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Reduction of seal-induced catch and gear damage by modification of trap-net design: Design principles for a seal-safe trap-net

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Abstract

During the last decade, seal-induced catch and gear damage have increased dramatically in the coastal trap-net fishery in the northern Baltic Sea. Our trials show that it is possible to markedly reduce seal damage by appropriate gear modifications and by careful choice of netting material. Five trap-net modifications and two traditional traps (four replicates of each) were compared under commercial fishing conditions. Modified traps were equipped with various types of fish bags made of strong seal-safe netting and a wire-grid in the funnel to prevent seals from entering into the bag. Four of the five modified models caught as much or more salmon as the traditional traps. In traditional traps, 30–50% of the total observed salmon catch was damaged. Trap modifications that were equipped with a fish bag made of double-layer netting held under tension offered the best protection; only 1–2% of the catch was damaged using these modifications. The proportion of seal-damaged catch varied between 16 and 27% for other modified trap designs. The use of thick and stiff polyethylene netting in the wings and middle chambers effectively prevented entangling of fish and thereby reduced their vulnerability to seal predation. Moreover, the seal-induced damage in the thick net was negligible compared with that of the thinner and more elastic nylon net of traditional traps.

Keywords: Grey seal; Trap-net; Catch damage; Gear damage; Mitigation of damage; Gear modification; Salmon; Whitefish

1. Introduction

Since the early 1990s, seal-induced catch damage has increased dramatically in the trap-net fishery for salmon (*Salmo salar*) and whitefish (*Coregonus lavaretus*) in the northern Baltic Sea, particularly along the coast of Gulf of Bothnia and Gulf of Finland (Baltscheffsky, 1997; Lunneryd and Westerberg, 1997; Westerberg et al., 2000; Kauppinen et al., 2005). Most damage is caused by the rapidly growing grey seal (*Halichoerus grypus*) population although the ringed seal (*Phoca hispida botnica*) also causes damage in the northernmost areas of the Gulf of Bothnia (e.g. Westerberg et al., 2000; Kauppinen et al., 2005). In the most affected areas, more than 50% of salmon catches are damaged by seals. Coastal fishermen consider seals to be a serious threat to their livelihoods.

The grey seal population in the Baltic Sea has been estimated at around 18,000 individuals (in 2004) and the estimated yearly growth rate for the population in the northern Baltic Sea is about 10% (Halkka et al., 2005; Stenman et al., 2005). Expanding seal populations are an increasing problem also for fisheries in many other areas along the northern Atlantic coast (e.g. Haug and Nilssen, 1995; Morris, 1996; Cairns et al., 2000; Moore, 2003).

In a traditional trap-net, seals can readily enter all parts of the gear. They can swim into the fish bag of the trap and eat and damage the catch. They can also remove the fish from such a bag. A seal can also easily eat or damage fish that are entangled in the netting of a trap-net, in any parts of the gear. It may also be able to damage the fish swimming inside the fish bag by lifting (outside) the bottom netting of the bag and chasing the fish into a netting corner, and then tearing and beating it through the netting. A seal can tear a hole in the

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fish bag, allowing fish escape through the hole. Fishermen have to waste substantial time at sea to repair gear damages. To effectively prevent seal damage, solutions are required for all potential damage-mechanisms.

In the early 1990s, fisheries scientists in the northern Baltic began to search for solutions to the growing seal problem by developing methods to scare away those seals that had become experts at feeding on fish caught in fishing gears (e.g. Westerberg et al., 2000). It soon became clear, however, that scaring seals away from fishing gear is not an easy task, especially in remote and exposed off-shore areas. It appeared that a more effective and practical way to reduce the seal-induced damage, at least in the trap-net fishery, is to prevent seals from entering the fish bag and thereby protect the fish already caught in the bag (Lunneryd and Westerberg, 1997; Lunneryd, 2001; Lehtonen and Suuronen, 2004).

Seal-safe trap-net modifications that have been tested in Sweden and Finland include a wire-grid installed in the funnel of a trap-net to prevent seals from entering through the funnel into the fish bag and various types of fish bags made of extra-strong Dyneema netting to prevent seals from entering the bag by ripping through the netting (e.g. Lunneryd, 2001; Lehtonen and Suuronen, 2004). Substantial progress in protecting catches from seals has been achieved, in particular with the so-called pontoon trap (see Lunneryd, 2001) that is in wide use in Swedish salmon fishery. However, it is a relatively complex and expensive gear, and its capture efficiencies for various fish species and various conditions encountered along the Baltic coast have not yet been proven.

In order to develop alternative gear modifications that are effective and practical in various conditions and for various species, a better understanding is needed of the effect of various gear design factors affecting fish and seal behaviour and their potential interaction during the act of capture. This study explores gear-related factors that markedly affect seal and fish behaviour in relation to a trap-net. The overall objective is to produce information and advice that would encourage and help the fishing industry to develop fishing practices and capture methods that minimize seal-induced damage, as well as reduce the incidental mortality of seals caught in gears.

2. Material and methods

2.1. Experiments in 2003

A trap-net is here considered to be a floating, bottom-anchored fishing gear. This concept includes traps where the fish bag is equipped with hoops, and traps with a large rectangular fish bag or house that is equipped with a roof-net. Depending on the type and material of a trap, fish may be guided and caught in the fish bag (i.e. by trapping) or they may become entangled or gill-caught (‘gilled’) in the netting of the wings, middle chambers and fish bag.

