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Assessment of current and alternative methods for killing young grey seals (*Halichoerus grypus*) during commercial harvest

Évaluation des méthodes d'abattage courante et alternative pour les jeunes phoques gris (*Halichoerus grypus*) durant la chasse commerciale

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ABSTRACT

A small commercial hunt for 5-7 weeks old grey seals (*Halichoerus grypus*) occurs intermittently around the Canadian Maritime provinces and may expand in the near future. We sought to better understand and, where possible, improve the harvesting methods of this hunt. We compared the use of the regulation club and the regulation Canadian hakapik to effectively crush the skull of these animals under field conditions. Both tools achieved this purpose, resulting in rapid, if not immediate, death of the animals, but a difference approaching significance was detected which suggested that the club requires fewer blows than the hakapik to crush the skulls. We also tested the efficacy of the .17 HMR (Hornady Magnum Rimfire) rifle cartridge, an ammunition of low energy but high velocity, to quickly kill seals of this age at close range with a shot to the head. All 12 animals studied under controlled conditions and 40 of 45 (88.9%) animals studied under field conditions died immediately or within a few seconds from a single shot. We believe that the latter proportion can be increased further with simple modifications to the method used during the field study and that the .17 HMR rifle cartridge can be an effective tool to quickly kill young grey seals during a commercial hunt, as a possible substitute to the use of the club or hakapik.

RÉSUMÉ

Une chasse commerciale à petite échelle visant les phoques gris (*Halichoerus grypus*) de 5-7 semaines se fait de manière intermittente dans les provinces maritimes et peut prendre de l’ampleur dans un avenir rapproché. Nous avons voulu mieux comprendre et, si possible, améliorer la méthode d’abattage employée durant cette chasse. Nous avons comparé sur le terrain l’emploi du gourdin et de l’hakapik canadien réglementaires pour broyer le crâne de ces animaux d’une manière efficace. Ces deux outils ont pu accomplir cette tâche et ainsi causer la mort rapide, sinon immédiate, des animaux, mais une tendance vers une différence significative fût détectée qui suggérait que le gourdin requiert moins de coups que le hakapik pour broyer le crâne. Nous avons également testé l’efficacité de la cartouche de carabine .17 HMR (Hornady Magnum Rimfire), une munition à faible énergie mais à haute vitesse, pour tuer rapidement les phoques de cet âge par une balle dans la tête à bout portant. Les 12 animaux étudiés dans des conditions contrôlées et 40 de 45 (88.9%) animaux étudiés sur le terrain sont morts immédiatement ou en quelques secondes à l’aide d’une seule balle. Nous croyons que cette dernière proportion peut être améliorée grâce à de simples modifications de la méthode employée sur le terrain et que la cartouche de carabine .17 HMR peut être un outil efficace pour tuer rapidement les jeunes phoques gris durant une chasse commerciale, comme substitut possible à l’emploi du gourdin ou de l’hakapik.

1. INTRODUCTION

The population of grey seals (*Halichoerus grypus*) in the northwest Atlantic has expanded considerably during the past few decades and currently stands at approximately 300,000 animals (Thomas et al. 2007). Some members of coastal communities in the Canadian Maritime provinces have expressed a strong interest in developing and expanding a commercial hunt for young grey seals for their pelt, blubber (a source of omega-3 fatty acids), and meat. These seals are approximately 5-7 weeks old when killed and are here referred to as beaters, in analogy to the animals of a similar age group targeted during the Canadian commercial harp seal (*Pagophilus groenlandicus*) hunt. It is important that, prior to setting up this new industry, proper methods for killing individual seals quickly in a manner compatible with sound principles of animal welfare be well in place and fully endorsed by the sealing industry and the public.

The commercial harvest section of the Marine Mammal Regulations (MMR) of the Fisheries Act of Canada (Anonymous 2010), designed primarily for the commercial hunt for young harp seals, allows only the use of a club, a hakapik, or a high-power rifle to kill these animals. The head of these seals is the primary target, and the aim of the sealer is to crush the calvarium (dome-shaped superior portion of the skull) and destroy the underlying cerebral cortex, which is the center of pain perception (AVMA 2007). For the grey seal hunt, sealers use a club or a hakapik because they hunt mainly on land, where there would be a high risk of ricochet by bullets from a high-power rifle. The skull of grey seal beaters is substantially thicker than that of harp seal beaters (Caraguel et al. 2012). This may decrease the efficacy of a club or a hakapik to quickly crush their skull and destroy their brain, and it may make it more difficult to determine by palpation through skin and blubber whether the skull has been crushed, as is currently required by the MMR for the harp seal hunt (Anonymous 2010).

The .17 HMR (Hornady Magnum Rimfire) rifle fires a small bullet at high velocity. Polymer-tipped and hollow-point bullets used in this rifle are intended to disintegrate on impact, which should ensure delivery of its entire kinetic energy into the target and, in the case of young seals, should thus cause maximum damage to the brain; this would also minimize the possibility of ricochets from bullet fragments. Therefore, this ammunition offers a potential alternative to the use of the club or the hakapik to kill grey seal beaters. These animals can be easily approached on land to within 2 m and could thus be shot from this distance or closer. If proven effective, a single shot from this type of ammunition could improve animal welfare by increasing the proportion of animals that are killed instantaneously.

This document reports a series of three separate studies aimed at better understanding the killing methods currently used during commercial hunts for grey seal beaters and at evaluating the .17 HMR rifle cartridge as a new method which might improve the conduct of these hunts from an animal welfare perspective.

2. MATERIALS AND METHODS

2.1. FIELD ASSESSMENT OF STUNNING AND KILLING METHODS, HAY ISLAND, NOVA SCOTIA, FEBRUARY 2009

Hay Island is a small island off the east coast of Cape Breton Island, Nova Scotia, (46.022276°N, 59.68587°W; surface area, 0.2 km^2; 1.8 km of shoreline) and has been a common site for small-scale hunts for grey seal beaters in recent past. The specific goals of this study were to: 1) compare the efficacy of the regulation Canadian hakapik and regulation club (as defined in the MMR [Anonymous 2010]; Figure 1) to achieve rapid crushing of the calvarium, according to the three-step process (stunning, checking by palpation of skull, bleeding) currently required by the MMR (Anonymous 2010); and 2) compare the times required for stunned seals to bleed out following severance of either one or both axillary arteries.

A crew of two experienced sealers, one killing the animal and the other bleeding it, was assigned to the observers. The sealer responsible for killing the animals was asked to alternate the use of the hakapik and the club. It was left to his discretion to determine the number of blows needed to crush the calvarium. Following the initial series of blows (time 0), he and one of the observers palpated the calvarium through skin and blubber, and the degree of damage was recorded as: intact (left and right sides not crushed), partially crushed, or completely crushed (both sides crushed). If not completely crushed, the sealer was asked to strike the skull with another series of blows (time 1). Palpation of the calvarium was repeated and, if necessary, further blows were applied (time 2). None were required a fourth time. The total number of blows was recorded.

The sex, standard length, axillary girth, and weight were recorded for each carcass prior to bleeding; blubber thickness at the level of the sternum was taken after bleeding. The latter consisted of an incision along the ventral midline from the mandibular symphysis midway along the carcass' length (the standard cut required for skinning the carcass) followed by severance of one or both axillary arteries alternately among carcasses. Determination of bleeding time was carried out consistently by one of the observers using a stop watch, and the recorded time was based on the interval between severance of the first axillary artery and cessation of a steady flow of blood from one or both arteries as assessed visually. Data recording and protocol enforcement were done by a third observer. Statistical analyses were performed using simple and multivariable linear regression models and basic non-parametric survival analysis in STATA software v.11 (StataCorp 2007).

Four skinned carcasses (two males, two females) were taken from the group of approximately 200 carcasses killed on the day of the study for closer examination at the Atlantic Veterinary College (AVC), University of Prince Edward Island (UPEI).

2.2. ASSESSMENT OF THE .17 HMR RIFLE CARTRIDGE UNDER CONTROLLED CONDITIONS, AMET ISLAND, NOVA SCOTIA, JANUARY 2010

In this study, we determined the rapidity with which death of grey seal beaters occurred following a single shot to their head with a .17 HMR rifle cartridge and assess the resulting lesions based on radiographic and macroscopic examination. The rifle used was a Savage Edge model; the bullets were V-Max Varmint 17-gr (1.1 g) with polymer tips (rated velocity, 2,550 ft/s [780 m/s]; rated energy, 245 ft-lb [332 J]).

Twelve grey seal beaters (eight female, four male) in good nutritional condition were selected from a herd of grey seals located on Amet Island, Nova Scotia, a very small island in the Northumberland Strait between Nova Scotia and Prince Edward Island (45.83515°N, 63.17720°W; surface area, 5,768 m^2; 0.31 km of shoreline). These twelve seals were handled individually in succession. Each animal was captured manually and brought to a site away from the rest of the seals. The animal was shot shortly thereafter by one of the authors from a distance varying between approximately 15 cm and 2 m. Immediately afterwards, the state of consciousness of the animal was assessed by two veterinarians, based on the degree of relaxation of the body, including the presence or absence of respiratory movements, and on the presence or absence of a corneal reflex; observations on the occurrence of postmortem (swimming) reflex (Daoust et al. 2002) were also made. Following confirmation of death and exsanguination, the animal's head was severed in the mid-cervical region and transported to the AVC for further examination.

