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Male gray seals specialize in raiding salmon traps

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ABSTRACT

In the Baltic Sea there is a severe conflict between small-scale fisheries and gray seals. One fishery severely affected by seal predation is the salmon trap fishery. Underwater cameras were placed in two pontoon traps to study the behavior of raiding gray seals. Seals observed on film were identified and a catalog of 'problem' seals was created, totaling 11 individuals. As part of this study, 8 pontoon traps modified for live-trapping raiding seals were set out in the same area. Trapped seals were killed and their markings photographed in order to try to match them with seals in the catalog. The eleven identified seals were responsible for 426 out of 600 visits to the two traps with cameras. Four of the eleven seals raided at least two traps and returned to raid traps frequently over the 2-year study period. Seals caught in the pontoon traps modified for live-trapping were mainly adult male seals. Three of these seals were identified as cataloged seals. This study has shown that it is generally adult male gray seals which have specialized in raiding fishing gear. These specialist seals have developed a characteristic behavior pattern and have persisted with it over a long period of time.

1. Introduction

The trap net fishery for salmon (*Salmo salar*), sea-trout (*Salmo trutta*) and whitefish (*Coregonus lavaretus* spp.) in the Baltic Sea is subject to severe levels of interference by gray seals, sometimes spelled as gray seals (*Halichoerus grypus*). Foraging seals cause both damage to fishing gear and catch losses. A new design of trap, which reduces their vulnerability to seal attacks (Lunneryd et al., 2003; Suuronen et al., 2006), was successfully introduced and implemented in this fishery in the 2000s (Hemmingsson et al., 2008). With this new trap design, known as the large mesh pontoon trap, the seals experience greatly reduced hunting success. However during recent years, reports of seals moving in and out of the trap entrances and trying to get into the fish chambers have become more common, indicating that there is still a problem in this fishery.

A prerequisite for finding effective mitigation measures is a detailed knowledge of the behavior of both seals and target fish in relation to the fishing gear. In situ studies can be carried out with the aid of underwater video recording; knowledge gained in this way was central in the development of the pontoon trap (Lunneryd et al., 2003). However, there remained several specific unanswered questions regarding the behavior of seals in and around fishing gear. One such question of immediate importance in the seal-fishery conflict is whether or not the gray seals raiding fishing gear are 'specialists'. Individuals with specialized behavior, often characterized as 'problem' animals, have been described in many studies, such as in Linnell et al. (1999) where support was given to the removal for management purposes of seals identified as 'problem' individuals. Graham et al. (2011) showed that the gray seals which specialize in foraging for salmonids in the rivers of the Moray Firth in Scotland, and which are labeled as 'problem' seals because they thereby come into conflict with fishing and angling interests, constitute less than 1% of the local gray seal population. Königson (2011) found that harbor seals (*Phoca vitulina*) raiding fyke nets off the west coast of Sweden were indeed the same individuals, repeatedly returning to the nets. If only a specialized and limited number of seals make a habit of raiding fishing gear, a promising management strategy would be to remove these individuals. Studies of seal behavior at salmon traps incorporating underwater photo-identification are therefore in the mitigation of this conflict.

Photo-identification techniques for marine mammals, involving recognition and recording of individual markings, have been developed and successfully applied to a number of species including both seals and whales (Würsig and Würsig, 1977; Katona and Kraus, 1979; Hiby and Lovell, 1990; Anderson et al., 2010). The photo-ID method has proved to be a reliable tool when applied to gray seals (Karlsson and Helander, 2005; Vincent et al., 2005;

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Gerondeau et al., 2007). It is mainly the markings on the head and neck of the seals which have been used as identifying features (Karlsson and Helander, 2005; Hiby et al., 2007; Vincent et al., 2005; Gerondeau et al., 2007). Almost all studies have been based on photos taken in air, although underwater photo-identification has been applied in the case of turtles (Schofield et al., 2008) and harbor seals (Königson, 2011). The present study is the first to use underwater photos (from video recordings) to identify individual gray seals.

