The conflict between grey seals (*Halichoerus grypus*) and the Baltic coastal fisheries -

new methods for the assessment and reduction of catch losses and gear damage

Cover picture: Grey seal (*Halichoerus grypus*) taking fish from a herring net. A four camera system with CamDisc Recorder and HelTel Player software was used. Photo S. Königson. September 2004.

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ABSTRACT

There is a problematic interaction going on between grey seals and the small scale coastal fisheries in the Baltic. A large number of seals are by-caught and drowned each year, and the viability of the fishery is threatened by catch losses caused by the seals. Traditional mitigation methods are not sufficient, or have in some cases not been properly evaluated. Available methods of quantifying and analysing the catch losses are also insufficient. This thesis consists of three parts, each studying a different angle of this conflict.

In the first part, new models for estimating catch losses are presented. In addition to the commonly used method of counting the number of damaged fish in the nets, the new models also allow for an estimation of the hidden losses. Hidden losses may be fish that are completely removed from nets without leaving any traces, fish that escape through holes in the net torn by the seals, or even fish that are scared away from the fishing gear. Such losses were found to be significant, and hence it is now clear that the traditional models seriously underestimate the total losses. The new models also allow for a deeper analysis of the interaction process. The first presented model compares catches between adjacent days (day-pairs), the second uses nets that are pre-baited before deployment, and the third relies on a detailed inspection and repair of all seal-induced damage to the net meshes.

In the second part, some traditional methods of mitigating the conflict are evaluated. A commercially available Acoustic Harassment Device was tested in a field trial. AHDs were deployed at several set-traps for salmonids for three consecutive years. The damage reducing effect was persistent throughout a season, as well as over the full three-year test period, and no “dinner bell” effect was observed. When seal attacks became frequent in the 1980´s, several of the traditional salmon traps were reinforced with newly developed extra strong net materials. These materials dramatically reduced the damage to the nets, and to some degree also the catch losses. However, the losses were still substantial, and the traditional gear was gradually phased out when better solutions emerged.

In the third part, new methods of mitigating the conflict are evaluated. A salmon trap was built, using net meshes which were large enough to allow seal-chased fish to escape through, but which would still guide and confine non-stressed fish. The trap was fitted with a fish chamber with a double wall of very taut netting, separating the catch from the surroundings by a fixed distance. Interference by seals was significantly reduced with this construction. Field experiments revealed that seals used their above-water vision to locate and search out buoys of the type that are used in the fisheries. Larger buoys were more readily found than smaller. A set of trials was initiated where certain geographical areas were made unattractive for seals prior to their seasonal arrival to the region, by deploying stationary AHDs. Finally, aquarium experiments demonstrated that underwater vision and hearing were equally important in seals’ detection of fish in a test box. It was also found that there was a “near zone”, within which seals stayed focused on a fish and attempted to catch it by a quick thrust of the head. These studies strongly suggest that new seal-safe fishing gear and mitigation methods should be based on, and would benefit from, an in-depth understanding and analysis of natural seal behaviour.

List of papers

I. Fjälling, A. 2005. The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap salmon fisheries. ICES Journal of Marine Science 62:1630-1635.

II. Königson, S., A. Fjälling, and S-G. Lunneryd. Grey seal induced catch losses in the herring gillnet fisheries in the north Baltic. *Manuscript.*

III. Fjälling, A., M. Wahlberg, and H. Westerberg. Acoustic Harassment Devices (AHD) for salmon trap nets in the north Baltic. *Submitted manuscript.*

IV. Lunneryd, S. G., A. Fjälling, and H. Westerberg. 2003. A large-mesh salmon trap; a way of mitigating seal impact on a coastal fishery. ICES Journal of Marine Science 60:1194-1199.

V. Fjälling, A., J. Kleiner, and M. Beszczyńska. Grey seals use above-water vision to locate baited buoys. *Manuscript.*

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INTRODUCTION

History

The conflict between seals and fisheries is world-wide and of ancient date. The first written record from the western hemisphere is found in classical literature (Oppianus A.D. 225). In Baltic waters the first records are from the 1660´s (Bromans 1954b). Over the next 200 years there were occasional written comments on the conflict, such as by Linné in his "Lappländska Resa" in 1732 (Linné 1796) and Cederholm (1778). The seal interaction at this period was seen as a nuisance, but was probably an accepted part of the conditions of being a fisherman. This was especially so since the seal itself was a very valuable resource, yielding meat, oil and pelts. The importance of this resource is indicated by records kept by the crown of individual skerries along the coast of the Bothnian Sea which were consistently used by seals as haul-out sites. Based on these records, landowners were obliged to pay a yearly tax to the crown for these assets, whether or not they were actually used by the seals. This coastline is subject to rapid isostatic rebound following the last ice age (nearly 1m/100 years), which in time obliged the seals to abandon the skerries registered as haul-outs. This did not, however, lead to the fishermen being relieved from paying taxes for those skerries. There were cases where the landowner had to sell his farm to pay the tax, or the community had to pay the tax when the landowner could not (Bromans 1954a).

The first attempts to collect data on the extent of seal damage in Swedish fisheries were made in the 1890´s (Lundberg 1895, Lönnberg 1898) and Ekman (1908). At this time the conflicts between seals and fisheries were increasing drastically. This is evidenced by a surge in newspaper articles in the late 1800´s and early 1900´s (Westerberg et al. 2000). The problems at this time probably coincided with a peak in the population of the Baltic grey seals. This had increased as a result of a drop in seal hunting some decades earlier (Ekman 1910), and reached about 100,000 animals just after the turn of the 19th century (Hårding and Härkönen 1999). The gillnet fisheries for herring (*Clupea harengus*), salmon (*Salmo salar*) and whitefish (*Coregonus spp.*) were most severely effected. Problems were also considerable in the set trap fishery for salmonids, and in the gillnet fishery for cod (*Gadus morhua*; (Ling (1895). To mitigate these problems, extensive hunting was resumed, supported by a bounty for each seal killed. This was a successful action from the fishermen's point of view, which led to a significant reduction of the seal population, and the seals-fisheries interaction was no longer an important issue.