The selected number of 12 animals for this study was modeled on guidelines for evaluation of killing trapping devices: such devices would meet the Agreement on International Humane Trapping Standards (AIHTS 1997) if: "(a) the number of specimens of the same target species from which the data are derived is at least 12; and (b) at least 80% of these animals are unconscious and insensible [based on loss of corneal and palpebral reflexes] within the time limit, and remain in this state until death". Although, based on AIHTS (1997), the time to death (more specifically, irreversible unconsciousness and insensibility) in fur-bearing animals can vary from immediate to 300 sec depending on the target species, immediate death or death within a few seconds was the criterion used in the present study to determine the success of the .17 HMR rifle cartridge.

This project was approved by the Animal Care Committee of the Maurice-Lamontagne Institute, Fisheries and Oceans Canada, and by UPEI's Animal Care Committee (UPEI ACC Protocol 10-003).

2.3. ASSESSMENT OF THE .17 HMR RIFLE CARTRIDGE DURING COMMERCIAL HARVEST. HAY ISLAND, NOVA SCOTIA, FEBRUARY 2011

A small-scale hunt for grey seal beaters was conducted on Hay Island. Approximately 100 animals were killed during the course of a few hours. During that time, two of the authors accompanied one of the sealers who had been granted a special permit to use .17 HMR rifle cartridges. The rifle used was a Browning model equipped with a telescope; the bullets were V-Max Varmint 17-gr (1.1 g) with hollow points (rated velocity and energy as in study #2).

The .17 HMR rifle cartridge was used to kill a total of 48 seals with a shot aimed at the calvarium. For each of these seals, the following parameters were recorded: distance from where the animal was shot, immediate reaction of the animal (including occurrence of swimming reflex), and degree of damage to the skull on palpation of the calvarium through skin and blubber. The sex of the animals was not recorded. Because seals of this age group can be easily approached on land to within 2 m and shot from that distance (based on results of study #2), it was agreed that this would be the maximum distance from which a seal could be shot. Immediately after the shot, the state of consciousness of the seal was assessed by a veterinarian, based on at least two of the following criteria: degree of relaxation of the body, including presence or absence of respiratory movements, presence or absence of a corneal reflex, and degree of fragmentation of the calvarium by palpation through skin and blubber. The skulls of six seals killed with a single shot were collected for radiographic and macroscopic examination at the AVC. This project was approved by UPEI's Animal Care Committee (Protocol #11-003).

3. RESULTS

3.1. FIELD ASSESSMENT OF STUNNING AND KILLING METHODS, HAY ISLAND, NOVA SCOTIA, FEBRUARY 2009

Forty seals were examined during the course of this study. Since the goal of a proper killing method is to achieve irreversible unconsciousness or death as quickly as possible, the required outcome was identified as the number of blows used to completely crush the calvarium and thus destroy the brain. All data recorded on these animals are provided in Appendix 1. Twenty animals were killed with a club, and twenty with a hakapik. The median number of blows necessary to completely crush the calvarium was 4 (range, 2-10). It took one series of blows (1-5 blows in total) to crush completely the calvarium of 23% of the seals, two series (3-10 blows in total) for 69% of the seals, and three series (5-7 blows in total) for 8% of the seals. Skull fragments felt by palpation through skin and blubber seemed generally larger than those of crushed skulls in harp seal beaters, as experienced by two of the observers.

The median number of blows necessary to completely crush the calvarium was 3.5 with the club (range, 2-7), and 4 with the hakapik (range, 3-10). The proportion of calvaria successfully crushed according to the number of blows used is reported in Table 1 for the club and the hakapik combined and separately. Figure 2 reports the survival curves to reach complete crushing of the calvarium across the number of blows with the club or with the hakapik. Based on a log-rank test, the difference between the two curves approached significance (*P*-value = 0.073). The club seems to require fewer blows than the hakapik to crush the calvarium of a grey seal beater. On average, the hakapik was associated with more total blows than the club (4.55 vs 3.70), and this association also approached significance (*P*-value = 0.07). None of the biological factors (sex, weight, standard length, axillary girth, and thickness of sternal blubber) were unconditionally associated with the total number of blows.

On average, the bleeding time was 21.3 sec (range, 9-70) (severance of one and both axillary arteries combined) (Appendix 2). All seals bled out in under 1 minute when both axillary arteries were severed, and 95% of them bled out in under 1 minute when only one axillary artery was severed (Appendix 1). Table 2 summarizes unconditional associations between the bleeding time and factors such as the number of axillary arteries severed (one vs both), the stunning tool used, total number of blows, and biological factors (sex, weight, standard length, axillary girth, and thickness of sternal blubber). On average, severance of both axillary arteries resulted in a shorter bleeding time, although this relationship was not significant (*P*-value = 0.146). There was also a non-significant trend in the unconditional association between bleeding time and total number of blows (*P*-value = 0.186), between bleeding time and thickness of sternal blubber (*P*-value = 0.118), and, particularly, between bleeding time and standard length (*P*-value = 0.056). These were further explored in a multivariable analysis.

From the unconditional association, a multivariable linear regression model was constructed using bleeding time on a logarithmic scale to respect normal distribution of the outcome (Table 3). In this model, accounting for confounding variables such as total number of blows and standard length, severance of both axillary arteries was found to be significantly associated with a shorter bleeding time; for an average standard length of 108.5 cm and an average total number of 4.1 blows, severance of both arteries would decrease the bleeding time by 6.05 sec. Additionally, the effect of total number of blows and of standard length could increase or decrease bleeding time depending on each other's values. Post-estimation diagnostics were satisfactory enough to validate the model (data not shown).

Examination of four skinned carcasses of grey seal beaters revealed, as expected, multiple fractures of the calvarium associated with multiple lacerations and hemorrhage of the brain; there were also variable degrees of fracture of the bones (mainly occipital and basisphenoid) forming the floor of the cranial cavity. In the two male carcasses, the approximate distances from the aortic valve (at the origin of the aorta from the left ventricle of the heart) to the axillary arteries at their emergence into the axillary regions were, respectively, 16 and 13 cm on the right side, and 15 and 16 cm on the left. A moderate amount of fresh blood was found in the stomach of two carcasses (one male and one female).

3.2. ASSESSMENT OF THE .17 HMR RIFLE CARTRIDGE UNDER CONTROLLED CONDITIONS, AMET ISLAND, NOVA SCOTIA, JANUARY 2010

Appendix 3 provides detailed information on field observations and on radiographic and macroscopic examination of the head of each of the 12 animals used in this study. No difference in these parameters was detected between sexes. The distances from which the animals were shot were approximately 15 cm in three animals, 30 cm in three animals, 1 m in five animals, and 2 m in one animal, although all animals could easily have been shot from a distance of 30-50 cm. Death was judged to be immediate in eleven animals, based on the sudden relaxation of the body, including absence of respiratory movements, and on the absence of corneal reflex. One animal (#10), shot on the right side from a distance of 30 cm, may have turned its head toward the rifle just as the shot was fired and did not demonstrate complete obliteration of central neurologic function immediately after being shot. Its body contracted, and its eyes were closed tight, which prevented evaluation of the corneal reflex. This body contraction was maintained for approximately 30 sec, after which a slight relaxation occurred. The animal was then bled out in order to ensure death. This and five other animals showed no evidence of swimming reflex; the other six animals showed only a very mild swimming reflex. In all animals, the external wound created by the bullet’s entry was very small; another small external wound also appeared in two animals, possibly created by the exit of a small bullet fragment or of a piece of bone from the skull. In all these instances, the wound could be seen well only because of extrusion of blood and often brain tissue from it. Slight to moderate fragmentation of the calvarium could be felt on palpation in 10 animals; the calvarium of two animals (#4 and #10) was intact on palpation.

On radiography, numerous small and a few large metal fragments could be seen in the skull and/or surrounding soft tissues of all 12 animals, indicating extensive fragmentation of the bullet (Figure 3A). Skull fractures were also evident in all of them. In 10 animals, macroscopic examination revealed much hemorrhage in muscles surrounding the head and cranial region of the neck and severe multiple fractures of the skull involving especially its caudal region and accompanied by extensive hemorrhage around and within the brain and extensive laceration of the brain (Figures 3B and 3C). No fracture of the cervical vertebrae was identified in any of the 12 animals. In one animal (#4) that died immediately after being shot on the right side of the head from a distance of 1 m, the skull fracture created by the bullet was confined to a large hole, 3.5 cm in diameter, in its right side (Figure 4A), the adjacent region of the brain showing severe hemorrhage and laceration. On radiography, metal fragments from the bullet were concentrated around the fractured petrosal part of the right temporal bone, located in the ventral region of this bone (Figure 4B). The animal that did not demonstrate evidence of immediate death after being shot (#10) had a large hematoma in soft tissues on the right side of its head, within which most bullet fragments appeared to be embedded on radiography (Figure 5A). This animal had multiple fractures of its right temporal bone (Figure 5B), including marked fragmentation of this bone’s petrosal part. This was accompanied by extensive subdural hemorrhage over the right cerebral hemisphere and over the cerebellum, but not over the left cerebral hemisphere (Figure 5C), and extensive hemorrhage on the left and right sides of the floor of the cranial cavity, including the ventral surface of the brainstem (Figure 5D).