Culling seals has been used for centuries as a mitigation measure for reducing damage to fisheries. When carrying out a seal cull, it is preferable to retrieve the carcases, both to ensure that the animals are in fact killed rather than injured and so that biometric data can be collected. Retrieval is complicated when it comes to marine mammals since they normally sink when dead, and as Baltic gray seals typically weigh between 100 kg and 300 kg, a general seal cull is not something to be undertaken lightly. It has been suggested that if trap-raiding seals can be shown to be specialists within the wider population, then selective culling of these individuals would be the most effective way of reducing damage to fisheries (Lunneryd and Fjälling, 2004; Lehtonen and Suuronen, 2010). For these reasons, both practical and ethical considerations led to a proposal to live-trap those seals raiding salmon traps in order to eliminate them in a controlled manner. In the second year of this two-season study, therefore, pontoon fish traps were modified to also function as seal traps. Seals caught in such traps could be expected to give important biometric information about the individual seals raiding the traps which is highly relevant for our understanding of the process. This data was therefore collected at the same time as we carried out the necessary procedures to gain type-approval of the modified trap. National agreements state that all new models of traps for catching and holding and/or euthanizing animals must be acceptable in terms of animal welfare. This means, among other things, that a pre-set number of trapped animals, in this case 20 individuals, must be examined for signs of stress and physical trauma before the traps can receive official approval.

The goals of the present study were: (i) to determine whether or not gray seals raiding salmon traps are ‘specialists’ who habitually raid such traps, (ii) to describe the pattern of visits of any identifiable seals, and (iii) to establish the biometric characteristics of the animals involved. After answering questions (i) and (ii) above, selective culling of specialist seals was introduced and some preliminary data on its effect on the fishery are also presented.

2. Materials and methods

In this study we analyzed and compared data from three sources; (a) a 2-year field study in which pontoon traps were filmed with underwater cameras in order to identify seals raiding traps, (b) a 1-year project identifying and examining seals live-trapped in specially modified pontoon traps and subsequently put down, and (c) reports from fishermen including fishing effort, fish catch data and notes on seal-induced damage to catch and gear.

2.1. Underwater filming in traps

The field study was carried out over two fishing seasons from June through August in 2006 and 2007, which is the time of the year when the salmon run peaks in the Bothnian Sea in the Northern Baltic. The study area is located about 300 km north of Stockholm, Sweden (Fig. 3). Trials were carried out in collaboration with local fishermen fishing for salmon, sea-trout and whitefish and using seal-safe pontoon traps (Fig. 2) (Hemmingsson et al., 2008; Lunneryd et al., 2003). The pontoon trap has several sections made from net panels. The leader net extends from the shore line and guides the fish to the entrance of the trap. The trap has ‘wings’ consisting of funnel-shaped sections, with gradually smaller openings. The trap wings are connected to the fish chamber, which consists of two sections, the entrance part and the actual holding chamber, which can be raised to the surface for emptying by means of inflatable pontoons. The entrance part is cylindrical, with a diameter of 2.8 m and a length of 6 m (Fig. 1). The entrance to this section is funnel-shaped and narrows to 700 mm by 700 mm. Seals may pass through all openings in the trap except the last one which leads into the holding chamber. This opening has a square metal frame with sides of 450 mm, divided vertically in the middle of the frame (225 mm from each side) by a 3 mm stainless steel wire to stop raiding seals wriggling through.

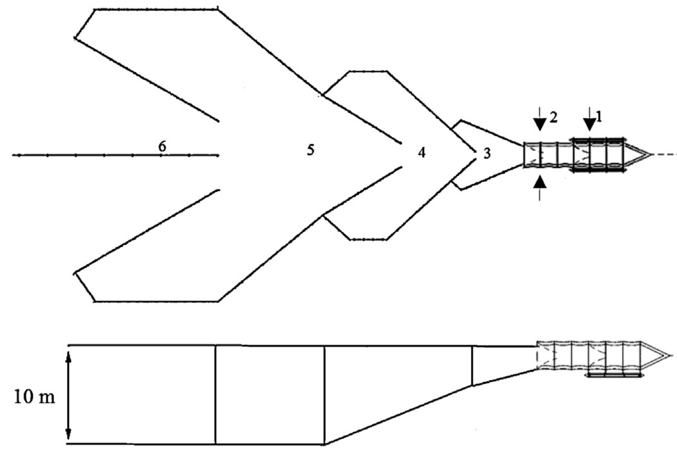

Fig. 1. Overall outline of the salmon pontoon trap, top and side view including the holding chamber (1) and the entrance part (2). These two sections are attached to a large mesh salmon trap consisting of: (6) leader net, (5) wings, (3–4) middle chambers. Arrows indicate camera positions.