Then, in the middle of the 20th century, high levels of bio-accumulating organochlorines (DDT, PCB) were found in grey seals (*Halichoerus grypus*) and ringed seals (*Phoca hispida*) in the Baltic Sea. These compounds caused severe damage to the reproductive organs of the females, making them infertile (Helle et al. 1976, Bergman and Olsson 1986, Olsson et al. 1994), and this led to a further, uncontrolled decrease in the grey seal population. In spite of legal protection in 1975 (Anon 2001b), the decrease continued and a count around 1980 revealed a total of only about 3,000 grey seals. Fortunately, since then the organochlorine pollution in the Baltic has been substantially reduced, which has allowed the grey seal population to recover (Hårding and Härkönen 1999, Halkka et al. 2005, Karlsson and Helander 2005). In 2004 the counted number of grey seals in the Baltic was 17,640 (Halkka et al. 2005). Their recovery, however, was linked to high and increasing levels of conflict with fishermen (Baltscheffsky 1997, Westerberg et al. 2000, Lunneryd 2001, Fjälling 2004, Kauppinen et al. 2005). Problems have been most accentuated in the small scale coastal fisheries. The increasing seal-induced problems in this fishery since about 1990 have played a part in the low recruitment and the subsequent reduction in the numbers of fishermen (Anon 2001c, Bengtsson and Brantäng 2002). The increase in seals-fisheries conflicts seems to be a repetition of what took place almost precisely one hundred years ago. However, this time an extensive seal hunt will not be considered as a solution. Other means to mitigate the conflict are required.

Seal biology

There are three seal species in the Baltic; the grey seal, the harbour seal (*Phoca vitulina*) and the ringed seal. They all belong to the family of true seals (*Phocidae*). The three species differ in food preferences, behaviour and physical features. It is mainly the grey seal which causes damage and losses in the commercial fisheries. The grey seal is an obligate piscivore and is the largest of the three species. An adult male may weigh 300 kg and a female up to 200 kg. The Baltic grey seals make seasonal migrations. During the summer the larger part of the population is distributed north of 59ºN. The part of the population that is resident south of 59ºN is relatively small and has a lower population growth than the northern part (Karlsson and Helander 2005). Grey seals tend to remain in one locality, but periodically they make long and rapid (>100 km/day) migrations to new areas, especially the males (Sjöberg et al. 1995). The young are born during February and March. The young are nursed for only 3-4 weeks and are then abandoned and mating takes place. The adults' moulting takes place for some weeks during May to June. During this period, grey seals spend most of their time on ice or land and do not forage much. Therefore, conflicts with the fisheries are minor at this time. Also, their main food source, herring, is abundant at this time of the year and into the early summer. During the late summer and autumn the grey seals' food consumption increases considerably as the blubber layer is built up for the coming winter. The interaction with fisheries therefore increases markedly with the progress of the season. The amount of fish consumed per day is dependent on its energy (e.g. fat) content, but an average daily intake of 4–7 kg is a commonly accepted figure (Rae 1960, Mansfield and Beck 1977). The composition of the diet, deduced from stomach remains, was studied by Söderberg (1974). Herring, cod, salmon and sea-trout (*Salmo trutta*) were found to be the most important food items of the 21 fish species encountered. In a recent study (Lundström et al. 2005), herring, whitefish and sprat (*Sprattus sprattus*) were found to be the most important of 24 fish species. The replacement of cod by other species, found in the latter study, is explained by the sharp decline in the cod population in later years. The grey seal is opportunistic and exploits the local fish fauna, so variations in diet reflect the habitat being exploited. It is clear that preferences in grey seals and in humans overlap.

The conflict at a general level

The conflict with the fishing industry is multi-faceted and complex. The interaction cuts two ways – fishing affects protected species (by-catch mortality) and the protected species affects the fishery (Table 1). These effects can be divided into direct and indirect effects, and the former can be further subdivided according to whether they act on the individual level or on the system or population level. Also, when mitigation methods are applied, secondary effects occur. If one tries to pursue the issue to the detailed level, it soon becomes very complicated (Table 2).

Table 1. Principal table over seals-fisheries interactions

Interaction		**Fishery → Protected species**	**Protected species → Fishery**
Direct	Ecosystem level	Depletion of food resources through over fishing	Competition for fish resources Impact on fish reproduction
	Indivudual level	Accidental by-catch	Damage to catch and gear Loss of fishing areas
Indirect		Disturbance in sensitive areas Noice	Increased prevalence of parasites Inaccessible protected areas