In experiments done in June 2003, six types of trap-nets were tested during the salmon spawning migration off the coast of Bothnian Sea, near Merikarvia (Fig. 1). All experiments were done under commercial fishing conditions in co-operation with four local fishermen. Each fisherman had all six trap-net models (Fig. 2) that were located randomly within his fishing grounds (Fig. 1). Two of the trap-nets (A and B) represented the traditional non-protected traps that are in common use along the Finnish coast of the Gulf of Bothnia. Four models (C–F) were modified and were equipped with a wire-grid in the funnel (wire diameter 2.5 mm) and a particular type of fish bag made of strong seal-safe Dyneema netting. All trap-nets had a similar type of leader netting made of stiff orange polyethylene (∼2 mm PE) netting of 300 mm full mesh size. The differences between experimental gears were in the design and/or material of wings, middle chamber, funnel and fish bag (Figs. 2 and 3). The most important design differences in the experimental traps were the following:

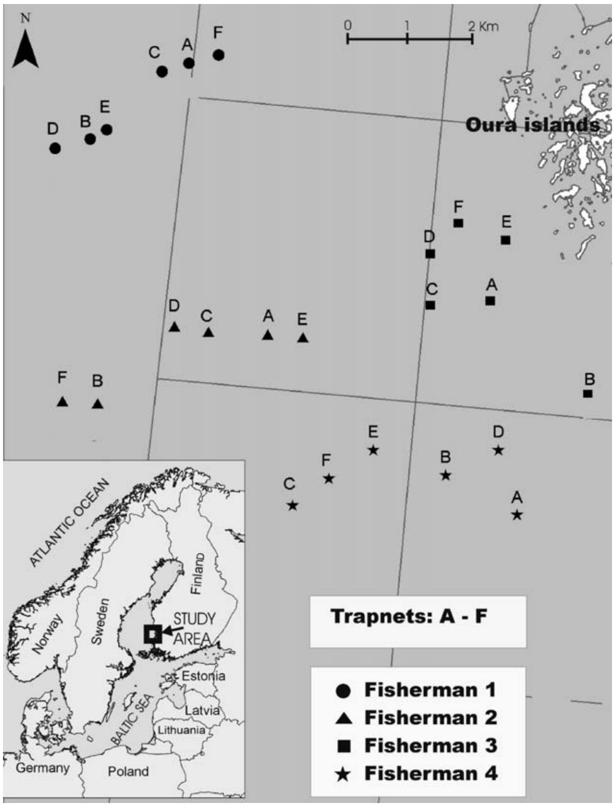

Fig. 1. Study area and the distribution of experimental gears in 2003 trials.

Model A: A conventional Bothnian Sea trap-net made of elastic multi-monofilament nylon netting designed to catch fish mostly by gilling and entangling in the wings, middle chambers, funnel and fish bag. The fish bag is relatively small. This type of gear is light, inexpensive, easy to handle, and its catching performance is good. Seals can freely enter all parts of the gear. Because fish are usually gilled, they are easily caught by the seal.

Model B: A traditional trap-design that differs from model A due to its capture principle that is based on catching and trapping the fish in the large fish bag. The fish bag and the

