (Median)	IDR (%)	N
1993/94	Area IV	4:14	4:00	29.4	330
1994/95	Area V	5:09	4:30	23.3	330
1995/96	Area IV + III E	5:16	4:50	29.3	440
1996/97	Area V + IV W	5:21	4:40	24.8	440
1997/98	Area IV + III E	4:01	3:30	31.7	438
1998/99	Area V + IV W	4:45	3:40	31.6	389
1999/2000	Area IV + III E	2:53	2:10	44.4	439
2000/2001	Area V + IV W	3:25	3:00	36.1	440
2001/2002	Area IV + III E	3:23	3:00	33.0	440
2002/2003	Area V + IV W	2:37	2:20	40.2	440

minke whales *Balaenoptera acutorostrata* in order to compare the effectiveness of explosive harpoons (259 individuals) vs. non-explosive harpoons (353 individuals) in the process of development of the Norwegian penthrite grenade. The results of explosive harpoons showed that TTD was affected by both body length and firing range and angle, while IDR correlated with firing range though body length had an effect only on whales not killed instantaneously. The relationship between harpoon wounds and TTD/IDR was; CNS (11 sec. / 92.6%) ,

heart (27 sec. / 78.7%) , lung (83 sec. / 62.7%) and abdomen (493 sec. / 15.9%) . These studies are in accord with our results and suggest that an effective killing method for whales should be considered as aiming at the vital organs such as the CNS and the heart, even though the whaling grounds and situations (coastal or pelagic, commercial or research) are different.

In spite of destruction of the CNS and heart, none of these cases showed an IDR of 100%. Ishikawa [14] reported case

studies of overestimations of TTD. Necropsies revealed that, in some cases, whales should have been rendered unconscious by destruction of the CNS earlier than the recorded time of death. One of the reasons for this discrepancy was that gunners tend to judge the death of whales after the total cessation of movement, which is required for safely hauling in the whales. Øen and Mørk [15] argued that total immobility was not as important as the moment of insensibility since whale movements often persist due to spinal reflexes, seizures and convulsions, as is also observed in the case of stunned domestic animals. Even when the IWC criteria of death were applied, gunners were often misled by the movement of flippers or mandibles caused by water currents and unconscious tale movements which they misinterpreted as vital signs. Knudsen and Øen [16] examined the brains of 37 minke whales killed by penthrite grenades and suggested that detonations even as far back as the rostral abdomen may cause fatal neurotrauma. These studies suggest that there might be many cases of overestimation of TTD in the field records, especially in whales that had suffered CNS injury.

The firing angle differed in the JARPA and Norwegian commercial whaling. In the JARPA, the average firing angle was 36.7° ; with no difference seen in the average between whales that were killed instantly and those that were not. On the other hand, in the Norwegian whaling, the most effective firing angle to achieve a short TTD was $45^\circ - 135^\circ$ to the body axis [13]. For comparative purpose, a statistical analysis was performed to compare the data in our study between firing angles greater than and those less than 45° . Results showed no significant differences in either TTD or IDR (t-test; $p=0.79$, chi-square test;

$p=0.79$). Therefore, the firing angle seems not to have affected IDR or TTD in the JARPA.

The difference in the firing angle between JARPA and Norwegian commercial whaling is due to a difference in chasing method. In Norwegian commercial whaling, many small boats (average size 20.3 m in 1993) are used. The whalers often wait for whales approaching the boat, or they idle the boat slowly towards the position where a whale will be likely to surface for easy harpooning. As such a method resembles that used in hunting terrestrial wild animals, it is called "approaching" or "stealthy approach" rather than "chasing". Although this approaching method provides a better aim at the vital organ (heart), relatively long time elapsed before firing can make it easier to miss the target [17, 18].