3.3. ASSESSMENT OF THE .17 HMR RIFLE CARTRIDGE DURING COMMERCIAL HARVEST. HAY ISLAND, NOVA SCOTIA, FEBRUARY 2011

One of the 48 seals killed with the rifle was shot from a distance of 10 m without prior knowledge of the observers, and for two seals, two shots were fired in rapid succession, and the state of consciousness of the seal, if any, between the two shots could not be evaluated. Therefore, data on these three animals was discarded. The distances from which the remaining 45 seals were shot were: <0.5 m in 33 seals, 0.5 m in seven seals, and 1 m in five seals. No effect of distance on the efficacy of the shot or the degree of damage to the skull could be detected. A single shot resulted in immediate death or death within a few seconds in 40 instances (88.9%). Based on palpation of the skull through skin and blubber, the calvarium was considered to be completely crushed in 22 seals, partly crushed in 10 seals, and not crushed in two seals; no description of skull palpation was available for six seals. In five of the seals with a calvarium that was only partly crushed or not crushed, a second shot was taken in order to complete the destruction of the calvarium.

In 30 seals killed with a single shot, the body relaxed immediately, and there were no corneal reflex or respiratory movements; a mild to moderate swimming reflex was observed in 15 of these seals, although in four of them this reflex occurred while or shortly after the skull was palpated to assess destruction of the calvarium. In 10 seals, the body contracted and the eyes closed immediately after the shot. This lasted for a few to several seconds before the body relaxed. Three of these 10 seals showed some swimming reflex. In three of these 10 seals, the skull was subsequently examined in details and had multiple severe fractures; in three others, the calvarium was determined to be completely crushed on palpation; and in the remaining four seals, the calvarium was determined to be only partly crushed on palpation.

In six seals that had been killed with a single shot (one with a completely crushed calvarium on palpation, two with a partly crushed calvarium on palpation, one with a calvarium that was not considered crushed on palpation, two for which no description of palpation of the calvarium was available), detailed macroscopic examination of the skull revealed multiple severe fractures of bones of the brain case in all instances (Figure 6). Radiographic examination of five of these six skulls showed only a very few small metal fragments (Figure 7), while several metal fragments, including some large ones, were present in the sixth skull.

Five (11.1%) seals were not killed with the first shot. Table 4 provides details of each case. In four of these seals, a second shot to the head was fired shortly afterwards, whereas a hakapik was used to crush the skull of the fifth seal.

Because the observers needed to stand back as the seals were being shot, it was not possible to make accurate observations about the occurrence of exit wounds by bullet fragments or lack thereof. Small gaps in the skin of the head, from which blood and/or brain tissue easily came out, were common (although the exact number of such instances was not recorded), but these could also have been caused by bone fragments from the skull. An exit wound was clearly observed in a single seal. This seal was shot in the front of the head at an angle almost parallel with the head’s axis, and a bullet fragment likely exited along the neck.

4. DISCUSSION

It has always been difficult to collect robust information about hunting methods during the course of the Canadian harp seal hunt because of its relatively remote location, the difficult field conditions, and the short duration of the hunt itself. By comparison, although also brief, the hunts for grey seal beaters that were observed in the course of this work were on a small scale and on secure ground. Variables were also minimized by following a single sealer in his hunt. Conversely, observation of several sealers would have better reflected the reality of the hunt. For the field assessment of the club and hakapik, different sealers would vary in strength, fitness, ability, and experience to deliver a blow to the best location on the skull in order to crush the calvarium after only one or a very few strikes. For the field testing of the .17 HMR rifle cartridge, different sealers would differ in their shooting skills, and the degree of maintenance of the rifle could also vary.

In the first study, both the regulation club and the regulation Canadian hakapik were considered effective tools to quickly and completely crush the skull of these animals under field conditions, thus resulting in their rapid, if not immediate, death. A difference approaching significance was detected between these tools: as compared to the club, the use of the hakapik was associated with more blows delivered to the skull. However, this difference could potentially be ascribed at least in part to the sealer's inexperience with the hakapik, as he commented that he became more comfortable with it as the day progressed. Because a single sealer was involved in killing the animals in this study, it is difficult to determine whether the weak difference observed between these two tools was a reflection of a personal preference or a true difference in stunning efficacy between these tools. Future studies should include multiple sealers in order to average the sealer effect and more observations in order to increase the power of the study.

All 12 grey seal beaters shot in the head with a .17 HMR rifle cartridge under controlled conditions and 40 of 45 (88.9%) seals shot under field conditions were considered to have died immediately or within a few seconds from a single shot, thus supporting the use of this type of ammunition as an effective tool to quickly kill these animals. In 11 and 30 of these seals, respectively, the body relaxed immediately. Contraction of the body and closure of the eyes occurred immediately after the shot in one (#10) of the 12 (8%) seals killed under controlled conditions and in 10 of the 40 (25%) seals killed under field conditions. In seal #10, the bullet had caused multiple fractures of the temporal bone, but most of its fragments had remained in the surrounding soft tissues, in association with a large hematoma. This animal may have been conscious or semi-conscious for a few seconds after the shot, until pressure on the brain resulting from the extensive subdural hemorrhage interfered with its function. Alternatively, the severe skull lesions observed grossly suggested that concussive forces from the bullet's impact may have been sufficient to cause immediate loss of consciousness. Contraction of the body and closure of the eyes in 10 of the 40 seals killed with a single shot under field conditions may also have indicated a brief moment during which some of the vital signs were still present after the rifle shot. However, observations in at least six of these 10 seals indicated severe multiple skull fractures, thus suggesting very extensive brain damage and thus immediate death. Nonetheless, this reaction complicated confirmation of the animals' death and thus reinforced the importance of careful palpation of the calvarium to ensure its complete destruction and consequently that of the underlying brain tissue. None of these seals exhibited a marked swimming reflex, and in some of them a swimming reflex of at most moderate intensity appeared to be triggered by palpation of the skull to assess destruction of the calvarium. In a similar manner, Daoust and Caraguel (2012) observed contraction of the carcass in some harp seals killed with a hakapik as these carcasses were being handled.

With a bullet with a polymer tip from a .17 HMR rifle cartridge, the bullet's extensive fragmentation is achieved from a combination of its high velocity, its special core design, and its polymer tip. On impact, the polymer tip acts as a "wedge" and pushes backward into the bullet core. The hollow cavity right behind the base of the tip allows the tip to build up kinetic energy before smashing into the largest part of the core. This ensures instant fragmentation even at low velocity, in long range shooting situations. The type of bullet (hollow-point) used in the field study was different from that used in the controlled study (with polymer tip), although it was not possible to determine to what extent, if any, this difference affected the degree of damage caused to the skull and brain. A hollow-point bullet might mushroom more than fragment on impact. Radiographs of the skulls in the two studies suggested this. Numerous small and a few large metal fragments could be seen in the skull and/or surrounding soft tissues of all 12 animals killed with a bullet with polymer tip, being spread out within the brain case in nine of these skulls; this would have ensured delivery of the bullet's entire kinetic energy into the brain case in most instances and would also have minimized the danger of ricochet from large bullet fragments. By comparison, only a very few small metal fragments could be seen in the skulls of five out of six seals killed with a hollow-point bullet and examined radiographically, suggesting less extensive bullet fragmentation and therefore the potential for exit of large fragments from the animal and their subsequent ricochet. However, the terminal ballistics of a bullet, including its degree of fragmentation, are influenced by several characteristics besides its tip, such as jacket thickness, metal composition, and speed on impact. Because modern bullets are designed to perform best within a certain range of velocities and thus distances, the degree and type of damage caused by a bullet fired at unusually close range might be different than if it were fired from a more normal distance. Conversely, the accuracy of the shot should be better at close range. Even at close range, however, the brain of a grey seal beater represents a relatively small target, and the typically long head of this species may induce the sealer not to aim far enough behind the eyes, as the position of the calvarium may be more caudal in young grey seals than in harp seals relative to a transverse axis along the orbits (Figure 8). This potential anatomical difference should be clarified as it could be an important point to emphasize during education and training of professional sealers, particularly in relation to the target area of the head to aim for with a blow from a hakapik or club or with a rifle shot. In addition, grey seals are sexually dimorphic, and some differences are observed at weaning between the two sexes (Baker et al. 1995). Male and female grey seals were included in the field test of the .17 HMR rifle cartridge, but their sex was not recorded. Therefore, a possible difference in ease to destroy the skulls between sexes could not be evaluated. This should be considered in future tests.

Five seals (11.1%) harvested under field conditions were not killed with the first shot, and at least one of these shots was missed because the animal moved its head just as the sealer was firing. These results are comparable to other forms of hunting in which the proportion of animals not killed with the first shot varied between 6.3% and 14.3% (Lewis et al. 1997; Nixon et al. 2001; Urquhart and McKendrick 2003). Nonetheless, it should be possible to improve this performance in a commercial hunt that involves shooting relatively immobile animals at very close range. Such improvement could easily be made through very simple modifications of the method used in the field study, which could be conveyed through information workshops for the sealers prior to the hunt. For example, the sealer should not shoot the seal unless it is stationary, and this could be made easier by approaching the animal slowly. A sealer can easily get to within 2 m of young grey seals without them showing an inclination to move away, and these seals can therefore be shot at very close range. However, it is not necessary, and perhaps counterproductive, for the barrel of the rifle to be <0.5 m from the seal's head as it may induce the animal to move its head. A few problems were also associated with the particular rifle used during the field study. The fact that it was equipped with a telescope likely interfered with proper aim of the shot at close range; empty cartridges got stuck in the barrel a few times, which suggested that the rifle had not been well maintained; and a single clip was available, whereas a spare, fully loaded clip should have been readily available at all times. The last two points would be critical in the event that a seal were only wounded with the first shot, and a second shot needed to be fired immediately afterwards. This emphasizes again the importance for the sealer to always carry a club or a hakapik with him, at least as a secondary killing tool.