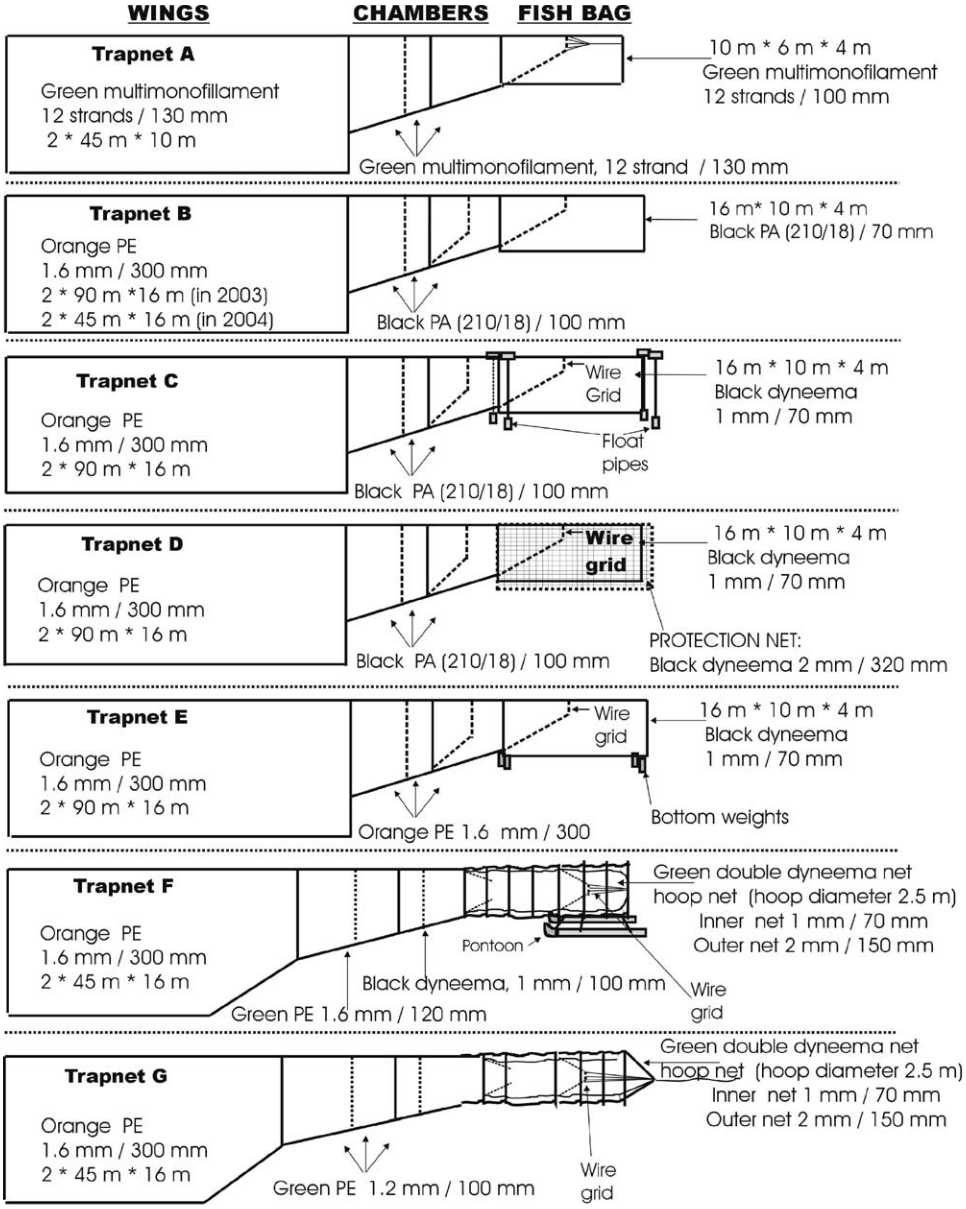

Fig. 2. Schematic view of the experimental gears (A–G) used in the 2003 and 2004 trials (not in scale). Mesh size is presented as full stretched mesh. All trap-nets had a similar type of 300–400 m long leader netting made of stiff large-meshed PE netting (leader netting not shown in the figure).

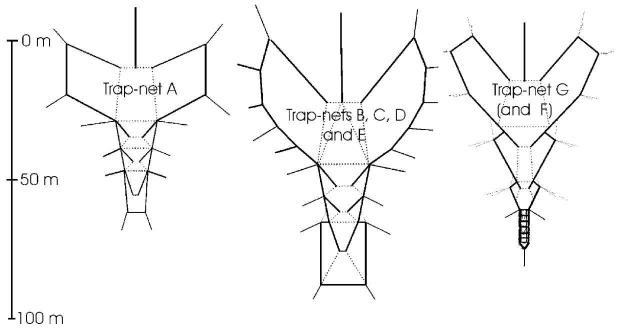

Fig. 3. General shape and anchoring of experimental gears (above view).

middle chambers are made of twisted polyamide-netting (PA). The wings are made of stiff PE-netting and they are rigged so that they effectively guide fish towards the chambers and fish bag (Fig. 3). As in model A, seals can freely enter all parts of the gear and can carry a fish away from the fish bag.

Model C (*pipe-trap*): This trap has a large Dyneema fish bag and is equipped with a large wire-grid (120 cm × 80 cm) with 20 cm wire spacing. The frame of the grid is made of 50 mm aluminum pipe (painted black). There is a floating anchor pipe in each corner of the bag (Fig. 4). These pipes have in their lower end a weight of ca. 25 kg that keeps them vertical and a chain-rope that is connected to the lower seam of the bag. Due to these pipes the netting of the bag is kept

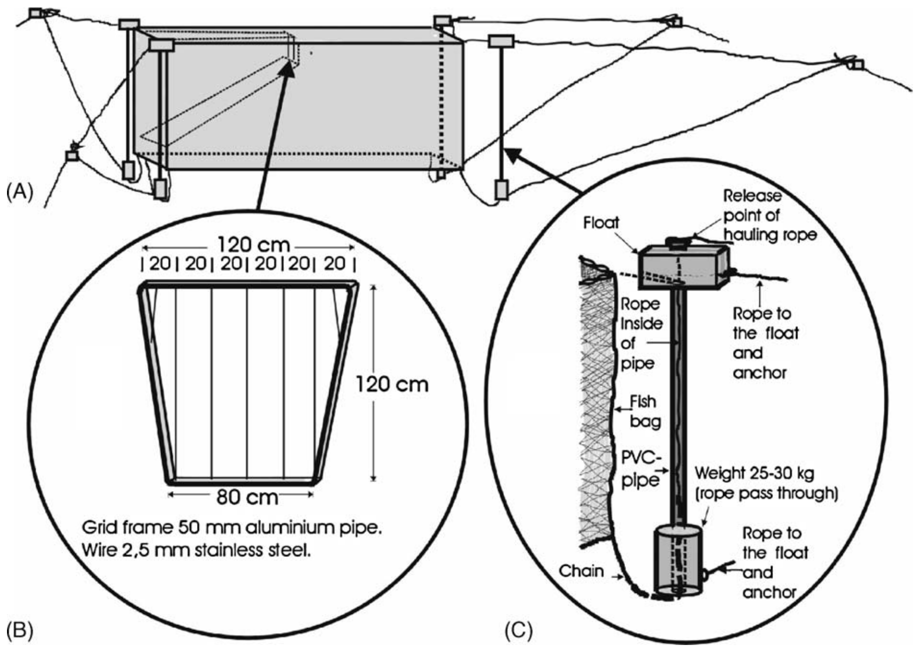

Fig. 4. The design principle and operation of the fish bag of a pipe-trap (model C). The large fish bag with the four anchor-pipes in the corners (A), the wire-grid installed in the funnel of fish bag (B), and the operation of an anchor-pipe that is holding the tension in the netting (C).

under tension. It was assumed that seal cannot lift the bottom net from below or push from the side, and rip or beat the fish inside the bag through the netting. The rope-release system allows fisherman to haul the gear in a normal way, i.e. by lifting it up. The middle chambers and wings are equal to model B.

Model D (*protection-net trap*): This trap is similar to model C except that instead of the float pipes there is a large-mesh protection net (Dyneema) rigged around the fish bag (Fig. 2). The outer netting has small weights at the bottom to keep it off the inner netting; however, there is no rigid system to keep the two nettings separate. The idea was to test whether such a relatively loose large-meshed netting around the fish bag would prevent seals from attacking fish through the netting (i.e. from outside) and whether such a construction would be practical.