Table 2. Attempt at a detailed account of the seals-fisheries interaction

Class	Group	Symptom	Cause	Result for fisherman	Economic consequences reduced income	 increased costs	 variation
Primary operational effects	Damage to catch	reduced catch	fish consumed by seals	fish lost to fisherman and to fishery	x		
		reduced catch	fish fallen off gear	fish lost to fisherman and to fishery	x		
		reduced catch	fish escaped	fish lost to fisherman	x		
		damaged fish	fish partially eaten by seals	fish of reduced value or worthless	x		
	Fishing disturbed	reduced catch	fish diverted by seals	fish lost to fisherman	x		
		baits gone	seal takes bait from gear	temporarily lessened fishing efficiency	x		
		reduced catch	fish avoid fishing gear / seals	fish lost to fisherman	x		
		seal near gear	avoiding bycatch of seals	fishing time lost	x		
		bycatch	seal in gear or aboard	fishing time lost	x		
				risk of injuries to crew		x	
				risk of product boycott	x		
			outselected small fish taken	risk of reduced fish recruitment			
	Damage to gear	torn net	gear damage by seals	temporarily reduced efficiency	x		
				labour and material costs for repairs		x	
				permanently reduced efficiency	x		
				expected life time of gear reduced		x	
				gear destroyed		x	
		tangled net	seal interference	temporarily reduced efficiency	x		
				fishing time lost while untangling	x		
		drive line damage	seal caught in propeller	fishing time lost, cost of repairs	x	x	
			seal bringing gear into propeller	fishing time lost, cost of repairs	x	x	
		reduced catch	smell traces	temporarily reduced efficiency	x		
Secondary operational effects	Adaptions of fishing	gear change	modification of existing fishing gear	investment in material		x	x
				labour, investment and ?		x	x
				temp / perm reduced efficiency	x		x
			new gear	investment in material		x	x
				labour, investment and ?		x	x
				permanently reduced efficiency	x		x
		method change	more frequent lifting of gear	fishing time lost	x		
				increased fuel costs		x	
				less fishing gear in operation	x		
			use of inshore fishing grounds	less productive waters	x		
			new (or distant) fishing grounds	rebuilding gear for new ground		x	
				increased fuel costs		x	
				less fishing time due to travelling time	x		
			shortened season	reduced fishing time	x		
			new fishing methods	learning, implementing	x	x	
				temp / perm reduced efficiency		x	
			increased variaton in catches	planning more difficult	x	x	x
Biological effects	Predator interaction		fish frightened away from area	temp / perm lower fish catch in area	x		
			fish density decrease in area from pred	permanent decrease in catch in area	x		
			competition for the resource	permanent decrease in catch	x		x
			predators induce lowered growth in fish	permanent decrease in fish production	x		
			fish behaviour changed	reduced efficency			x
			competition threatens populations	long-term risks			x
	decreased quality		scars and damage to flesh of fish	fish of reduced value or worthless	x		
			parasite infections	fish of reduced value or worthless	x		

In the case of grey seals in the Baltic, the direct effect on the fisheries dominates the debate, rather than competition over the total fish resources. The most severe damage and losses are reported from the Gulf of Bothnia. They are most pronounced in coastal fisheries with static fishing gear, such as the set trap fishery for salmon, sea-trout and whitefish, and in the gill net fisheries for herring and whitefish. Fisheries using active fishing gear, such as trawling, are less affected. Losses are largest in the late summer and autumn. Seal-induced losses in the entire Swedish fishing industry were assessed in 1997 at approximately US $3 million (Westerberg et al. 2000). The annual increase was proportional to the increase in the seal population. Direct catch losses and indirect costs in 2005 were estimated at more than US $7 million, amounting to 15-20 % of the annual catch value of the entire Swedish coastal fishery

(Westerberg et al. 2006). Additional costs relating to lost and damaged gear and reduced fishing opportunities were not included in this estimate. A disturbing part of the conflict is that a substantial number of seals are by-caught and drowned in the course of fishing operations each year. In 2001, the Swedish by-catch of grey seals was estimated at 462 individuals (360-575, 95 % c.f.; Lunneryd et al. 2003). Since the population increases at a high rate (Halkka et al. 2005, Karlsson and Helander 2005), by-catch of this magnitude cannot at present be considered a threat to the population. By-catch mortality, however, constitutes an ethical problem for society in general and a practical problem for the fishermen. In 2001, the Swedish parliament set as a goal that by 2010 the by-catch of marine mammals should amount to less than 1% of the respective total populations (Anon 2005). This goal is based on the expectation that modifications to fishing gear and the development of deterrent techniques will not only diminish seal-induced damage but also decrease the risk of by-catch. If these do not have enough effect, restrictions on the coastal fisheries might also have to be introduced.

Seal interactions in other fisheries

Fishing operations world-wide have become increasingly intense and efficient over the last hundred years, and fish resources are today generally considered to be over-exploited. In many regions the fishery sector is constrained by diminishing fish stocks and structural problems. This is valid also for Swedish coastal fisheries (Piriz 1999). Small scale fisheries often suffer both from these factors and from the seal conflict. Simultaneously, the public attitude to animals and the environment has changed, and this has resulted in restrictions on fishermen engaging in protective hunting. The seal conflict has become aggravated following the considerable increase in some seal populations (Hammond and Fedak 1994). Several studies of seal-fisheries interactions in the North East Atlantic have been made in recent years (Hammond and Fedak 1994, Henriksen and Moen 1997, Morizur et al. 1999, Anon 2001a, Bjørge et al. 2002). Marine fish farms, especially those farming salmonids, also face serious problems with seal interactions. This is true in Northern Europe, one example is Norway (Johansen and Elisassen 1999), as well as in other parts of the world (Pemberton and Shaughnessy 1993).

Some seal species are more often involved in conflicts with fisheries than others: in approximate order of ‘conflict potential’, the grey seal in the North West and the North East Atlantic, the harp seal (*Phoca groenlandica*) in the North East Atlantic, the northern fur seal (*Callorhinus ursinus*) in the North West Pacific, the Californian Sea Lion (*Zalophus californianus*) in the North East Pacific, and the South African fur seal (*Arctocephalus pusillus*) in the South East Atlantic. Another species, which causes at least some problems in the North East Pacific and the North East Atlantic is the harbour seal (Northridge 1984, 1991, Wickens 1995).