In 2006 two traps were deployed at a distance of 3.3 nautical miles apart. The traps were each fitted with three digital cameras. Two of the cameras were positioned to cover each side of the opening to the entrance part from a distance of approximately 1 m, and the third camera was positioned to cover the opening to the holding chamber (Fig. 2) at the same distance. This arrangement allowed for a full body image of both sides of each seal to be recorded. If the seal tried to get into the holding chamber, a close-up of the head could also be obtained. In 2007 three cameras were mounted on a trap placed at one of the locations used in 2006. The video system in both seasons included monochrome Watec WAT-902H2 Ultimate cameras. Images were stored on a CamDisc Recorder with exchangeable hard disks of 80-200GB powered by a 12 V Global deep cycle gel type lead-acid battery. This allowed 36 h recording between charging. Recording was done at a frame rate of 3–4 frames per second, and a time-stamp was displayed in each frame. The

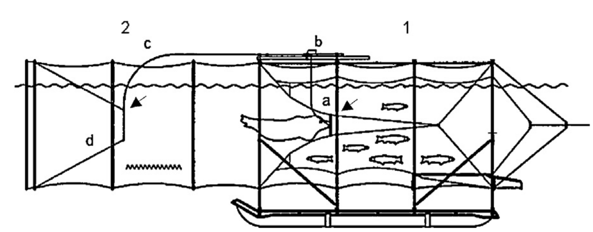

Fig. 2. Side view of the final section of a pontoon fish trap (the fish chamber) modified for trapping seals live, with the fish holding chamber (1) and the entrance part (2). The seal is caught in the entrance part. The triggering device is placed at the entrance to the holding chamber (a). The pneumatic closing mechanism including a GSM alarm (b), the trigger wire connecting the servo system with the closing mechanism (c) and the closable opening to the entrance section (d) are shown. Arrows indicate camera positions in pontoon fish traps without the modification for live trapping of seals.

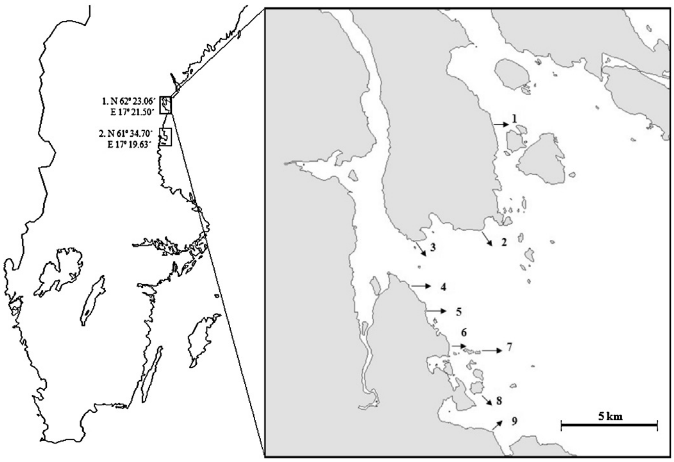

Fig. 3. Box 1 shows the location of live seal traps and camera traps used in the study. Arrows show position and alignment of traps. Trap 6 was equipped with cameras in 2006 and 2007. Trap 3 was equipped with cameras in 2006. Traps 1–5 and 7–9 were modified for live trapping of seals in 2007. Box 2 shows the area where traps modified for live trapping were set out in 2008.

recorder and battery were contained in a floating waterproof case (Pelicase 1620) fastened to the pontoon fish chamber by a line. The bright summer nights in this northern area and the sensitivity of the cameras allowed recording 24 h a day from mid May into late July without artificial lighting. The battery and the hard disk were exchanged once a day. The traps were lifted and the catch emptied approximately every second day, depending on the weather.

2.2. Live trapped seals

In the 2007 trials, a total of 8 traps used by five fishermen were modified to catch seals as they entered the traps. The modified traps were similar to traps trialed by Lehtonen and Suuronen in 2007. In these traps, as in the traps used in this study, the seals were caught in the entrance part so that the captured seal can still reach the water surface to breathe (Lehtonen and Suuronen, 2010). To modify a trap, the frame at the entrance to the holding chamber was fitted with a triggering device. The lower edge of the frame was hinged, and the top edge was connected by a wire to a valve controlling a pneumatic servo system which operated a closing mechanism on the opening to the entrance part (Fig. 2). After the live-trap system was set, a seal trying to enter the holding chamber would activate the trigger and the servo system, causing the opening to the entrance part to be shut, thus confining the seal. At the same time, an alarm (SRT290) would be activated, transmitting a text message via GSM to the experiment supervisors. Care was taken to float the holding chamber well in order to secure free access to the water surface for the trapped seal to breathe freely. The modified traps were set out in the middle of June in the vicinity of the traps equipped with cameras, within a radius of 6.4 nautical miles (Fig. 3). At the end of July, the triggering mechanisms were disarmed so that no further seals could be caught while fishing continued. In another area about 24 nautical miles further south, two more traps were likewise modified to catch seals and were operated from the beginning of June until the middle of August 2007.