Model E (*large-mesh trap*): The basic construction of this design is similar to model C and D (excluding float pipes and protection net). Extra weights (15 kg) are attached at the bottom corners of the Dyneema fish bag to prevent seals from lifting the bag outside. The middle chambers are made of large-meshed (300 mm full mesh) and stiff PE-netting. The idea with this large-mesh net was that when seal is present, fish being pursued by seal would be able to quickly escape through the net. This is assumed to discourage seals from visiting the gear (see Lunneryd et al., 2003). It was further assumed that when seal is not present, the fish would follow the large-mesh net into the fish bag.

Model F (*pontoon trap*): This trap-model has been designed in Sweden (see Lunneryd, 2001). The basic principle to prevent seal-damage in the fish bag is the double-netting held separate and under tension with the help of a rigid aluminium frame. Seals cannot enter the inner small-mesh netting wall of the bag because of the outer large-mesh protection netting made of strong Dyneema. There is a small (40 cm × 40 cm) wire-grid in the funnel with 20 cm wire spacing, i.e. one wire vertically attached in the middle of the grid. The funnel and the rear part of the middle chambers are made of Dyneema netting and the front part of chambers of stiff PE-netting (Fig. 2). The middle chambers are rigged so that there are no steep netting angles that may disturb fish when escaping an attacking seal (Fig. 3). The wings are made of large-mesh PE-netting and there is no bottom netting. This trap has a pontoon-system below the bag that allows an easy and rapid hauling of the gear with help of air compressor (it is commonly called a push-up trap).

2.2. Experiments in 2004

Further experiments were done in June 2004 in Merikarvia in co-operation with the same fishermen as in 2003. Two of the three experimental trap-net models, B and F, were similar as in 2003 trials (except that in model B the length of wings were only half of that used in 2003 trials and a bottom netting was included in the wings of model F). The third trap-model, a new design, was the following:

Model G (*folded-hoop trap*): This trap-net has a double net fish bag (Dyneema) where the netting is held under tension with help of 2.5 m hoops (Fig. 2). During capture, the bag is kept horizontally stiff by help of an anchor that is fixed at its end. The middle chambers are made of PE-netting (not as thick as in model F). The rigging of chambers is designed so that there are be no steep netting angles that may disturb fish when avoiding an attacking seal (Fig. 3). There is a small (40 cm × 60 cm) wire-grid in the funnel with 18.5 cm wire spacing. Wings are equipped with bottom netting.

In 2004 trials, each of four fishermen had the traditional model (B) and the folded-hoop model (G). In addition, two fishermen had the pontoon trap (F). That is, there were only two examples of this latter model in 2004 trials. As in 2003 trial, traps were located randomly within the fishing grounds of each group.

2.3. Recording and analysis of data

Generally, traps were hauled once a day. Catch, catch and gear damage, and entangling or gilling of fish was recorded in detail for each experimental gear for each haul by the FGFRI staff. All salmon caught were weighed and measured (total length). Where a part of the fish had been eaten by a seal, the weight was estimated on the basis of the length. Salmon that had no seal-induced damage or had only such slight damage that it had no effect on its market-ability were classified as undamaged salmon. The potential catch damage caused by seabirds was not separated from seal-induced damage. However, the damage to fishes observed in this study were of the type typically caused by grey seal (see Kauppinen et al., 2005). Hauls with no catch or remains of damaged fish were excluded when analyzing the seal-induced catch damage proportions.

The 2003 data were analysed as for weeks 23–26 (i.e. the first 4 weeks of June 2003) when all experimental gears were set out simultaneously. The effect of trap-net location was tested with one-way ANOVA. No statistically significant difference in catch rates and seal-induced catch damage was observed between different locations ($p > 0.05$) for any particular trap-net model. Hence, the differences between the models could be tested with statistically relevant methods.

The differences in measured parameters between the gear-models were tested with repeated measures ANOVA. These data were analysed as weekly gear-related mean-values. Tukey's *B* test was used for pair-wise post hoc comparisons. Because of very small catches in the large-mesh trap (model E), data from it were excluded from the statistical test when assessing the proportion of total damaged catch.

In 2004 experiments, major failures were observed in the construction and rigging in the funnels of the folded-hoop traps. These failures were partly corrected during the first 2 weeks of June. The data from these traps were therefore analysed only for June 10–29. Because of the small number of hauls, large number of hauls with no catch, considerable variation in catch, and unequal number of test gears (only two pontoon traps), it was not possible to do reliable statistical tests on the 2004 data. These data, however, are worth of presenting here because they help to interpret the 2003 results and they include a new gear model (G) that was developed on the basis of 2003 experiences. This model was considered to have considerable interest for the development of an effective, practical and inexpensive trap modification.

3. Results

3.1. Quantity of salmon caught (catching efficiency)

Four of the five modified trap-net models caught as many, or more, salmon than the traditional models. In 2003, the total observed average salmon catch (undamaged and damaged fish) caught by the different models differed significantly (ANOVA $F_{5.18} = 5.108$, $p = 0.04$). Model E represented the poorest catch (on average only 0.5 fish/haul) and Tukey's *B* test shows that it differed significantly when compared with models B, C and F (Fig. 5). There were no significant differences in the average number of salmon caught between the other models (1.8–2.4 fish/haul).

When counting only those fish that were caught in the fish bag, there was a significant difference between the models in the 2003 trials (ANOVA $F_{5.18} = 7.454$, $p = 0.01$). That is, these results were similar to whole gear examination except that in addition to trap-model E, there was low catch also in model A fish bag and also it differed significantly from models B, C and F fish bags.