Current methods for the calculation of catch losses

In several reports on the ‘seals versus fisheries’ conflict, the percentage of damaged fish found in the catch is given as a measure of loss (see Wickens (1995). Such figures are often used to derive estimates of the overall impact on large scale fisheries, as in David (1987) and Wickens et al. (1992). Data on the number of seal-disturbed fishing efforts are also used. However, these data, important as they may be, give only relative estimates of the losses. Besides the obvious seal-induced catch losses (damaged fish), there are likely to be other losses that are hidden to the observer. Fish may be eaten whole by the seals, or remains of larger fish simply fall off the gear or are taken by other predators such as sea birds. Also, live fish contained in the fish chamber of a trap will readily escape through any holes torn in the net by a seal, leaving no traces to be recorded. The occurrence of such incidents was suggested by Mountford and Smith (1963), Greenwood (1981), Wickens (1993), and reported by Wickens (1995). Fishing trips with empty nets may often be looked upon as just days of poor fishing, which is an accepted part of the fisherman's everyday life. Sometimes, however, sudden low catches fall outside of established patterns, or there are other signs that indicate losses (e.g. no catches in spite of strong fish echoes on echo sounders, seal activity near the nets, or damaged fishing gear). It is then assumed that there are hidden losses due to seal activity. Attempts to estimate parts of these hidden losses were made by Potter and Swain (1979), referred to in Harwood and Greenwood (1985), and Westerberg et al. (2000). The major difficulty in assessing the total losses is to establish figures on the expected catch, i.e. what the catch would have been, had there been no seal interference. This figure, when available, can be compared with the landed catch, and hence give an estimate of the total losses. Estimating the expected catch is greatly complicated by the naturally very large spatial and time-dependent variations in fish catches.

How seals exploit fishing gear

There are several ways in which seals may take fish from traps. One of the most convenient must be to swim into the fish chamber (Bonner 1982). It is also common for seals to tear holes in the net to get to the fish inside a trap, as well as to catch and chew fish through the net (Anderson and Hawkins 1978, Bonner 1982). Seals will also easily take a fish from a gill net. Seals also use nets as traps by chasing fish on to them (Bromans 1954b). In fish farms seals have been observed to take a run from a distance of tens of meters and push the side of the net up to 4m into the pen, and then to grab fish through the net (Pemberton 1989). Similar observations were made by Lehtonen and Suuronen (2004) in salmon traps where seals lifted the netted bottom from below. Seals have been observed to climb over float lines (Mansfield and Beck 1977), and in fish farms over fences up to 1m high (Schotte and Pemberton 2000). Even when seals stay well outside a trap, there may still be negative effects on the fishery. Rae (1960) reported that seals were lying in wait near the leaders of salmon traps. Morris (1997) and Schotte and Pemberton (2000) reported from salmon farms that seals returned repeatedly to attack a particular spot on the netting. It seems clear that it is mainly male seals which attack fishing gear (Anderson and Hawkins 1978, Pemberton and Shaughnessy 1993, Sand et al. 1998, Hume et al. 2002). Males were also over-represented among seals by-caught in Swedish fishing operations (59% of all 621 by-caught grey seals that were analysed by the Swedish Museum of Natural History during 1965-2004 were males; $p<0.01$). It is a common saying among fishermen that some very large male individuals are responsible for causing extreme amounts of damage. They are impossible to scare off, yet are very wary to the presence of fishing boats. Hume et al. (2002) found that there also was a clear difference between seal species in the ways they tried to overcome predator protection systems in fish pens.

Gear development up till now

Historically, mechanical seal protection has been used in some Swedish fisheries: for example the fish bags on larger eel fyke nets were given a wooden cover. Other technical mitigation methods were however uncommon until recently (Westerberg et al. 2006). Salmon and whitefish traps have been the gear category subject to the greatest economic damage in the Swedish fisheries. This has to a large extent been as a result of the traditional trap design used in the northern Baltic, which permits or rather invites an efficient hunting strategy by seals. The seals chase the fish towards the trap, where they entangle themselves in the side panels and can then be taken easily. Materials used have been weak enough to allow seals to break in through the net panels. A typical approach to such problems has been to gradually make it more difficult for the seals, e.g. making net panels tauter, using stronger net materials, adding entrance obstacles etc. Initially much was gained in reducing the tearing of fish trap nets by changing to a new, stronger netting material (Dynema, approximately 4 times as strong, and expensive, as nylon). The levels of damage to the catch remained high however, as the seals soon learned to get into the trap through the entrance. This led to the introduction of different forms of entrance gates to keep the seals out of the fish chamber. As a result the seals learned to chase fish from the outside and to corner them in such a way that they could be chewed through the net. This kind of 'arms race' is typical when traditional fishing gear is modified to withstand seal raids. Such developments are perhaps necessary in the short term, but usually do not in themselves offer a long term solution. Another problem is that fish are sensitive, and even small changes in the fishing gear can lead to a marked loss of catch. This may cancel any gains made in protection against the seals.

Traditional attempts to modify seal behaviour

In earlier times shotguns were sometimes kept onboard fishing vessels and fired at seals near fishing gear. This did not often kill the animal, but caused painful injuries which probably led to the seal in question at least avoiding fishing boats. Other attempts to cause avoidance have been tried. Some years ago it was common practice in the Baltic to anchor a boat, sometimes fitted with a scarecrow, close to a trap. This was sometimes effective for a few days, but then the seals usually reappeared. Odorous substances have also been tried, with limited effects, but by far the most common deterrent method is to use sound. For some years in the late 1990s it was permitted to try to scare seals away from fishing gear by shooting at the water surface near them (hunting was forbidden at the time). This caused a loud sound upon impact, above and below the water surface. It achieved only a limited deterrent effect, however. Also, since the fisherman tried to shoot as near the seal as possible, the method involved a serious risk of injuring the animals. Underwater playback of killer whale sounds was shown to have a short term effect on harbour seals on the Swedish west coast, but no effect at all on grey seals in the Baltic (Bisther pers. comm. 2005). This can presumably be explained by the fact that killer whales do not occur in the Baltic, and hence the grey seals lack personal experience of killer whale attacks. A large number of experiments with different kinds of deterrent sound sources were reviewed by Jefferson and Curry (1996). They found that essentially all audible disturbances gave a short-term avoidance effect, but that habituation was usually quite rapid. Indeed, an opposite effect could arise, the sounds coming to act as a 'dinner-bell', attracting the seals to the fishing gear. The only category of acoustic scaring devices which, at least to some degree, seemed to work over time was the so-called Acoustic Harassment Device (AHD), which produces signals strong enough to cause pain when the seal comes too close (Yurk and Trites 2000, Terhune et al. 2002). Most of the experiments with AHDs, however, were made in aquaculture operations and only a few in open sea fisheries. Jefferson and Curry (1996) implicitly stated that these kinds of experiments generally lacked a thorough scientific approach as to design and evaluation, and stressed the need for such studies. Hence, there are apparently several uncertainties as to the real long term effects of AHDs in the open seas.