The location of the bullet's impact could also influence the degree of damage to the skull and, potentially, how rapidly the animal dies. In particular, impact on the lower, petrosal, part of the temporal bone, which houses the inner ear and is composed of very dense bone (Miller 1964), might cause fragmentation of the bullet in the immediate vicinity of this bone and thus limit the damage to other regions of the skull and brain. For this reason, we recommend avoiding the lower part of the sides of the head when shooting grey seal beaters with a .17 HMR rifle cartridge and aiming instead for the top of the head, from either the front or the sides.

Palpation of the skull through skin and blubber corresponds to the second step of the three-step process (stunning, checking, bleeding) for ensuring rapid death of the seals, as recommended by IVWG (2005) and now required by the MMR (Anonymous 2010), and is a practical means of confirming skull fracture and thus destruction of the underlying brain tissue. The top of the skull of a grey seal beater is on average almost twice as thick as that of a harp seal beater (4.88 mm and 2.64 mm, respectively) (Caraguel et al. 2012). Likely because of this, and whether the animals were killed with a hakapik or a club or with a .17 HMR rifle cartridge, larger skull fragments were felt on palpation of the calvarium through skin and blubber, and assessed visually during laboratory examination of some of the carcasses, as compared to skulls of harp seal beaters examined in other studies (Daoust et al. 2002; Daoust and Caraguel, 2012). These larger skull fragments made it slightly more difficult for the observers to assess by palpation the degree of crushing of the calvarium in these animals, especially when bone fragmentation involved the caudal region of the skull, a region difficult to reach by palpation. It would be useful to objectively measure the difference in solidity of the calvarium in harp seal and grey seal beaters. This could be done through a combination of mechanical tests and anatomical measurements that would need to take into account not only the thickness of different regions of the skull, but also the gross and microscopic architecture of the calvarium.

Fractures of the calvarium in carcasses examined in the laboratory were accompanied consistently by fractures of the floor of the cranial cavity, as was observed in harp seals killed with a hakapik or a rifle (Daoust et al. 2002; Daoust and Caraguel 2012). Fractures in this location imply severe functional, if not structural, damage to the brain stem, which rests on the floor of the braincase. Because this part of the brain contains respiratory and cardiovascular control centres that are essential for life (Guyton 2006), such damage would indicate rapid, if not immediate death, although it would not be possible to feel by palpation the fractures in this deep location. Despite these observations, and although fractures were severe even in skulls whose calvarium was not considered completely crushed on palpation, it would be easy to complete this step by firing another bullet from a .17 HMR rifle cartridge or by striking the seal's head with a hakapik or a club. Therefore, we believe that the latter tools remain essential in the seal hunt.

Taking into account a number of confounding variables, severance of both axillary arteries resulted in a significantly shorter bleeding time as compared to severance of only one of these arteries in grey seal beaters killed with a hakapik or a club. This bleeding time was shorter than that for harp seal beaters killed with a hakapik: 21.3 s (CI:14.7-27.9; range:14-35) when both axillary arteries were cut, and 50.3 s (CI: 26.7-74.0; range: 12-75) when only one axillary artery was cut (Daoust and Caraguel 2012). These times are less than the time of one minute that animals are required to bleed before being skinned under the MMR (Anonymous 2010). These observations also support veterinary recommendations and the current MMR (Anonymous 2010) that step three of the three-step process be done by severance of both axillary arteries. Subjective assessment of the end point of bleeding time may involve some degree of error. Furthermore, whereas the end point of bleeding confirms the arrest of blood flow to the brain, which is the main purpose of step three of the three-step process, bleeding time is probably not the most appropriate parameter for evaluating the efficiency of bleeding as far as the whole carcass is concerned. This efficiency is a function of the amount of blood left in the organs and tissues. The degree of exsanguination reflects how efficiently the blood is ejected out of the body and is related to cardiovascular function (pulse, rhythmic contraction and relaxation of the left ventricle of the heart) and the number of outlets for the blood. When only one artery is severed, a larger fraction of the blood volume will continue to be pumped back into the circulatory system, and a substantial portion of the body will not be exsanguinated properly. Other parameters besides bleeding time, such as volume of blood loss should be evaluated to verify the hypothesis that severance of both axillary arteries results not only in a faster bleeding time but also more complete bleeding.

Fresh blood was found in the stomach of two of four whole carcasses examined in the laboratory. A small quantity of blood, either fluid or clotted, was also observed in the stomach of seven (7.9%) of 88 harp seal beaters killed during a commercial hunt and examined specifically for this purpose, this blood having presumably been swallowed from the head injury (Daoust and Caraguel 2012). The swallowing process becomes involuntary once liquid or a bolus of food enters the pharynx, and this reflex includes delivery of liquid or food along the esophagus from the pharynx to the stomach (Guyton and Hall 2006). It is therefore conceivable that, in an animal that is irreversibly unconscious but not dead, blood accumulating in the mouth from fractures of the skull and/or snout would reach the pharynx and thus trigger a swallowing reflex. This indicates that the presence of blood in the stomach of a dead seal does not necessarily represent evidence of poor animal welfare. Nonetheless, this observation of blood in the stomach deserves to be explained more precisely.

The main goals of this work were to better understand the logistics of the hunt for grey seal beaters in order to improve its harvesting methods where possible, and, more specifically, to determine whether the .17 HMR rifle cartridge provides reliable killing power for young grey seals shot at close range, while having a low risk of ricochet from bullet fragments. Based on our current knowledge, we believe that this ammunition meets these criteria, although further field observations are needed to refine our assessment of its performance. This could be done by taking advantage of the use of this ammunition during commercial harvest, including both types of bullets (polymer tip and hollow-point) for comparison, and taking into account the recommendations included in this report. Predicting bullet performance and lethality based on known principles of terminal ballistics is very complex, and the wide range of ammunition and bullet types available further complicates this process. It is therefore likely that more than one type of ammunition can fulfill the criteria required for use at the hunt for grey seal beaters. However, all things considered, and as with any hunt, the most important element remains the professionalism and ethical behaviour of the sealer/hunter.

5. ACKNOWLEDGMENTS

This work could not have been carried out without the cooperation and trust of sealers from the North of Smokey Fishermen's Association, particularly skippers Robert Courtney and Pat Briand. We greatly appreciated the participation of Leonard Doucette, technician in the AVC's necropsy laboratory, during the field study; his assistance was invaluable. We are also very grateful to Denis LeBlanc (Tracadie-Sheila, New Brunswick) and Glenn Williams (Iqaluit, Nunavut) for their insightful comments on terminal ballistics.

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Table 1. Kaplan-Meier survival table. Comparison of the proportion of young grey seals with calvaria completely crushed relative to the number of blows received from a club or a hakapik (Hay Island, Nova Scotia, February 2009). For any given number of blows observed, the count and the proportion of crushed calvaria are reported for the club and the hakapik combined and separately.

Club and Hakapik combined

Nb of blows	Nb of seals	Completely crushed	% of completely crushed	Cumulative % of completely crushed
2	40	2	5%	5%
3	38	12	31.6%	35%
4	26	16	61.5%	75%
5	10	5	50%	87.5%
6	5	2	40%	92.5%
7	3	2	66%	97.5%
10	1	1	100%	100%

Cub only

Nb of blows	Nb of seals	Completely crushed	% of completely crushed	Cumulative % of completely crushed
2	20	2	10%	10%
3	18	8	44.5%	50%
4	10	6	60%	80%
5	4	3	75%	95%
6	1	0	0%	95%
7	1	1	100%	100%
10	-	-	-	100%

Hakapik only

Nb of blows	Nb of seals	Completely crushed	% of completely crushed	Cumulative % of completely crushed
2	20	0	0%	0%
3	20	4	20%	20%
4	16	10	62.5%	70%
5	6	2	33.3%	80%
6	4	2	50%	90%
7	2	1	50%	95%
10	1	1	100%	100%

Table 2. Young grey seals killed with a club or a hakapik (Hay Island, Nova Scotia, February 2009). Unconditional associations between bleeding time, the number of axillary arteries severed, the stunning tool used, total number of blows, and biological factors.

Dependent variable	Bleeding time (seconds)	
Independent variables	Mean (S.E.)	*P*-value
Severed arteries		
one (n=19)	24.79 (4.537)	
both (n=20)	18.05 (2.453)	0.146
Stunning tool		
club (n=19)	21.58 (4.669)	
hakapik (n=20)	21.10 (3.344)	0.919
Total number of blows (n=39)	-2.12 (1.574)	0.186
Sex		
female (n=10)	26.60 (5.067)	
male (n-20)	19.70 (6.206)	0.276
Weight (g) (n=36)	.529 (.3954)	0.190
Standard length (cm) (n=38)	.720 (.3619)	0.054
Axillary girth (cm) (n=38)	.280 (.5293)	0.599
Sternal blubber (mm) (n=34)	.695 (.4331)	0.118

Table 3. Young grey seals killed with a club or a hakapik (Hay Island, Nova Scotia, February 2009). Summary table of the multivariable linear regression analysis that identified factors associated with bleeding time (logarithmic scale).