In 2004, the average number of salmon caught by the pontoon trap (7.1 fish/haul) was about twice as high as by the folded-hoop trap (3.4 fish/haul) (Fig. 5). The poorest average catch in the 2004 trials was observed in the traditional trap-net (model B, 2.5 fish/haul).

The average size of salmon captured in 2003 and 2004 was 5 kg, the largest fish weighing about 20 kg.

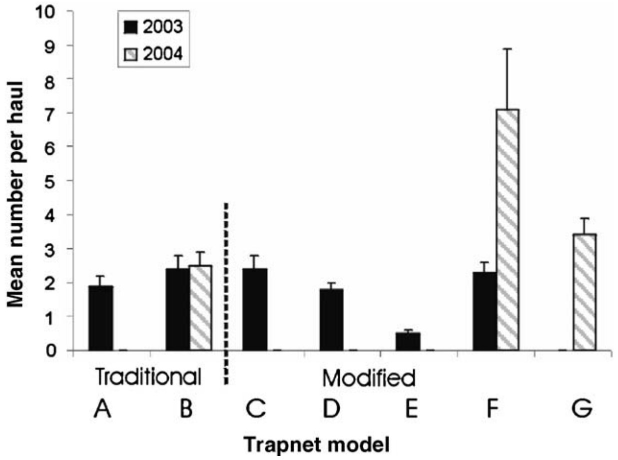

Fig. 5. Average total salmon catch per haul (in numbers) in experimental traps (A–G) in 2003 (black columns) and 2004 (striped columns) trials. The catch presented here includes all fish observed in all parts of the traps, and also those damaged by seal. Error bars indicate one standard error (S.E.) of the mean. C, float-pipe trap; D, protection-net trap; E, large-mesh trap; F, pontoon trap; G, folded-hoop trap.

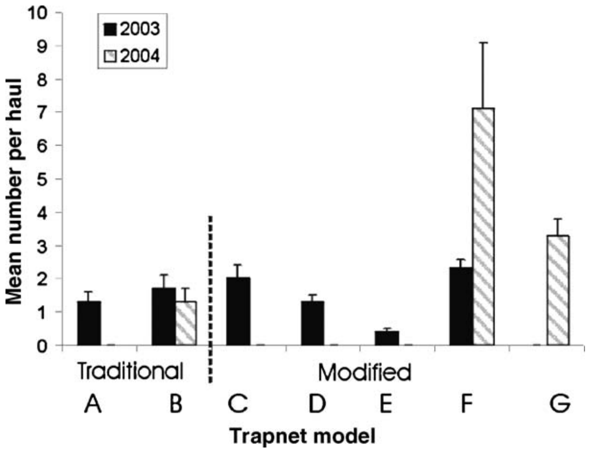

Fig. 6. Average undamaged salmon catch per haul (in numbers) in various trap-models in 2003 and 2004 trials. The catch presented here includes all undamaged fish observed in all parts of the traps. Error bars indicate one standard error (S.E.) of the mean. C, float-pipe trap; D, protection-net trap; E, large-mesh trap; F, pontoon trap; G, folded-hoop trap.

3.2. *Quantity of undamaged salmon caught*

In the 2003 trials, there were significant differences in the average number (ANOVA $F_{5.18} = 3.347$, $p = 0.026$) and weight (ANOVA $F_{5.18} = 3.029$, $p = 0.037$) of undamaged salmon caught per haul between the trap-models (Fig. 6). The pontoon trap (F) had the highest average undamaged catch per haul (2.3 fish/12 kg). The second highest undamaged catch (1.9 fish/10 kg) was taken with the pipe-trap (C). The lowest average undamaged salmon catch per haul was caught with the large-mesh trap (model E; 0.4 fish/2.3 kg). This trap differed significantly from the pontoon trap (F) in numbers and in weight of undamaged catch.

In the 2004 trials, the highest average undamaged salmon catch per haul was caught with the pontoon trap (7.1 fish/40 kg; Fig. 6). The second highest undamaged catch was caught with the folded-hoop trap (3.3 fish/16 kg). With the traditional trap-net (B) the average undamaged catch was at the same extent as in the 2003 trials (1.3 fish/8 kg).

3.3. *Proportion of salmon catch damaged by seal*

In 2003, there were significant differences in the proportion of seal-damaged catch per haul between the trap-models (ANOVA $F_{5.18} = 4.778$, $p = 0.011$). In the traditional non-protected traps (A and B) on average 30% of the total observed salmon catch (in numbers) was damaged by seals (Fig. 7A). In the pontoon trap (F) the average proportion of seal-damaged salmon was only about 1%. Tukey's B test showed that the proportion of total damaged catch in the pontoon trap differed significantly from both traditional models (A and B). In the pipe-trap (C) the average proportion of seal-damaged catch was 19%, and in large-mesh traps (E) 16%. In the protection-net trap (D) the proportion of damaged catch was 27%.