Background to the present study

In 1994, the Swedish government decided to change the direction of the seal management policy away from paying annual damage compensation to fishermen and towards seeking long-term solutions. The task was not small since the problems were by then already widespread and intensifying. It was acknowledged that development work of this kind required a sound scientific foundation. An umbrella project called Seals & Fisheries was formally organized and a subgroup called SSR (Seals, Cormorants and Fishing Gear Development) was formed within the Swedish Board of Fisheries and given the task of developing and evaluating mitigation methods. Already early in this work it was clear that detailed analysis of catch data was required in order to provide long-sought after quantitative data on the impact of seals on the fisheries, and on the current trends. Another early insight was that mitigation methods needed to be based on the natural behaviour of the seals in order to be effective over extended periods of time. The results presented in this thesis emanate from studies made within this framework.

MAIN AIMS OF THIS THESIS

The ultimate aim of this thesis is to produce and present new knowledge and new methods that would be useful for reducing the seals-fisheries conflict. The focus is on the direct impact on the fisheries; by-catches of seals and competition over fish resources are not dealt with. However, it is assumed that methods which minimize the direct catch impact will also contribute to solving the by-catch problem. The thesis deals mainly with the conflict between the grey seal and the small scale commercial coastal fisheries in the Baltic, but the results should also be applicable in other geographical areas and in fisheries which have similar conditions. Three themes run throughout this thesis:

1. *Development of new and improved methods for quantification and analysis of catch losses*
2. *Evaluation of some current mitigation methods*
3. *Development of new principles for long-lasting mitigation methods, based on the natural behaviour of seals.*

MATERIALS AND METHODS

This section will outline the most important methods used within the framework of this thesis. More details are often given in each paper. A key issue has been how to deal with the often very large temporal and spatial variations in data derived from the fisheries and from field studies of the types in question. The seal-fishery interaction takes place underwater where direct observations can only rarely be made; indirect methods were therefore generally used.

Papers I and III depend, to a large extent, on a database of detailed fishing records from contracted licensed fishermen (Lunneryd et al. 2005). This database was launched in 1997 and presently (2005) holds nearly 38,000 records. The number of variables collected has been increased during the years. They presently include fishing data (type and number of fishing gear, fishing effort, seal protection method, and location) and catch data, number of by-catches (birds or seals), amount of damaged fish specified as caused by either seals or birds and damage to fishing gear (size and position).

In Paper I such data, collected from set traps for salmonids, were analyzed according to a system where consecutive days (pairs, trios, and quartets) were selected from the data base and compared. Within the selected series, one of the days had signs of one (or more) seal visits, whereas the other days did not. Such signs would include the occurrence of seal damaged fish or damage to the net. The undisturbed day(s) in the series would give a measure of the expected catch, with which the other days could be compared. The differences between the averages of the undisturbed and disturbed days in respect to catch, damage etc. were then analyzed. This was done to cancel out the vast site- and time-dependent variation in catches (a factor of 50 was not uncommon) and seal activity. Basic statistics were then used for the analysis of the relatively large samples.

In paper III the same type of data from the database were used, but in this study there was also an experimental factor involved. Set traps for salmonids were equipped with AHDs. These were standard and modified LofiTech Fishguard units, generating a 15kHz tone with a source level of 191 dB re 1 µPa pp re 1 m. The AHDs were moved between traps in order to create time series both with and without AHDs, which would cancel out time- and site- dependent variation in catches and seal activity.

Papers IV and V present dedicated experimental field studies. In paper IV an experimental set-trap for salmonids was compared to a trap of traditional design. The experimental trap had side panels made of large-mesh (400mm stretched mesh) netting whereas the side panels in the traditional traps were the ordinary 200mm mesh. The large meshes would allow seal-chased and panicking salmon to pass through the side panel, whereas less stressed fish would still be guided towards the fish chamber. Catches (number and weight per fish species) and seal interactions (damage to net, direct and video observations of activity) were studied in some detail. The experiment was performed in an area near a river mouth where high catches as well as intense seal interactions could be expected. The positions of the two traps were switched over in the midst of the trial period, in order to compensate for the site factor. A mathematical model was built to further separate the effects of site and time from those of the experimental design. A follow-up study was carried out the following year to evaluate the long-term effects of using only experimental traps in the area throughout that season.

In paper V, experimental buoys of different sizes and colours were compared as to how often the bait dispensed under them disappeared. In order to assist the evaluation and eliminate possible sources of bait loss other than seals, environmental data (wind, sight, underwater visibility) were collected. In addition, camera traps were used to identify the animal species taking the bait. Also, systematic observations of seals were made in connection with tending (rebaiting and relocating) the buoys. For the analysis a logistic regression was used.

Paper II, dealing with herring gill net fisheries in the north Baltic, combined data from the mandatory logbook kept by licensed fishermen, data from the database generated by selected, contracted fishermen (Lunneryd et al. 2005), and data from dedicated field experiments. In the field studies, experimental gill nets were pre-baited with marked fish and deployed linked to a commercial fisherman's nets. The number of fish (marked and unmarked) remaining after a trial period and their condition (whole or damaged) were used to determine if seal visits had taken place or not, and for estimating hidden losses. Detailed data were also collected on the catches in the fisherman's own nets and the number of damaged fish therein. Seal observations were made systematically in connection with setting and hauling the nets. The rate of fish falling off the net due to wave action or in connection with setting and hauling the net was measured and compensated for.