	Coefficient (log scale)	S. E.	*P*-value	[95% CI]
One artery (baseline)	-8.66	5.43	0.120	-19.7; 2.38
Both arteries	-0.327	0.154	0.041	-0.64; -.013
Total blows	+2.72	1.85	0.073	-.265; 5.72
Standard length	+0.112	2.25	0.032	0.01; .214
Blows*length (interaction)	-0.026	-1.92	0.063	-.054;.001

Table 4. Five young grey seals not killed with the first shot from a .17 HMR rifle cartridge (Hay Island, Nova Scotia, February 2011).

Seal #	Comment
1	Distance, 0.5 m. The sealer did not wait for the animal to be stationary. The first shot grazed the top of the head. A second shot was fired shortly afterwards.
3	Distance, <0.5 m. The seal moved its head just as the sealer was shooting. The first shot hit the snout. A second shot was fired shortly afterwards.
32	Distance, <0.5 m. The entry site of the first shot was not recorded. The seal rolled down a hill for a few seconds before it stopped and the second shot could be taken.
42	Distance, 1 m. The first shot hit the snout. The animal moved its head a lot after this. Therefore, a hakapik was used to crush its skull.
48	Distance, 0.5 m. The first shot hit near the atlanto-occipital joint. The seal shut its eyes and did not breath, but then opened its eyes. A second shot was fired shortly afterwards.

Figure 1. Comparison of the regulation club (short and thick tool) and the regulation Canadian hakapik (long tool, with a metal ferrule at one end).

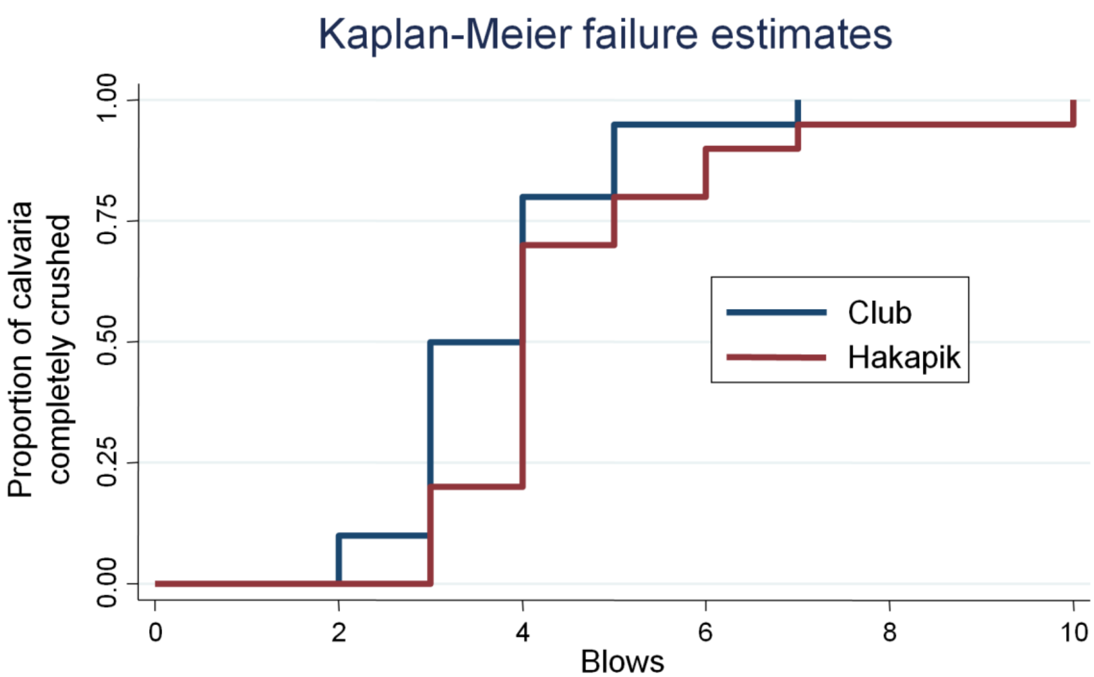

Figure 2. Kaplan-Meier survival plot. Comparison of the proportion of young grey seals with calvaria completely crushed relative to the number of blows received from a club or a hakapik (Hay Island, Nova Scotia, February 2009). Based on a log-rank test, the difference between the two survival curves was close to significance (P-value = 0.073).

Figure 3. Young grey seal #7, shot in the head from a distance of 1 m with a .17 HMR rifle cartridge (Amet Island, Nova Scotia, January 2010). This animal died immediately. A) On radiography, small metal fragments from the bullet are scattered in the skull (arrows). (R, right side of head).

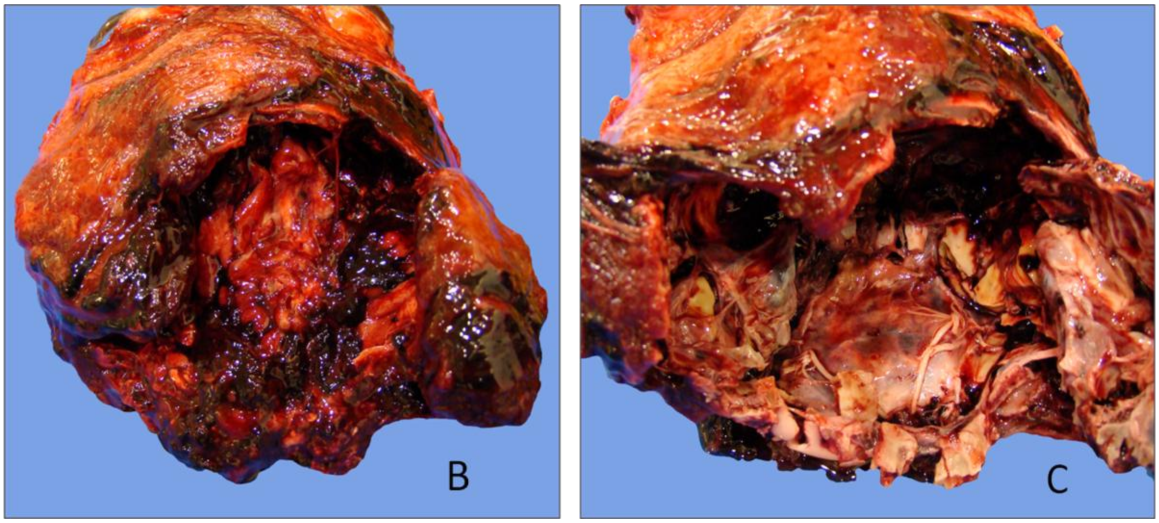

Figure 3 (contd). Young grey seal #7, shot in the head from a distance of 1 m with a .17 HMR rifle cartridge (Amet Island, Nova Scotia, January 2010). This animal died immediately. B) Severe multiple fractures of the caudal region of the skull (bone fragments reflected out), accompanied by extensive hemorrhage and laceration of the brain. C) Cranial cavity cleaned to show the multiple bone fragmentation, particularly of the base of the skull.

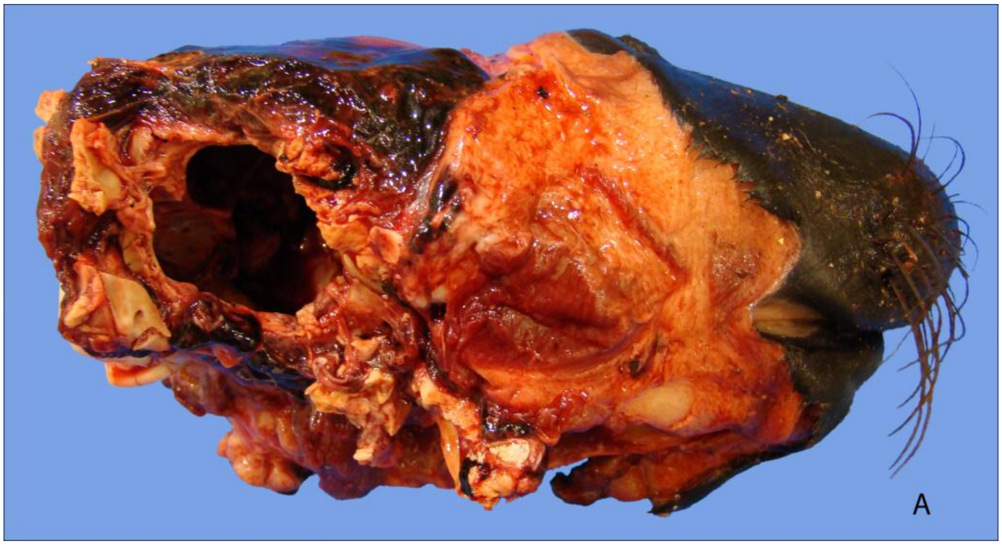

Figure 4. Young grey seal #4, shot in the head from a distance of 1 m with a .17 HMR rifle cartridge (Amet Island, Nova Scotia, January 2010). This animal died immediately. A) Large hole, 3.5 cm in diameter, created by the bullet in the right temporal and parietal bones (bone fragments reflected out). No other fracture was present in the skull. B) On radiography, most metal fragments from the bullet are concentrated around the fractured petrosal part of the right temporal bone (arrow). (L, left side of head.).