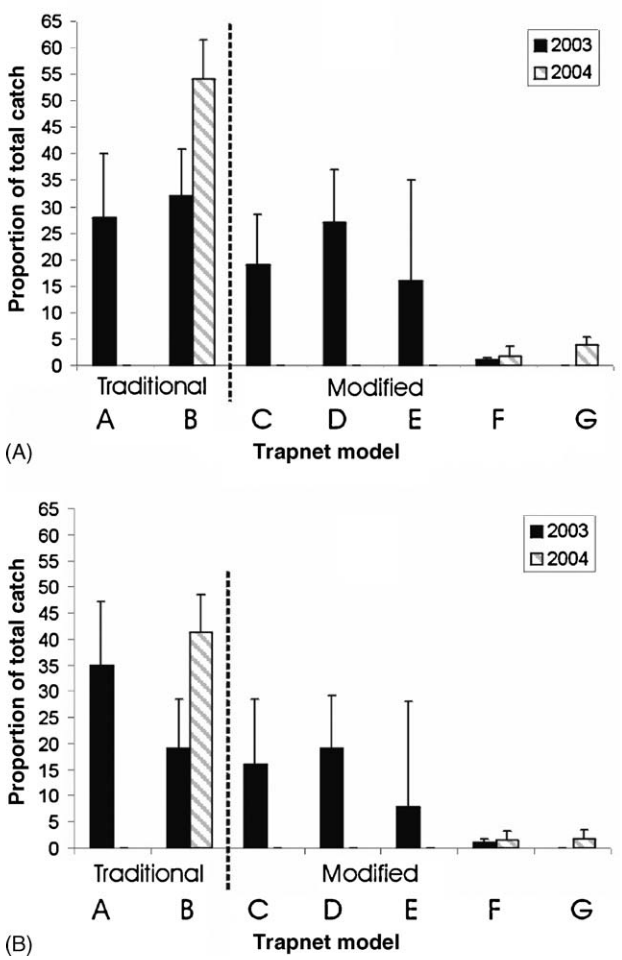

Fig. 7. Average proportion of seal-damaged salmon (in numbers) of the total catch in the gear as a whole (A) and in the fish bag (B) in the experimental traps (A–G) in 2003 and 2004. The numbers cover all those salmon that were damaged by seals and observed in the trap. Error bars indicate one standard error (S.E.) of the mean.

In 2004, there was substantial variation in the proportion of seal-damaged salmon catch between the traditional trap-net and the two modified trap models (Fig. 7A). In the traditional trap (B), the proportion of damaged salmon was, on average, as high as 54%. In the pontoon trap (F), the proportion was at the same level as in 2003, on average 2%. In the folded-hoop trap (G) it was 4%.

When comparing catch damage only in the fish bag (Fig. 7B), trap model A differed in the 2003 trials from all other models in that the damage proportion was higher in the fish bag (35%) than in the whole gear (28%). Hence, the few fish that were caught in the fish bag of this model were highly vulnerable to seal predation. In model B, catch damage in the fish bag was at the same 20% level as in the pipe-trap (C) and protection-net trap (D). In 2004, the proportion of damaged catch in the fish bag of model B was twice as high as in 2003 (Fig. 7B). In contrast, catch damage in the fish bag of the pontoon trap (F) was as low as in 2003. It is notable that the average catch damage in the fish bag of the folded-hoop trap

Table 1
Proportion of salmon catch (in numbers) observed as entangled in the middle chambers of various trap-net models (A–G) in 2003 and 2004 trials (in case of trap-net model A, the numbers also include the fish captured in the wings)

	Year			
	2003		2004	
	%	S.E.	%	S.E.
A (traditional multi-monofilament)	84	4.2	–	–
B (traditional twisted nylon)	21	9.4	20	9.8
C (pipe-trap)	25	9.1	–	–
D (protection-net trap)	28	11.9	–	–
E (large-mesh trap)	0	0	–	–
F (pontoon trap)	0	0	1	0.5
G (folded-hoop trap)	–	–	2	1.8

(G) was very low in the 2004 trials, less than 2%, i.e. at the same level as in the pontoon trap.

3.4. Distribution of salmon catch among various parts of the traps

The netting material in various parts of a trap-net played a marked role in the capture process and seal-protection. In 2003, a total of 84% of all salmon caught in the traditional trap-net model A were observed in the middle chambers and wings (Table 1). That is, most of those salmon were tangled or gilled in the net before reaching the fish bag. They were often eaten by seals and sometimes only remains were left hanging on the meshes or lay on the bottom net. In the pontoon trap (F) and large-mesh trap (E), where the middle chambers and wings were made of stiff PE-netting, there were no fish entangled or gilled in those nettings; practically all fish were caught in the fish bag. In models B, C and D, that had middle chambers made of twisted nylon, on average of 21–28% of all the salmon captured were observed in the chambers, and they were mainly entangled or gilled. In these traps the wings were made of stiff PE-netting and there were no fish entangled there.

In 2004, the results were similar to those of 2003. In the traditional non-protected trap-net (B) about 20% of all the salmon caught were observed to be entangled in the middle chambers that were made of twisted nylon (Table 1). In the pontoon trap and folded-hoop trap, where the middle chambers were made of thick and stiff PE-twine and designed with no steep netting angles, the proportion of fish caught in the chambers was 1–2%.

3.5. Distribution of seal-induced gear damage in different parts of the traps

The netting material also affected the location and severity of damage caused to the gear by seals. They damaged mainly those sections of a trap where the fish were entangled or gilled. Strong and thick materials were more resistant to the attacks of hunting seals.

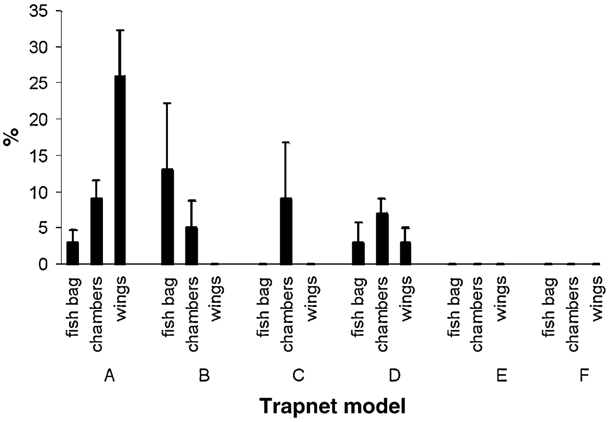

Fig. 8. Seal-induced gear damage frequencies (hauls when damage was observed) in different parts of the traps (A–G) in 2003 trial.