RESULTS AND DISCUSSION

Quantifying catch losses in the seals-fisheries conflict

The day pair model

The key problem in quantifying catch losses is to establish an estimate for the expected catch, with which to compare the landed catch. A new method of deriving such figures, using day-pairs, trios and quartets, was developed and evaluated using catch data from salmon set traps (Paper I). It was shown that the total losses (the difference between the expected catches and the landed catches) were indeed high (57%) for a day with a seal visit. It was also found that a part of these losses was hidden, i.e. the observed losses (damaged fish in the net) were significantly smaller than the calculated total losses. The commonly used model of assessing losses by counting the observed damaged fish underestimated the losses by 37%. A loss factor was calculated per trap type and fish species, and a calibration table was made (Table 3). With such a table a better estimate of the true losses can be derived from the conventional measure of losses. It was cautioned that such loss factors must be calculated separately for different areas and periods and that the estimates presented are only minimum figures. The day-pair model (Paper I), in combination with systematic seal observations, may also allow for an estimation of losses due to seals scaring fish away from the vicinity of the traps, an otherwise very difficult factor to measure. One indirect indication of such seal disturbance to the catch process was that the number of liftings without catches decreased from 11% to 6% when an AHD (Paper III) was in operation (there were no signs of seal visits to the trap on either of the days). The day-pair model could also be used in other fisheries, with both passive and active gear. It was used as a starting point for estimations of the effects of seals on the Swedish fisheries as a whole (Westerberg et al. 2000). The basic limitation of the day-pair model is that it requires that days without seal visits occur regularly, and that the day to day variation in catches must not be too large. It is also dependent on there being detectable signs of a seal visit having taken place. This may however be artificially arranged if necessary, for instance by offering seals small but tempting bait in direct conjunction with the fishing gear.

Table 3. Observed and estimated losses per trap type and species, and loss factor (calibration factor).

		Observed losses			Estimated losses (from day-pair model)			Loss factor		
		Number of counted remains per effort			Number of fish per effort			Number of fish per remains found		
	Number (no.) of day-pairs	Salmon	Sea trout	Whitefish	Salmon	Sea trout	Whitefish	Salmon	Sea trout	Whitefish
combi trap	293	1.2	0.5	3.0	1.5	0.6	15.6	1.3	1.2	5.3
combiD trap	416	1.3	0.6	2.2	1.5	1.0	11.2	1.2	1.5	5.2
Traditional trap	345	1.1	0.1	–	1.7	0.4	–	1.6	4.1	–
All traps	1 054	1.2	0.5	2.4*	1.6	0.7	12.9*	1.3	1.5	5.1*

*There was no catch of whitefish in the traditional salmon traps, this was expected as this gear has large meshes which whitefish normally pass through, average figures were thus calculated for combi and combiD traps only.

Using the day pair model (Paper I), some new insights into the seal-fisheries interaction process were gained. It was found for example that seal visits correlated with rising catches (‘salmon runs’). Another result of the analysis was that there were after-effects of seals visiting traps. That is, catches were lower than expected even on a ‘seal-free’ day, where this followed a day with a seal visit. This effect is well known among fishermen. It is believed to be a result of the scent of seals adhering to the nets and frightening fish away. This was also suggested in the literature Bonner (1982), with some experimental support by Alderice et al. (1954). The reason for the after-effect found in the present study (Paper I), however, was deemed to be mainly a result of structural damage to the net panels that had not yet been repaired. This conclusion was based on the observation that traps which were made of an extremely strong material (Dynema), and hence did not get many holes, did not suffer any significant after-effects, whereas traps made of a weaker material (Terylene) did. The day-pair model may allow for an even deeper analysis of the damage process, for instance a rough estimate of the preferences of seals with regard to fish (e.g. species and size).

Pre-baited nets

A second method for the calculation of seal-induced catch losses (using nets pre-baited with marked fish) was tried out and used in a study of seal-induced catch losses in herring gill nets (Paper II). The proportion of missing marked fish was found to be very high. Seals visited herring nets in 14 of the 19 trials. In 11 of those, more than 95% of the marked fish went missing. These figures were actually so high that it was not possible to reliably calculate the expected catch, nor the actual losses, as planned. Such calculations would be based on the ratio between the number of recaptured marked fish and the number of marked fish. The number of newly caught unmarked fish would then be divided by the quotient in order to determine the expected catch. In this experiment the number of marked fish remaining, and thus the quotient, was often zero and hence, did not allow for divisions. This reveals the major drawback of this model: that losses must not be too high (e.g. several baits must be left). A strong point, however, is that the model is usable even if seal disturbance is a daily event and variations in catches are large. Also, if the bait fish are individually marked, seal preferences can be evaluated in detail (by species, size, sex, quality factor etc), even more so than using the first described method. The second model was used successfully in two other studies of gill net fisheries, one on pike-perch (Söderlind 2004) and one on cod (Sundqvist 2005). In the study of seal-induced losses in the herring fishery (Paper II), on the other hand, data from official and voluntary (Lunneryd et al. 2005) logbooks were also used. These analyses showed that 60% of all fishing efforts were reported as seal-disturbed in the voluntary logbook. There was a large variation over the year; disturbance was lowest in June, and highest in October to December (Figure 1). The seal-induced losses were also very large, estimated at 43% in paired data from the official log-book for the herring gillnet fishery (using the principles of the day-pair model but over time periods of more than one day), and there was a negative trend in catch per effort in the period 2000-2005. In trawl fisheries in the same general area, which are not much affected by seals, there was instead an increase in catches over the same period (Figure 2). The total losses in the herring fishery were estimated to be much larger than the seals present in the vicinity of the gear could have consumed. It was therefore inferred that seals must have scared fish away from the nets, thereby affecting the catch levels.