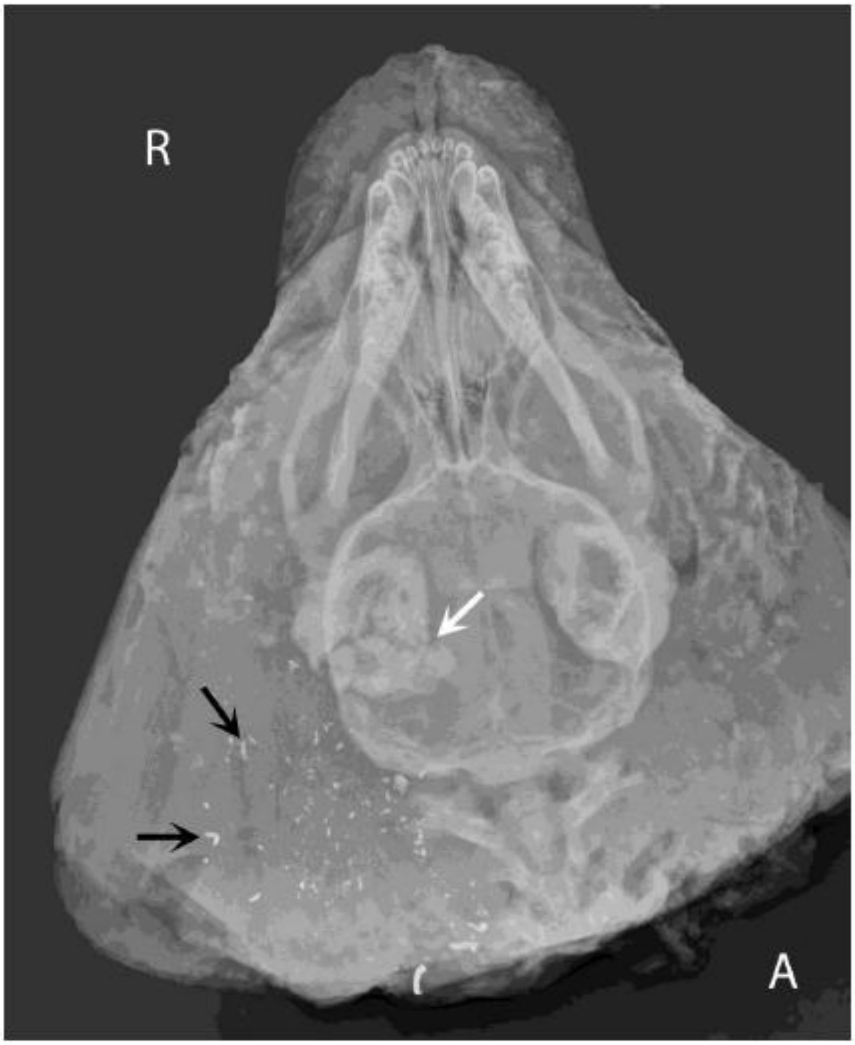

Figure 5. Young grey seal #10, shot in the head from a distance of 30 cm with a .17 HMR rifle cartridge (Amet Island, Nova Scotia, January 2010). This animal did not demonstrate evidence of instantaneous death after being shot. A) On radiography, many small metal fragments from the bullet are in soft tissues (including a large hematoma) on the right side of the head (black arrows). The petrosal part of the right temporal bone is fractured (white arrow). (R, right side of head).

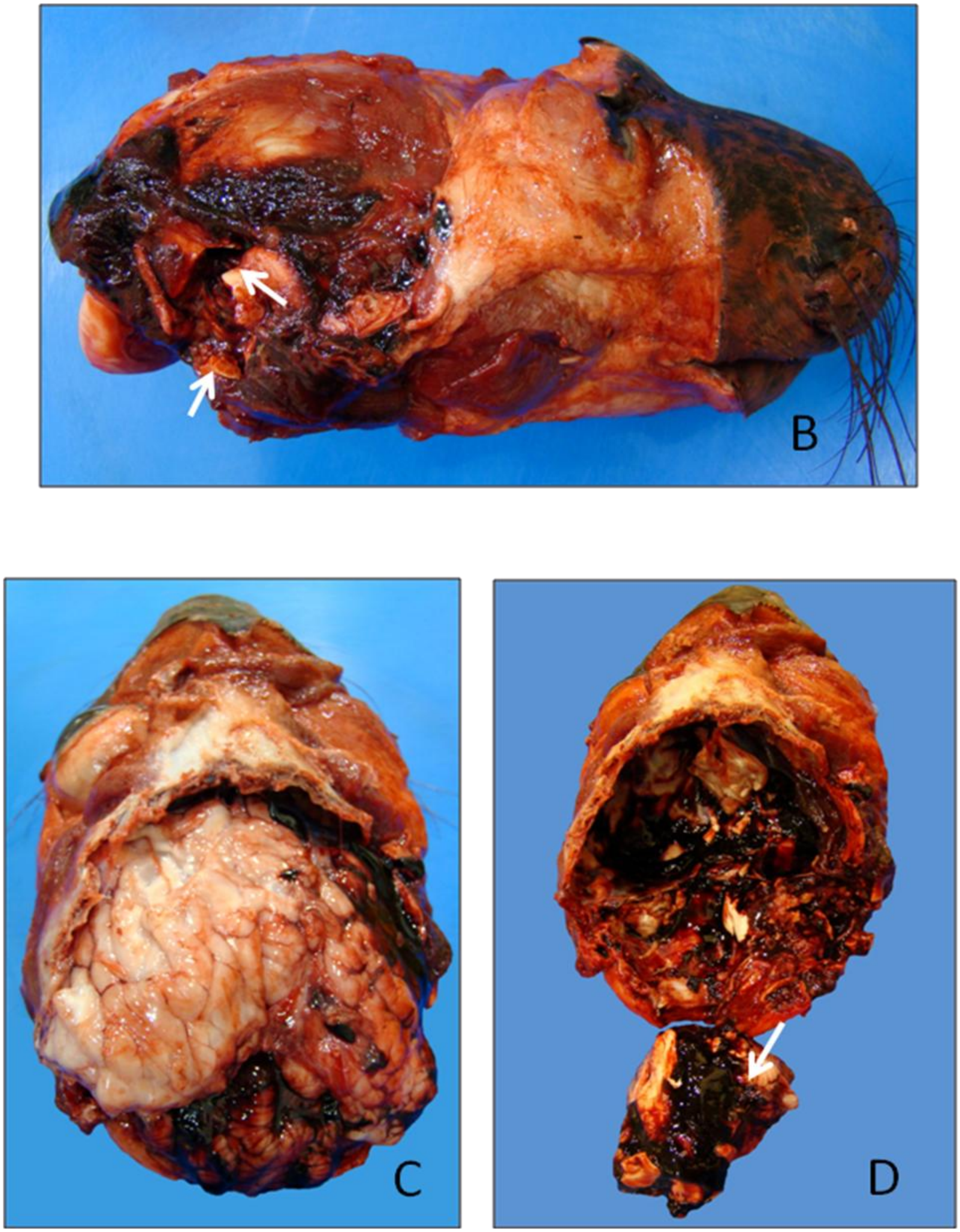

Figure 5 (contd). Young grey seal #10, shot in the head from a distance of 30 cm with a .17 HMR rifle cartridge (Amet Island, Nova Scotia, January 2010). This animal did not demonstrate evidence of instantaneous death after being shot. B) Multiple fractures of right temporal bone (arrows) (some bone fragments removed). C) Subdural hemorrhage over the right cerebral hemisphere and over the cerebellum, but not over the left cerebral hemisphere. D) Extensive hemorrhage on the left and right sides of the floor of the cranial cavity and on the ventral surface (arrow) of the brainstem (taken out of the cranial cavity).

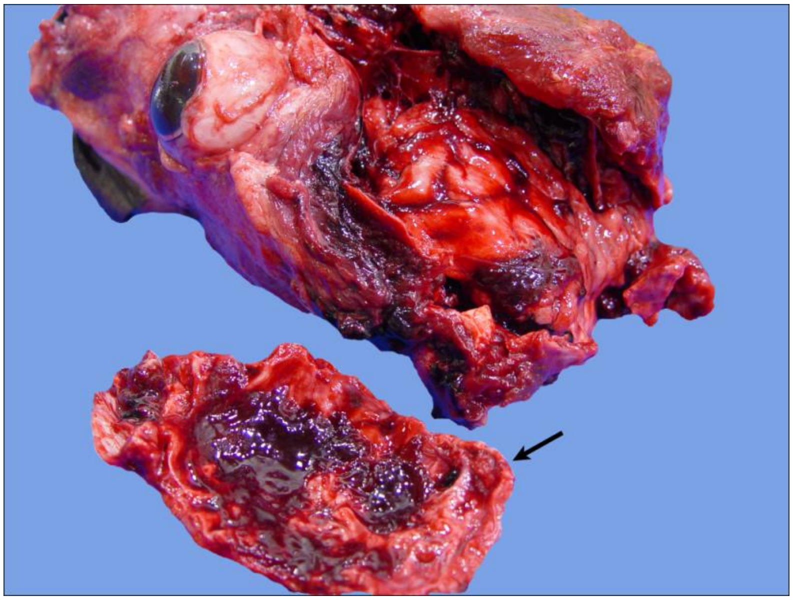

Figure 6. Skull of a young grey seal killed with a single shot to the head from a .17 HMR rifle cartridge (Hay Island, Nova Scotia, February 2011). The calvarium (dome-shaped top of the skull) of this seal was not considered crushed on palpation through skin and blubber. However, macroscopic examination revealed multiple severe fractures of bones of the brain case, including an almost complete separation of the left parietal bone and left portion of the frontal bone (arrow) from the rest of the calvarium.