All seals caught in 2007 during the testing of the trap were put to death and photographed before transportation to the National Veterinary Institute where they were weighed and the sexes determined. In 2008 the seal traps were type-approved by the Swedish Environmental Protection Agency. Fishermen began to set out traps in the beginning of June that year, at the start of the salmon fishing season. Seals caught in 2008 were sent to the Swedish Museum of Natural History in Stockholm for examination, where they were sex determined, weighed and aged and the blubber thickness was measured on male seals. The most northerly trap to catch a seal was placed at 62°28′N and 17°41′E, and the most southerly one was at 61°28′N and 17°16′E (Fig. 3).

2.3. Identification and activity of identified seals

Video recordings were manually screened. All sequences with seal or fish activity were given a code based on trap number, time of day, and camera position, and saved as separate files. All seal activities observed were classified and data were saved to a database in Excel. For each seal visit, a series of frames was extracted from the respective film sequences and saved as still photos in jpeg format for ID-analysis purposes.

Well focused and clear photos of the seals were selected to build up an ID catalog. Video sequences that were of insufficient quality, due to murky water or poor light conditions, were not included.

Several photos, including views of both sides of the seal, were usually available for each seal visit. We selected three to five identifying features to characterize an individual, most often distinct patterns of limited size on specific parts of the seal's body, such as 'a dark clover-shaped pattern just below the right flipper' encircled in the last picture in Fig. 4. As the catalog was built up, new images of visiting seals were compared manually to the existing records. A seal was deemed to be identified when at least three features matched the identifying features described in the catalog If only one or two features matched, the seal was considered unidentified and was not included in the analysis. If it was not possible to match any of the features of a visiting seal to any of the individuals' features in the catalog, it was entered as a new individual. Videos are provided as supplement and are available online.

2.3.1. Test of minimum number of identifying features

A trial was conducted to determine whether a minimum of three identifying features on a seal was sufficient to provide a reliable match with any of the seals in the catalog. From our collection of seal photos, we selected those featuring seals which had been positively matched using at least three ID features and also those featuring seals which could not be matched at all and remained unidentified, thus excluding the group of partially identified seals. From this selection we created three sets of test samples. The first set consisted of 40 randomly chosen photos of seal visits each displaying one seal showing only one identifying feature. The second set consisted of photos of 35 randomly chosen seals displaying two matching features each; some seals had two photos in order to show both ID features clearly. The third set consisted of 33 seals displaying three identifying features each. Each sample was then matched to the seals in the catalog by both the researcher and, separately, by her assistants, using one, two or three identifying features as provided in the three different sample sets. The researcher's results from all three tests were then compared to the assistants' ID matches for the set with three identifying features. The consistency between the researcher's and the assistants' matching results was measured using kappa statistics. (Cohen's kappa measures the agreement between two raters who each classify a number of items into categories. An index κ is calculated using the observed data to determine the probabilities of each worker randomly choosing each category. If the raters are in complete agreement then $\kappa = 1$. If there is no agreement among raters (other than what would be expected by chance), then $\kappa \leq 0$).

2.3.2. Test of consistency in matching seals

A test was carried out to investigate the consistency of matches between the assistants and an experienced researcher. Sets of photos showing different views of a seal visiting the trap were collected from 44 randomly selected film sequences of visiting seals, i.e. 44

Fig. 4. An example of photos taken from a seal visit, showing the same seal from different angles. One of the seal's clear identifying features is encircled in the last photo in the row.

sets of photos from 44 film sequences. These photos were presented to an experienced researcher as a new sample. The researcher then compared the photos in the sample with those in the ID catalog already prepared by the research assistants, by matching the identifying features in the sample photos with the features described for the cataloged seals. Cohen kappa statistics were used to measure the agreement between the scores obtained by the research assistants and the researcher.