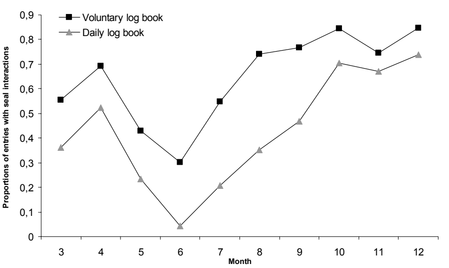

Figure 1. Proportion of entries with notes of seal interaction per month for 2003 and 2004 for the voluntary journals, and for 2000 until 2004 for the EU log book.

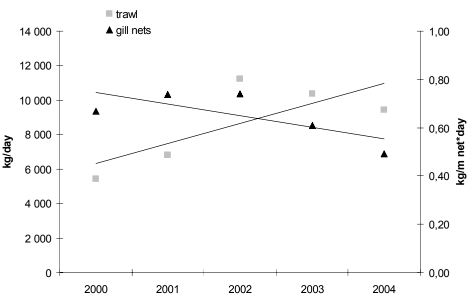

Figure 2. Catches in the herring gillnet fisheries (kg/m net and day) and in the herring trawl fisheries (kg / boat and day) 2000 – 2004.

Detailed accounts of damage to net meshes
A third method of estimating catch losses (using detailed accounts of structural damage to the net) was tried out and used in another experiment (Paper IV). The traditionally designed trap that was studied suffered a total of 187 holes in the 9 test weeks, owing to seal raids where fish were pulled from the net. In this type of trap fish do not gill in the side net panels unless, as frequently happened during this experiment, chased by seals. The number of holes was assumed to reflect the number of salmon that had been taken by seals. This method was also used in a test of large mesh net panels, intended for a seal-safe whitefish set trap. Gill nets were then deployed along the outside of large mesh net panels in order to capture fish passing through the meshes. No fish were found in these nets, but a careful screening of damage to the net revealed that fish had in fact been gilled in the nets and then been pulled off. When this had been confirmed (seals had taken the fish), the number of holes in the net could be used as a measure of fish losses (i.e. passages of fish). Generally, using this method, it is suggested that repairs are carried out using a twine of a colour which is easily discernible from that of the original net panels. In this case, nets that cannot be regularly screened, can be hung up and inspected after the end of the fishing season. Losses from nets that are not repaired at all (e.g. gill nets used in commercial fisheries) can be estimated from screening new nets and counting the holes the first few times they are used.

Some current tactics for mitigating the conflict

Stronger net materials
Seal damage became problematic in set traps for salmonids in the late 1980s. These traps were made from relatively thin materials (nylon). The problem involved both traps in which the fish were gilled (salmon traps) and traps where the fish was contained (Combi traps). Many of the traps of the latter type were later modified with a stronger net material (Dynema) in some sections, especially in the fish chamber. Using the day-pair method on data from 1993 to 2001 for an analysis (Paper I), it was found that for days without seal visits, the landed catches in the modified traps were no higher than in conventional traps (26.8 vs. 25.4 kg/day). For days with seal disturbance, however, the catches in the reinforced traps were significantly higher (12.6 vs. 8.3 kg/day; $p<0.001$). The stronger material obviously had a damage-reducing effect. Seal damage in traps of the non-reinforced types has increased even more since this study was made, and the traditional traps are being gradually phased out. In 2000 the Combi traps (traditional and reinforced) constituted 83%, and in 2005 70% of all traps for salmonids in the official log-book data-base. The corresponding figures for the traditional salmon traps were 17% and 9%, respectively. The new, seal-safe pushup trap using other principles (Paper IV) was first commercially available in 2001. In 2002 this trap already made up 7%, and then in 2005 21% of the total numbers of traps. This development was described by Hemmingsson and Lunneryd (2006). Further work has since been made on the improvement of traps using traditional principles, especially in Finland. These changes include the testing and introduction of seal-excluding entrance grids (Lehtonen and Suuronen 2004, Björnstad 2005, Björnstad and Fjälling 2005) and changes in materials and designs (Kauppinen et al. 2005; Suuronen et al. (in press)). The losses to seals in these test traps were significantly less than in older constructions, but were still a problem. Also, since seals are still able to get a considerable reward from raiding the traps, there remains a risk of a gradual adaptation to the modified gear. The authors concluded that the new pushup trap was the most efficient trap type as to reducing the seal-induced catch losses.

Sound (Acoustic Harassment Device)
The repellent effect of a strong sound source (AHD) was evaluated in a full scale and long term field experiment at salmon trap nets in the north Baltic (Paper III). The AHDs emitted sinusoud pulses of 250 - 500 ms duration with a frequency of 15 kHz and a source level of

191 dB re 1 µPa pp re 1 m. AHDs were deployed during three consecutive fishing seasons. The landed catches were significantly higher in traps with AHDs as compared to controls (25.5 kg/day compared to 12.0 kg/day), and catch damage was lower (3.5 kg/day versus 6.7 kg/day). The effect was stable over the season, and traps with an AHD could be left in the water later in the season than those without. However, by that time damage to the catches was common even in traps with AHDs. The higher catches and generally lower levels of catch damage were stable throughout the three year experiment (Figure 3 (a) and (b)). This study shows that the commercially available AHD may be a useful supplementary tool in the mitigation of seal-fishery conflicts in certain types of fisheries. However, there are practical limitations to the use of AHDs, especially in arranging a continuous supply of electricity (about 30W is needed) in the often remote places where the fishing gear is set. There are also environmental concerns, as AHDs may severely disturb other marine mammals than seals; such are however rare in the areas concerned.