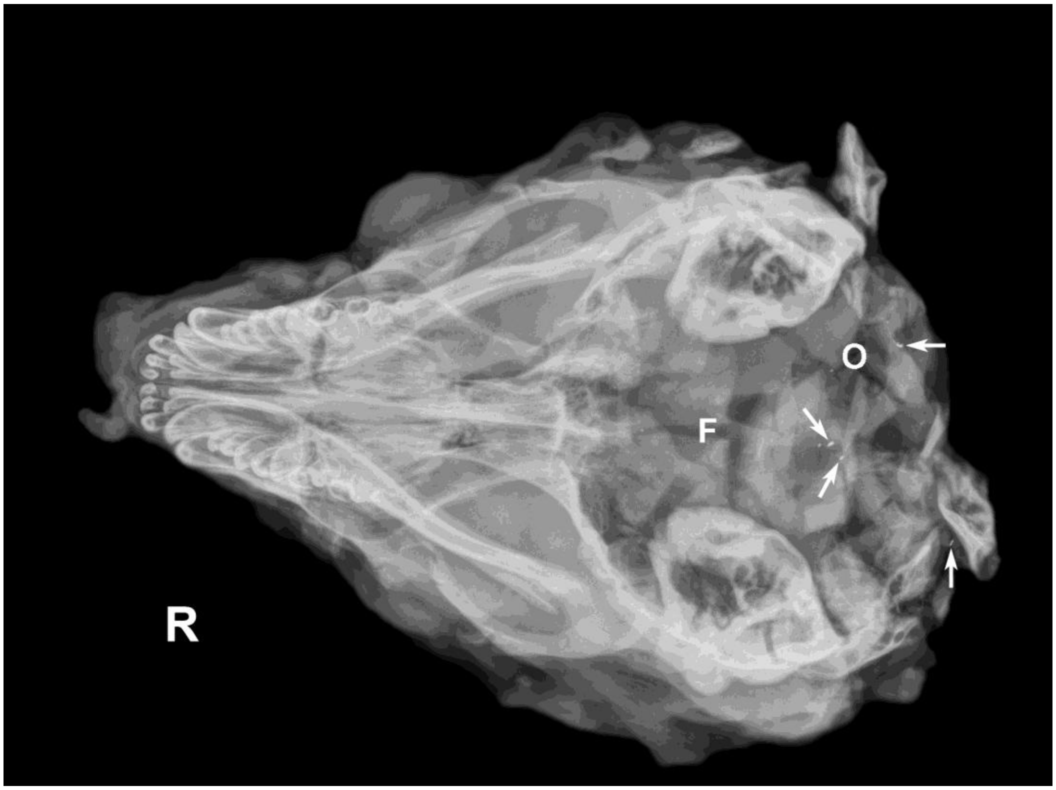

Figure 7. Dorso-ventral radiograph of the skull of a young grey seal killed with a single shot to the head from a .17 HMR rifle cartridge (Hay Island, Nova Scotia, February 2011). Only a very few small metal fragments (arrows) can be seen in the caudal region of the brain cavity. There are severe fractures of the floor of the brain case (F) and of the occipital bone (O).

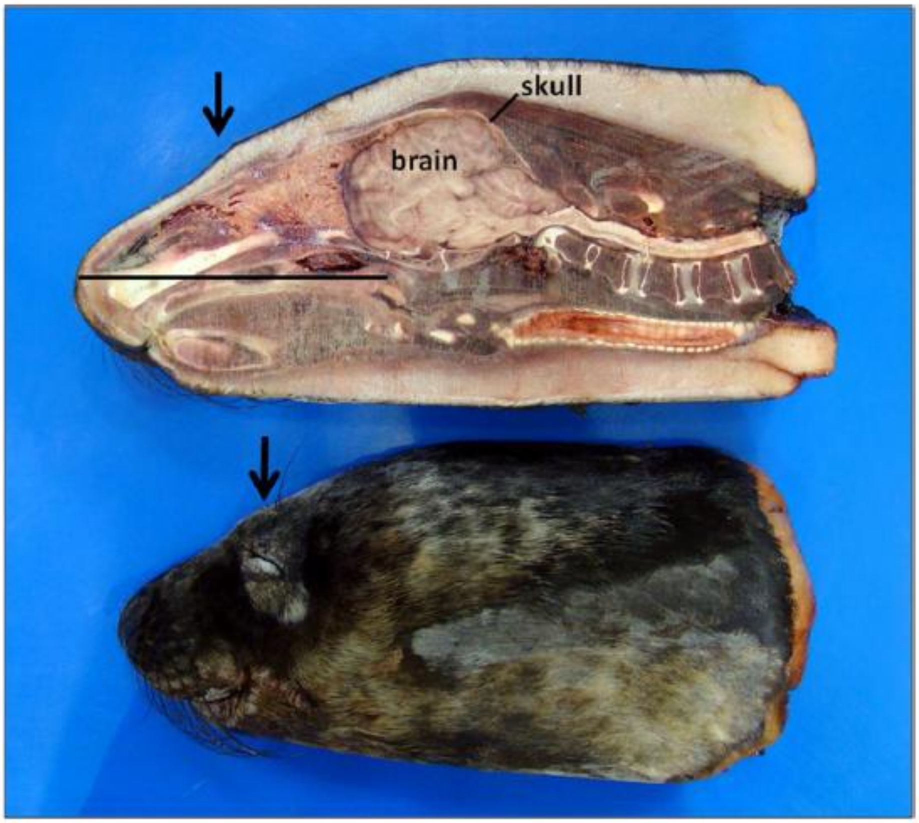

Figure 8. Right (above) and left (below) sides of the intact head of a young grey seal cut in half longitudinally, showing the position of the brain relative to that of the eyes (arrows). The black bar traced horizontally across the right half is 15 cm (~6 inches) long.

Appendix 1. Complete set of data recorded on 40 young grey seals killed on Hay Island, Nova Scotia, in February 2009, with a regulation club or a regulation Canadian hakapik and bled by severance of one or two axillary arteries. nr, not recorded.

seal nb	***stunning tool***	***blows at t0[1]***	***crushed skull at t0[2]***	***blows at t1***	***crushed skull at t1***	***blows at t2***	***crushed skull at t2***	***Blows total***
1	club	3	partial	1	complete	0		4
2	hakapik	2	partial	2	complete	0		4
3	club	3	partial	2	complete	0		5
4	hakapik	2	partial	2	complete	0		4
5	club	3	complete	0		0		3
6	hakapik	3	partial	1	complete	0		4
7	club	3	complete	0		0		3
8	hakapik	3	partial	1	complete	0		4
9	club	3	complete	2	complete	0		5
10	hakapik	3	partial	2	complete	0		5
11	club	3	partial	0		0		3
12	hakapik	3	parrtial	3	complete	0		6
13	club	3	complete	0		0		3
14	hakapik	3	intact	4	complete	0		7
15	club	3	intact	2	complete	0		5
16	hakapik	5	intact	5	complete	0		10
17	club	3	intact	1	complete	0		4
18	hakapik	2	partial	1	complete	0		3
19	hakapik	2	partial	2	complete	0		4
20	hakapik	2	intact	2	complete	0		4
21	club	2	intact	2	complete	0		4
22	cub	1	intact	2	complete	0		3
23	club	2	complete	0		0		2
24	hakapik	3	intact	1	complete	0		4
25	club	3	intact	1	complete	0		4
26	hakapik	2	intact	2	complete	0		4
27	hakapik	2	partial	2	complete	0		4
28	club	4	complete	0		0		4
29	hakapik	2	intact	2	intact	1	complete	5
30	club	2	partial	1	complete	0		3
31	hakapik	3	complete	0		0		3
32	club	2	partial	1	complete	0		3
33	hakapik	3	partial	1	complete	0		4
34	club	3	intact	3	partial	1	complete	7
35	hakapik	3	intact	2	intact	1	complete	6
36	club	2	complete	0		0		2
37	hakapik	3	complete	0		0		3
38	club	1	intact	2	complete	0		3
39	hakapik	2	partial	1	complete	0		3
40	club	2	intact	2	complete	0		4

Appendix 1. (cont'd)

seal nb	severed artery	Sex	Bleeding time (sec)	Standard length (cm)	weight (kg)	axillary girth (cm)	sternal blubber (mm)[3]
1	2	nr	26	nr	nr	nr	nr
2	1	nr	32	116	48	101	55
3	2	nr	18	106	43	102.5	44
4	1	nr	17	99.5	35	91.5	47
5	2	nr	14	98	33	93.5	42
6	1	nr	16	111	47	106.5	37
7	2	nr	17	95	28	87	45
8	1	nr	19	97.5	36	96	50
9	2	nr	13	110	44	106.5	45
10	1	female	35	104	42	96	na
11	2	male	23	108.5	43	102.5	45
12	1	male	25	106	44	94.5	50
13	2	female	73	114	46	102.5	45
14	1	male	27	104.5	43.5	98.5	41
15	2	male	17	102	37	91.5	47
16	1	male	9	107.5	45	97	60
17	2	male	15	111	46	103	53
18	1	female	21	103	34	97.5	53
19	2	male	13	121	45	96.5	49
20	1	male	33	112	53	110	60
21	2	male	9	112	na	102.5	na
22	1	male	70	126	na	100.5	65
23	2	female	Nr	105	36	97.5	55
24	2	male	17	118	46	101	na
25	1	female	17	105	43	102.5	50
26	2	male	9	113	44	103	50
27	1	male	14	105.5	33	96.5	40
28	2	male	11	107	44	102	50
29	2	male	15	111	37	97.5	50
30	1	male	16	108	43	100.5	50
31	1	female	49	108	44	96.5	50
32	2	male	13	104	43	97	40
33	1	male	28	108	47	101.5	na
34	2	female	11	113	45	101.5	55
35	1	female	17	104	41	99.5	50
36	2	male	17	115	38	95	50
37	1	female	13	106	45	101.5	50
38	2	female	18	112.5	48	104	45
39	1	male	13	111	46	101	50
40	2	female	12	113	43	96.5	50

[1] *Series of blows at times 0, 1 and 2 were separated by palpation of the calvarium.*
[2] *Degree to which the calvarium was felt to be crushed by palpation through skin and blubber (intact, partially crushed, completely crushed).*
[3] *Values for this parameter are not accurate as a large cut was made along the sternum prior to measurement of blubber thickness and variable amounts of blubber were often left on the carcass at that level.*

Appendix 2. Summary of data presented in Appendix 1.