In 2003 there was very little seal-induced gear damage in the fish bags made of Dyneema netting (models C–F; Fig. 8). Likewise, there was no gear damage in the middle chambers (models E and F) and wings made of PE-netting (models B–F). The most frequent gear damage was observed in trap-model A that was made of elastic multi-monofilament nylon. Damage was observed on average on every fourth haul, and mainly in the wings. In the B-model where the fish bag was made of twisted nylon (PA), gear-damage in the bag was observed on average on 13% of the hauls. In the middle chambers made of twisted nylon (models B, C and D) damage was observed in around 5–10% of the hauls.

Gear damage in the 2004 trials was similar to that experienced in 2003. There was no damage in the wings made of PE-netting (trap-models B, F and G). Damage frequency in the middle chambers of the folded-hoop trap was almost negligible (less than 4%) and negligible in pontoon trap (less than 0.5%). Both models had the chambers made of PE-netting and they were designed and rigged with no steep netting angles. In the traditional trap-model B where fish bag and chambers was made of twisted nylon, damage frequency was 26%.

4. Discussion

Our trials showed that it is possible to reduce seal-induced catch and gear damage markedly by appropriate gear modifications and by careful choice of proper netting materials. Three of the five modified trap-net models showed promising results in terms of seal-protection. The pontoon trap (model F) was the most successful design; seal-induced catch damage was almost insignificant, the capture efficiency of salmon was very good and the hauling of the gear was very easy. However, the disadvantage of this design is the high price; the majority of coastal fishermen are not able to purchase this gear unless they are economically supported.

The folded-hoop trap (model G) also showed promising results although it was a prototype tested first time in 2004. Seal protection was almost as good as in the pontoon trap but

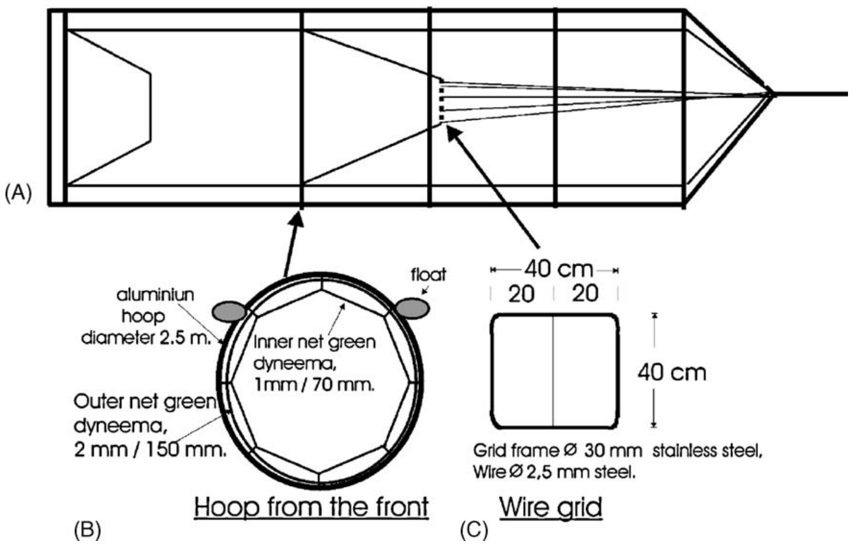

Fig. 9. General construction principles of a seal-safe fish bag using hoops to keep the two layers of netting under tension and separated (modified from the G-model). Side view (A), transection view (B) and the construction of a wire-grid attached at the end of the funnel (C).

catching efficiency was only about half as good. This was likely because of the problems encountered in the design and rigging of the funnel of this trap. In addition, hauling of the folded-hoop trap, especially in poor weather condition, was more difficult than that of pontoon trap. It is likely, however, that catching efficiency and hauling technology of the folded-hoop trap can be improved by further testing. The folded-hoop trap can be manufactured by the fisher and is markedly cheaper than the pontoon trap.

Our observations with trap-models F and G support the view that marked improvements in seal-protection can be obtained by building the fish bag of double-layer netting that is held under tension. The tension can most easily be attained by using rigid hoops. The upper large-mesh protection net has to be made of strong Dyneema netting or netting material with the same strength. Fig. 9 summarizes the major design principles that can be used in designing a low-cost seal-safe fish bag for a trap-net. The dimensions of the bag can be adjusted depending on the conditions and fish species in question but the space between the inner and upper netting has to be at least 20 cm. The gap has to be even larger if the netting is not tense.

Our results show that stiff and thick netting material should be used in all those parts of the trap where fish could be gilled or entangled in the netting. Materials in which fish become entangled are most prone to seal-induced damage. This is in line with the observations of Lehtonen and Suuronen (2004) and Kauppinen et al. (2005). In addition, rigging of wings, middle chambers and funnels should be designed so that there are no steep netting angles which may disturb fish when avoiding an attacking seal. All corners should be as rounded as possible to guide the fish as fast as possible into the fish bag, where they are protected against seal attacks.

The design of a wire-grid installed in the funnel of a trap-net is critical for a seal-safe trap-net to work properly. The grid has to prevent all sizes of seals from entering the fish bag but it should not inhibit fish from swimming into it. Our results suggest that the wire spacing has to be less than 18 cm to prevent young grey seal squeezing through the grid into the bag. It is noteworthy, however, that it is not possible to totally prevent the passage of the smallest grey seals (typically pups) through the wire-grid unless the wire-spacing is perhaps less than 15 cm. However, such a small space may dramatically reduce the capture efficiency of the gear, at least in case of salmon. In a salmon trap-net the grid has to allow large (up to 20 kg) fish to pass through the wires (see also Lehtonen and Suuronen, 2004).