2.4. Reports on catches and seal interactions

The fishermen involved in the field study reported catches, damaged catches and soak times for each emptying of a trap according to specified protocols both in 2006 and in 2007. In 2006 the fisherman reported his catches from four traps and in 2007 from seven traps. Data were quality controlled by research staff who joined fishing trips, counting and measuring the catches. The frequency of reports of trap emptyings which included seal interactions (i.e. with evidence of damage to gear or predation on fish in the trap) was compared before and after the elimination of the seals caught in the modified traps. Frequencies were compared with Fisher's two-tailed exact test.

3. Results

3.1. Underwater filming in traps

The traps were filmed during 113 days for a total of 1907 h (Table 1) in which time 600 seal visits were recorded. The visits lasted for a total of 185 min. Most seal visits in 2006 were made to trap 3. Visits to trap 3 comprised 141 min and visits to trap 6 of 26 min (Table 1). In 2007 seal visits to trap 6 added up to 17 min. Well focused and clear photos of the seals possible for identity matching were obtained during 90% (1721 h) of all hours filmed.

3.2. Live trapped seals

In 2007, 11 seals were caught in five of the eight seal traps situated in the main experimental area and nine seals were caught in traps in adjacent areas. In 2008, an additional 18 seals were caught by fishermen and dispatched to the Museum of Natural History. All captured seals were found to be sub-adults or adults. 36 of the 38 trapped seals were males (95%), with a clear dominance of adults over 10 years of age (Table 2). The two females were adults, weighing 103 kg and 154 kg respectively. The largest female was aged to 19 years.

Table 1
The number of days and hours the trap were filmed and the number of days when seals were observed on film in the different traps.

Trap	Year filmed	Hours filmed	Days filmed	Days with observed seal visits	Number of visits
Trap 6	2006	881	47	31	428
Trap 6	2007	506	34	23	89
Trap 3	2006	520	32	16	83

Table 2
Median, 25th and 75th percentiles of investigated parameters from 36 male gray seals captured in a seal trap in connection with a pontoon trap.

	Age (years) ($n = 23$)	Weight (kg) ($n = 33$)	Blubber thickness (mm) ($n = 18$)
25%	11	112	25
75%	16	144	50
median	12	129	40
max	22	172	70
min	4	66	18

3.3. Identification and activity of identified seals

3.3.1. Test of minimum number of identifying features

The researcher matched the three sets of test samples (comprising photos of seals showing one ID feature in the first set, two in the second set and three in the third set) to the cataloged seals; the matching agreed almost perfectly with the assistants' matching. Two ID features were equally as effective as three in matching a seal accurately to the catalog, while accuracy dropped off slightly with only one feature (Table 3).

3.3.2. Test of consistency in matching seals

The matching of photos agreed closely among raters ($\kappa = 0.94$). In the two cases of mismatch, the researcher scored 'unknown seal' while the assistant scored 'identified seal'.

3.3.3. ID matches

In 426 out of the total of 600 filmed visits (71%), the visiting seal was matched to a seal already in the catalog or added to the catalog as a new seal. At the end of the experiment, the ID catalog included 11 seals each having three distinct features. In 129 visits (21.5%), seals could not be identified due to low quality of the photos, caused by murky water, poor light conditions or the

Table 3
The agreement between the researchers and the assistants' results when the researcher was shown test samples with one, two or three identifying features.

Test sample	κ
One identifying feature	0.86
Two identifying features	0.97
Three identifying features	0.97

Table 4
Number of days the different traps were visited by the identified seal and number of visits to the traps. The total number of days the trap was visited by the identified seal as well as the total number of visits is shown in the last row. The seals identified in the seal traps are also shown in the table given the letter S for seal and numbers in following order. The seals with bolded idnumbers are the seals revisiting more than one trap. The id number followed by a star is the seals caught in a trap modified for live-trapping.

Identified seal	2006				2007	
	Trap 3		Trap 6		Trap 6	
	Days	Visits	Days	Visits	Days	Visits
S1	2	7				
S2	2	7				
S3	1	3				
S4	2	5	2	4		
S5	3	12	1	1	4	7
S6*			8	78	1	4
S7*			12	97	4	9
S8*			5	42		
S9			7	132		
S10					4	4
S11					4	14
Total	10	34	35	354	17	38

seals presenting an awkward angle to the camera. In three visits (0.5%) only one or two known identifying features were seen. In 42 visits (7%) it was determined that the seal in question did not have any of the cataloged seals' identifying features but nor did it have the minimum number of three different identifying features which would have added the seal to the catalog. Therefore these seals were characterized as new individuals but not included in the analysis.