Variable	Nb animals	Mean	Std. Dev.	Min.	Max.
blows - t0	40	2.6	0.744	1	5
blows - t1	31	1.87	0.921	1	5
blows - t2	3	1.0	0	1	1
total blows	40	4.1	1.488	2	10
bleeding time (sec)[1]	39	21.3	14.384	9	70
std. length (cm)	39	108.5	6.304	95	126
weight (kg)	37	42.1	5.219	28	53
axillary girth (cm)	39	99.3	4.514	87	110
sternal blubber (mm)	35	49.1	5.898	37	65

[1] severance of one and both axillary arteries combined.

Appendix 3. Field observations and radiographic and macroscopic examination of the head of 12 young grey seals shot in the head with a .17 HMR rifle cartridge, on Amet Island, Nova Scotia, in January 2010.

Seal #	**Site shot**	**Comment**
1	right side	Field observations: Male. Shot from ~30 cm (1 foot) in caudal region of head. Immediate death. Very little swimming reflex. On palpation, calvarium feels generally intact, but some fragments are felt in occipital region. Large hematoma quickly formed on left side. Radiographs: Numerous small metal fragments in soft tissues on left side of head. Fracture of petrosal part of left temporal bone and of left part of occipital bone. Macroscopic examination: Entry wound not visible. Large hematoma in soft tissues on left side of head. Complete destruction of left parietal bone; severe fracture of left temporal bone and of left part of occipital bone; complete separation of dorsal part of occipital bone from the rest of the calvarium.
2	Back	Field observations: Female. Shot from ~15 cm (6 inches). Immediate death. Very little swimming reflex. Blood and brain tissue coming out of wound. Calvarium crushed on palpation. Radiographs: Numerous small metal fragments more or less confined to skull. Fracture of calvarium and of petrosal part of right temporal bone. Macroscopic examination: Severe fracture of calvarium involving right parietal bone, left and right temporal bones, left frontal bone, and occipital bone. Fracture of base of skull at junction between ventral part of occipital bone and basisphenoid bone.
3	right side	Field observations: Female. Shot from ~15 cm just above right eye. Immediate death. No swimming reflex. Brain tissue spurting out of wound. On palpation, calvarium crushed mainly on right side. Radiographs: Numerous small metal fragments more or less confined to skull; one large fragment in soft tissues on left side of head. Fracture of rostral region of calvarium. Macroscopic examination: Severe fracture of right side of calvarium involving right frontal bone and right temporal and parietal bones; separation of left parietal bone from rest of skull; fracture of frontal bone from its attachment to nasal bones. Fracture of base of skull at junction between ventral part of occipital bone and basisphenoid bone.
4	right side	Field observations: Male. Shot from ~1 m. Immediate death. No swimming reflex. Calvarium intact on palpation. Radiographs: Numerous small metal fragments concentrated around fractured petrosal part of right temporal bone. Macroscopic examination: Severe fracture of right temporal bone and of adjacent portion of right parietal bone; diameter of hole created, 3.5 cm. No fracture anywhere else.
5	Front	Field observations: Female. Shot from ~2 m between the eyes. Immediate death. No swimming reflex. Brain tissue coming out of wound. Large bone fragments on palpation of the skull. Radiographs: Numerous small metal fragments distributed mainly along left side of skull, also in soft tissues on dorsal side of head; some large fragments extending into neck. Fracture of calvarium. Macroscopic examination: Severe fracture of left frontal bone, of left parietal and temporal bones, and of occipital bone; partial fracture of right part of frontal bone and of right parietal bone. Fracture of base of skull at junction between ventral part of occipital bone and basisphenoid bone.

Seal #	Site shot	Comment
6	left side	Field observations: Female. Shot from ~1 m. Immediate death. Very little swimming reflex. Large bone fragments on palpation of the skull. Radiographs: Numerous small metal fragments in skull; a few large fragments in neck. Fracture of calvarium and of caudal region of skull. Macroscopic examination: Severe fracture of all parts of the skull, including calvarium and base. Large gap in caudal region of skull.
7	left side	Field observations: Female. Shot from ~1 m in caudal region of skull. Immediate death. No swimming reflex; then after ~20 sec, fairly strong swimming reflex for ~10 sec. On palpation, rostral region of calvarium intact, large fragments felt in caudal region. Radiographs: Numerous small metal fragments in skull, extending into soft tissues of neck. Fracture of petrosal part of right temporal bone and of caudal region of skull. Macroscopic examination: Entry wound not found on external examination. Severe fracture of occipital bone and of right and left parietal bones; partial fracture of left and right temporal bones. Fracture of base of skull at junction between ventral part of occipital bone and basisphenoid bone.
8	right side	Field observations: Female. Shot from ~1 m in caudal region of skull. Apparent exit wound (from deviated bullet fragment or from piece of bone?) behind left eye. Immediate death. A few wide, slow movements of swimming reflex. Large bone fragments on palpation of the skull. Radiographs: Numerous small metal fragments in skull, extending into soft tissues; a few large fragments in soft tissues along caudal region of skull. Fracture of calvarium and of caudal region of skull. Macroscopic examination: No entry or exit wound found on external examination. Severe fracture of occipital bone, of left and right parietal bones, and of left temporal bone; partial fracture of left and right frontal bones.
9	left side	Field observations: Male. Shot from ~30 cm. Very little blood and some brain tissue coming out of wound. Immediate death. Some swimming reflex when moved after ~30 sec. Very little fragmentation of calvarium on palpation. Radiographs: Numerous small metal fragments in skull; some large fragments extending into soft tissues of neck. Fracture of caudal region of skull and of petrosal part of right temporal bone. Macroscopic examination: Severe fracture of whole dorsal part of occipital bone; fracture of left parietal bone and of left temporal bone (separated from the base of the skull); partial fracture of right parietal bone. Fracture of base of skull at junction between ventral part of occipital bone and basisphenoid bone.

Seal #	Site shot	Comment
10	right side	Field observations: Female. Shot from ~30 cm in lateral region of head; the animal may have turned its head toward the rifle just as the shot was fired. No movement, but animal contracted, with eyes shot; therefore, corneal reflex could not be checked properly. Calvarium intact on palpation. The whole body contraction was maintained for ~30 sec. A slight relaxation then occurred. Animal bled out in order to ensure death. Radiographs: Numerous small metal fragments in soft tissues of right side of head and neck. Fracture of petrosal part of right temporal bone. Macroscopic examination: Large hematoma in soft tissues on right side of head. Multiple fractures of right temporal bone, including marked fragmentation of its petrosal part. Linear fracture extending cranially from this multiple fracture; another extending caudo-medially and into the right part of the occipital bone. Linear fracture of the base of the occipital bone, slightly on the right, starting at the occipital foramen. Large amount of clotted blood visible around the spinal cord at its exit from the foramen magnum. Much subdural hemorrhage over right cerebral hemisphere and over cerebellum, but not over left cerebral hemisphere. Extensive hemorrhage on left and right sides of floor of cranial cavity, including the ventral surface of the brainstem.
11	Back	Field observations: Female. Shot from ~15 cm. Only brain tissue coming out of wound. Immediate death. Very little swimming reflex. Calvarium crushed on palpation. Radiographs: Numerous small, and some large, metal fragments in skull. Fracture of calvarium and of caudal region of skull. Macroscopic examination: Complete fracture of occipital bone, including base of skull; severe fracture of left and right frontal bones and parietal bones, and of right temporal bone.
12	right side	Field observations: Male. Shot from ~1 m above right eye, but blood spurting out from a wound several cm caudally. Immediate death. No swimming reflex. Bone fragments in caudal region of calvarium on palpation. Radiographs: Numerous small metal fragments in skull. Fracture of calvarium and of petrosal part of right temporal bone. Macroscopic examination: The only hole found “above” the right eye was the ear; a hole of traumatic origin was found several cm caudally. The animal may have been bleeding from the right ear. Severe fracture of right side of occipital bone, of whole base of skull, and of right parietal and temporal bones; fracture of base of left part of occipital bone.