It is worth noting that in the type of wire-grid we used, the height of the openings should not be more than about 40 cm. If it is higher, seals can squeeze through the space by pushing the wires slightly apart. Consequently, if the grid frame is higher than 40 cm, it should be divided into compartments that are only 40 cm in height. This can be done by horizontal wire or Dyneema twine that is tightly attached in the vertical wires. It is worth noting that adult grey seal can exert very high forces when attempting to enter through the wire-grid into the fish bag. The wire-grid has to be very strong and it should maintain the tension in the wires even when a 250 kg seal is ripping them.

Our visual observations during the study suggest that the wire-grid should be as stable as possible. If the grid moves too abruptly for instance due to the waves, it apparently frightens fish, so that they are reluctant to swim through the wires (see also Lehtonen and Suuronen, 2004). In the pontoon trap the vertical movement of the fish bag and grid is greatly dampened by the large pontoons that are below the bag. Moreover, the rigid frame further helps to keep the system stable and the funnels open. The high stability in rough sea conditions is likely one of the major reasons for the high capture efficiency of this gear type. It is notable that in the pontoon trap fish swam into the bag through a very small wire-grid (frame 40 cm × 40 cm). A small grid can apparently be used if it is stable and the funnels always remain open. In a large fish bag where the wave-induced vertical movement of the bag cannot be prevented, the funnels and the grid must be larger (120 cm × 120 cm or 80 cm × 120 cm).

The colour and the contrast of the wire-grid may play a marked role in the capture efficiency of a trap-net. Our observations suggest that a black grid-frame may have a too high contrast against the water surface. Fish may, in some circumstances, be reluctant to swim near the grid and through the wires, reducing the capture efficiency of the gear and making fish highly vulnerable to seal attacks. Aluminium appears to work better in most conditions; probably because of its lower contrast. However, the grid-frame should not be too bright because glittering-light may also disturb fish. Apparently, the overall construction, colour pattern, and the rigging of the grid can still be improved in many ways to improve the capture efficiency and to prevent the entrance of young seals into the fish bag.

The mesh size of wings and middle chambers may play a role in the seal-protection. Lunneryd et al. (2003) showed that large-mesh netting in the chambers may help salmon to escape through the netting when being pursued by seals. They speculated that seal might soon become uninterested of such a trap and leave it. However, the results of our large-meshed trap (model E) trials were not very encouraging from the capture efficiency point of view, as catches were substantially lower than in other models. Apparently fish captured in the chambers swam through the large meshes to open water. This is in contrast to Swedish observations where salmon appeared to be reluctant to pass through large-mesh nets (Lunneryd et al., 2003). Our design, however, was not identical to that of Lunneryd et al. (2003).

It is notable that the non-rigid pipe-trap (model C) showed promising results in our 2003 trials (technical problems prevented the proper testing in 2004). Seal protection was not quite as good as with the pontoon trap and folded-hoop trap but it was markedly better than in other designs. It is worth noting here that the proportion of slightly damaged salmon was substantially higher in the pipe-trap (14%) than any other models (on average 3%). Apparently, anchor pipes keep the netting of the fish bag under some tension; this makes the attack of seal through the netting more difficult but does not prevent it completely. This design had a practical disadvantage though; it took substantial extra time to haul the fish bag because fisherman has to release the pipe-ropes before hauling. The difference is particularly noticeable when compared to the pontoon trap. There is, however, substantial potential to improve the “anchor pipe” system.

It is noteworthy that some small grey seals that were able to squeeze through the grid into the fish bag of the pontoon trap were drowned. Fish traps should be designed and set out in the water in a way that seals inside the bag have access to the surface; and it is possible to release them alive.

There are several factors that may have caused bias in our experiments and analysis. For instance, the catches were relatively poor during the study period and the frequency of empty hauls was high. Therefore, the effect of random incidents into the results of statistical tests may have been high. There may also be a marked difference how well a catch-damage can be observed in various trap-net models. In the traditional models, a seal may carry a fish away from the bag without leaving any trace. Moreover, fish caught in the fish bag of a traditional trap can escape through a seal-made netting-hole. In the traditional model A where the fish were entangled and gilled in the netting of the wings and chambers, the remains of partly eaten fish may have easily sunk to the sea bed, leaving no visible traces of a seal’s visit to a trap. In the modified traps, seals generally could not enter into or tear the fish bag although in some cases seal could slightly damage fish from outside; these fish, however, have been observed with a high likelihood during the hauling. Clearly, the catch damage and eventual loss caused by seal may have been roughly underestimated in the traditional traps (see also Fjälling, 2005).

In conclusion, our trials show that it is possible to markedly reduce the seal-induced catch and gear damage by appropriate gear modifications and by careful choice of netting material. However, further research is needed to develop designs that keep (or scare) seals away from the wings and middle chambers of trap-nets, or allow fish to take other safer routes to the bag. More efforts should also directed for testing approaches that would make the finding of fishing gears more difficult for seals. With seal populations expanding, there may soon be no coastal areas in the Baltic where static fishing gears are safe from seal attacks. If effective mitigation measures for seal-induced damage are not found, the conflict between the protection of seal stocks and the existence of the coastal fishery will become very serious. The seal-fishery conflict in the northern Baltic is already extremely severe and complex, and it will soon touch all countries bordering the Baltic Sea. The problem requires rapid, practical and sustainable solutions and gear modification appears one of the most promising mitigation tools in this conflict. It is notable that by replacing gill-nets by seal-safe trap-nets may solve at least some of the problems faced by the coastal gill-net fishery, where seal-damages are extremely difficult or impossible to prevent.

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