All 11 seals caught in seal traps in 2007 were photographed before disposal. The photos of 8 of the trapped seals were of acceptable quality for ID-matching. Three of these seals, caught in traps 8 and 9, were first cataloged visiting trap 6 (Table 4: seals S6, S7 and S8). Two of these seals were recorded in 2006 as well as in 2007. A fourth seal visited both traps 3 and 6 in 2006 as well as trap 6 again in 2007 (S5). Consequently, four seals (S5, S6, S7 and S8) were raiding at least two traps and continuing to raid traps over the two seasons.

3.3.4. Patterns of activity in identified seals

In 2006, ten of the eleven identified seals returned to the traps for new raids during a 2-day period, and one seal visited one trap several times on one single day. The individual seals' activity patterns varied. Some seals were active over a short time period while other seals were active over the whole fishing season (Table 5). Seal visits were most frequent at the middle of the salmon fishing season, which is during the first half of July. Some seals (S5, S6, S7 and S8) who were the most frequent visitors returned to raid the same trap in subsequent years and also raided different traps at different times. The seal (S9) that paid the highest number of visits to trap 6 in 2006 was active during only 3 days at the beginning of the season.

3.4. Reports on catches and seal interactions

The frequency of reports of seal interactions from traps in the experimental area where seals were eliminated decreased significantly after culling began in 2007 (Fisher's two-tailed exact test; $p < 0.05$). During the whole of 2006 and the first part of the 2007 season traps were emptied 142 times and damaged salmon and whitefish were noted 8 times. From the 5th July 2007, when the seal culling began, until 5th August 2007, traps were emptied 95 times without any reports of damaged fish.

4. Discussion

The present study has successfully used underwater photos and video recordings to identify individual gray seals and study their behavior in the vicinity of fishing gear, even though it is a difficult task. Apart from the obvious technical challenges, certain difficulties are inherent in matching photos, potentially leading to both false positive and false negative matches (Hammond et al., 1990). Carlson and Mayo (1990) showed the importance of using experienced workers during photo-identification in order to minimize matching errors. In this study the research assistants who analyzed the ID photos very quickly became familiar with the seals' identification features, so that they could easily recognize the individual seals. Our tests also showed that three identifying features were, in most cases, more than enough to identify a visiting seal. All in all, underwater photo-identification proved to be a useful method for identifying individual seals trying to raid fishing gear.

The hypothesis that only a small proportion of the individuals in a predator population are 'problem' or 'rogue' animals, so-called either because they specialize in certain prey items or feed in areas also exploited by commercial interests, or because they come into conflict with human interests in other direct ways, has been suggested many times (Linnell et al., 1999; Graham et al., 2011; Sukumar, 1991). However there are not many examples of the hypothesis being tested, partly because, among other things, this requires repeated identification of individual animals. There are however studies which show specialized behavior in seals. Graham et al. (2011) found that a small proportion of a population of gray and harbor seals returned repeatedly to the same rivers to prey on salmon. It has also been shown that seals return repeatedly to the same foraging location at sea (Bjorge et al., 1995; Tollit et al., 1998).

The results of the present study are consistent with the results from the Scottish study in that a few individual seals specialize in using certain areas for foraging. They also support the more explicit 'specialist' theory, i.e. that a few individual gray seals specialize in raiding fishing gear during their foraging. A small number of seals did indeed return to the same salmon traps to feed and this behavior continued over two seasons. These 11 seals were responsible for a large number of the seal visits (426 out of 600). The seal population in this area is counted annually at their main haul-out area 45 miles south of the study location; 11 seals represent less than 1% of the population in this area (personal communication, Olle Karlsson). There was also an individual variation in activity patterns; according to the observations on film, five seals returned to the trap 20 times or more and according to both film observations and records of trapped seals, four of them returned in the second seasons of the study period. The remaining six seals returned sporadically over shorter time-periods.

One conclusion from this study is that the specialist seals can be expected to carry on with their behavior indefinitely or at least over extended time periods. We do not know the number of specialist seals or if this number is increasing at the same rate as the total population. What is certain is that both the Baltic gray seal population (Hårding et al., 2007) and the seals-fisheries conflict have increased in recent years (Baltscheffsky, 1997; Kauppinen et al., 2005; Westerberg et al., 2006).