In the JARPA, minke whales were sampled randomly in order to collect samples representing the population. This requires species identification, confirmation of school size, estimation of individual body length, and selection of the individual to be taken using a table of random digits before firing [19]. The whaling boats in the JARPA (SSVs) were required to approach within 0.2 miles of the school to follow those procedures. Furthermore, the selected whale should actually be taken to ensure mathematical accuracy. The sampling rate (success rate) of selected individuals ranged from 89 % [20] to 92 % [21] in recent research. Therefore it is almost impossible to approach the whales without being noticed, and the SSVs are often required to pursue them at high speed. Consequently, this increases the number of shots fired from behind the whale, and thus the firing angle tends to be lower than in the case of Norwegian whaling.

Fig. 5 Yearly changes in instantaneous death rate (IDR) of minke whales compiled by JARPA. Numbers on the horizontal axis represent the years in which the research was conducted. For example, the 7th year was 1993/94 JARPA, and the 16th year was 2002/03 JARPA.

Fig. 6 Yearly changes in time-to-death (TTD) of minke whales compiled by JARPA. Numbers on the horizontal axis represent the years in which the research was conducted. For example, the 7th year was 1993/94 JARPA, and the 16th year was 2002/03 JARPA.

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Although destruction of the CNS is the most effective method to kill a whale instantly, harpooning the CNS directly is not practical because whales surface to breathe with their head first followed by the dorsal and lateral side of the body, making it difficult for gunners to aim at such a small area as the CNS in the head. The heart, which is larger than the CNS and located behind the pectoral fin (Fig. 3), is a more appropriate target among the vital organs. In conclusion, considering the chasing method used in the JARPA and the surfacing pattern of whales, aiming for the heart is the best way to harpoon the whale expecting the internal tracks of: thorax → skull (heart and CNS), penetration of thorax (heart) as well as abdomen → thorax (heart).

TTD and IDR in the JARPA have been steadily improving (Figs. 5 and 6). Gunners and crews of SSVs are briefed at a pre-cruise meeting on the results of killing methods obtained from previous research and are encouraged to achieve shorter TTD. Even during the research cruise, the latest necropsy records are sent to the gunners as soon as possible so that they can review the detailed results of their shots while their memories are still fresh. Firing accuracy has been improved as gunners gain knowledge about the best target areas and firing angles by combining their experience with the anatomical and medical data from the veterinarian on board. This rapid-analysis and data-feedback system has been the main component in the successful improvement of TTD in the JARPA [22].

The next step was to achieve further improvements in the whaling devices used. We conducted comparative tests between the improved Norwegian grenade introduced in 1999 and the Japanese grenade [23]. Improvements in the Japanese grenade are already underway, and the results will be reported in the near future.

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要 約

(財)日本鯨類研究所は、国際捕鯨取締条約に基づき日本国政府が計画した南極海鯨類捕獲調査 (JARPA) を 1987/1988 年から毎年行い、生物学的特性値の解明などを目的として年間最大 440 頭のクロミンククジラを捕獲している。鯨の捕獲には 75mm 捕鯨砲と爆発銃が用いられ、即死しない個体については 2 次的捕殺手段として大口徑ライフルもしくは非爆発銃が用いられている。1993/94JARPA ~ 2000/2001JARPA で捕獲されたクロミンククジラ 3246 個体の致死時間と即死率を、捕

獲個体の検死で得られた結果と比較分析した。体長との関係では、鯨の体長が大型化すると致死時間が延長する傾向が見られたが、即死率は体長 6m 以下の個体を除き体長に影響されなかった。銃による損傷部位との関係では、脳 (94%)、頸椎および胸椎前部 (89%)、心臓 (77%) の順に即死率が高く、頭骨のみの損傷や腹腔臓器および腰尾椎損傷では致死効果が低かった。銃の命中角度は平均 36.7° で、即死個体と非即死個体の間に有意差はなかった。体内の銃の弾道は腹腔→胸腔、胸腔→頭部、胸腔の貫通で即死率、致死時間共に好成績を示し、これらの弾道を狙った射撃を行うことで致死時間の短縮が期待された。日本の捕獲調査ではこれらの分析結果を生かした種々の努力の結果、即死率、致死時間ともに年々改善されている。今後は漁具のさらなる改善が課題である。

キーワード：南極海鯨類捕獲調査、クロミンククジラ、捕殺方法、致死時間、即死率

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