The finding that most captured seals were males (95%) fits well with data from a seal cull carried out in the vicinity of fishing gear (salmon traps) in 1997, where all culled seals were adult males (Westerberg et al., 2006), as well as with a study on seal traps carried out in Finnish waters (Lehtonen and Suuronen, 2010). It should be noted that in all these cases, culled seals were actively searching out, or entering into, salmon traps, whereas in other data sets from by-catch studies, seals just passing by may have been randomly trapped in, for instance, gill nets. This may be one explanation why Bäcklin et al. (2011a) found the sex ratio in by-caught gray seals

Table 5
The activity of the identified seals are shown as the number of visits per week by the different seals in traps 3 and 6 equipped with underwater cameras in 2006 and 2007. The seals id number followed by a star are the seals caught in a trap modified for live-trapping.

Year	Trap	Identified seal/week	24	25	26	27	28	29	30	31	32	Total visits *Total hours filmed*
2006	3	S1								7		7
	3	S2								7		7
	3	S3							3			3
	3	S4			5				1	3		9
	3/6	S5			10/1	1/–			1/–			12/1
	6	S6*				54		5	14	5		78
	6	S7*				54	2	13	27	1		97
	6	S8*				7	29	1	5			42
	6	S9			123	8				1		132
	3/6	*Hours filmed*	*–/71*	*–/69*	*74/105*	*69/149*	*12/71*	*124/95*	*106/105*	*57/114*	*–/19*	*442/798*
2007	6	S5			1	6						7
	6	S6				4						4
	6	S7				5	3	1				9
	6	S10			4							4
	6	S11						14				14
	6	*Hours filmed*	*–*	*20*	*55*	*73*	*115*	*117*	*93*	*8*	*–*	*481*

(all types of fishing gear) to be less skewed (62% males) than in the present study, however there was still a correlation with age (50% males at age up to 3, and 75% males at age 4 or more). The general opinion among experienced fishermen in the North Baltic Sea agrees that it is mostly large males which visit fishing gear. It has been shown in several mammal species that males are over-represented in depredations on livestock, e.g. individuals trapped or shot during depredation attempts (Linnell et al., 1999; Sukumar, 1991). Gray seals are polygynous and the males are likely to have a greater variance in reproductive success than the females. This may well lead to a selection pressure favoring a high risk-high gain strategy for the males (Sukumar, 1991; Trivers, 1985). Raiding traps can be seen as high risk behavior because of the vicinity to human activity as well as the risk of getting entangled in the fishing gear. Sjöberg and Ball (2000) found that smaller, inexperienced gray seals concentrated on exploration while large adult animals focused on exploitation of the resource already identified. The behavior of the adult male seals in this study fits this model in that they repeatedly returned to the traps to forage.

The blubber in the captured animals in this study was thicker than in that found by Bäcklin et al. (2011a) in by-caught seals, which were referred to as 'starving'. This may indicate a successful specialization, especially in light of the current general decline in blubber thickness in gray seals which began about 5–10 years ago (Bäcklin et al., 2011b). This trend may be the result of a rapid population development, and an increased pressure on the fish resource reducing the availability of food. In this situation an increased search for alternative food sources can be expected. This is evident at a smaller scale each year in that in the late fall when fish are more scarce in general, seal attacks on fishing gear become increasingly severe (Fjälling, 2005; Fjälling et al., 2006).

After the first season of this study it was already clear that we were indeed dealing with specialist trap-raiding seals and in the second season we were able to live-trap and cull the individual seals concerned. No further seal raids were reported by fishermen in the month following the cull. This dramatic improvement to the seals-fishery conflict could have been partly due to seasonal variations, but the most likely conclusion from the results is that eliminating specialist seals does indeed have a positive effect.

The main conclusion from this study is that some individual adult male gray seals specialize in raiding fishing gear. Only 11 seals were identified as being responsible for the vast majority of trap visits. A few trap-raiding seals may have been missed through not being positively identified (7% of visits) and a few may have slipped through in the photos discarded due to insufficient quality, but still the trap raiders are unlikely to represent more than 1% of the local population. A logical measure to reduce seal induced losses in the fishing industry would be to eliminate these specialist seals. This strategy is shown to be both possible and effective: the fishermen's reports indicated a significant decrease in seal damage after the culling of specialist trap raiders began.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2013.07.014.

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