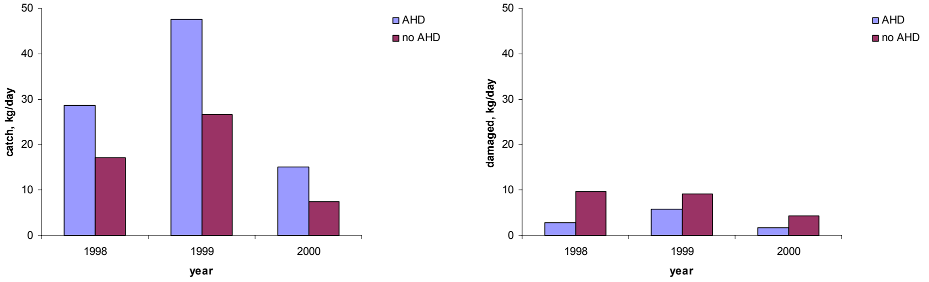

Figure 3. (a) Mean landed catch (kg/day) in traps with and without AHDs and (b) Mean estimated weights of damaged fish (kg/day) in traps with and without AHDs, both in relation to year.

In search of behaviour-based mitigation methods

A new large-mesh salmon trap with a pushup fish chamber

The new large mesh trap with a rigid frame fish chamber mounted on pontoons that could be filled with air, the whole set-up named "pushup trap" (Figure 4), had larger landed catches than the standard trap (21.7 and 30.9 kg/day respectively before adjustments for site factor etc.), but not significantly so (Paper IV). It was estimated that the escape rate through the large meshes in the new trap was 52%, while the losses owing to seal predation in the standard trap amounted to 65% of the potential catch. The seal activity in and around the standard trap was up to 16 times higher than with the new trap. This indicated that seals experienced little reward from visiting the new trap. The seal activity near traps decreased even more (by 85 %) the year following the trials, when only large-mesh traps were used in the area. There were no holes in the net panels of the new trap compared to 187 holes in the standard trap. No fish were found gilled in the net panels of the large mesh trap whereas 38 were found gilled in the net panels of the standard trap. The new traps were found to be labour-saving and ergonomic in a recent survey, and were being emptied on average once per 1.7 days compared to once per 1.3 days for the traditional traps (Hemmingsson and Lunneryd 2006). The main limitations of the new trap design is that the response of the target fish species to the large-mesh side panels is critical; therefore the trap has to be tested, and possibly modified, for each target fish species. The new trap is also more expensive to purchase than a traditional trap. However, this is possibly counterbalanced by a longer life span. There are now more than 250 traps of the new design in use in Swedish waters.

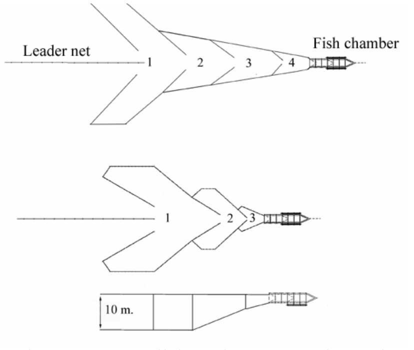

Figure 4. Traditional set-trap for salmonids (combi trap; though equipped with a non-standard pushup fish chamber, above), and a large mesh trap of the new design (below).

Experiments with baited buoys
The experiment with baited buoys tested whether or not seals used their above-water vision to find the buoys (Paper V). The same type of buoys was utilized as are commonly used in coastal fisheries to mark fishing gear. Some of the buoys were equipped with camera traps to identify the animal species taking the bait. Weather data were collected from official weather stations (SMHI) as background information. The rate of disappearing baits (mean 18%) was significantly correlated both with the buoy size and the wind speed. There was also a significant correlation between the bait loss rate and the number of seals observed near the buoys. Only grey seals were captured on the five photos obtained. Fish-eating birds (cormorants, mergansers) were never observed near the buoys. Based on these results, it was concluded that the main cause of baits going missing was grey seals taking them. Strong winds, leading to increasing wave action, may have contributed to the bait losses. The camera trap buoys had a somewhat lower bait loss rate than other buoys, which probably could be attributed to a scaring effect of the camera arrangement. The colour of the buoys (red, white and grey) did not have any effect. The rate of bait loss did not vary between the two study areas in spite of the fact that the number of seal observations was significantly different ($p=0.003$). This experiment shows that seals probably use their vision to find fishing gear. A natural source of above water visual information for seals in the food search would be aggregations of fisheating birds.

An experiment testing the use of olfaction in grey seals (Beszczyńska 2005) was made in parallel with the vision experiment described in Paper V. The buoys used for the test were deployed in the same manner as the buoys of different sizes in the visual experiment. A set of white styrofoam buoys were hollowed out and their walls perforated. The cavities were filled with material that would give an attractive scent (cut fish), a repulsive scent (sponge with seal oil), or a neutral scent (ballasted). There were no significant differences in the relative frequency of missing baits between the treatments. It was therefore concluded that the seals did not use airborne smells to localize, or discriminate between, the visually identical buoys in this trial, and that the smell of fish on the air is not a primary cue for seals in finding fishing gear.

AHDs in new applications
In recent years there have been an increasing number of reports of seals taking up residence in the entrance of the seal-safe trap described in Paper IV, acting like ‘goal-keepers’ and thus disturbing the catch process. An AHD positioned in an appropriate place near the entrance

should limit this behaviour. AHDs may also be used in other, fundamentally new ways. Some reports indicate that seals' motivation (e.g. hunger) have a strong influence on their tolerance towards the sound from AHDs. At Ballard Locks, Washington State, USA, an AHD was not able to deter resident pinnipeds accustomed to feeding on migrating salmon near a fish ladder, but it did hinder the recruitment of new individuals (NOAA 1997). The subsequent removal of the habituated individuals to an animal park resulted in the termination of the predation (London et al. 2002). The conclusion is that the time and place for AHDs should be carefully chosen, ensuring that the motivation of the seals is as low as possible at deployment. Following this line of thought, a trial was initiated in 2004 where an AHD was deployed in the narrow entrance of a deep bay (Gudingen, Västervik). It was done well in advance of the start of the fishing season. The intention was to create an 'unpleasant sound zone' which would be avoided by the seals as they later arrived to the area, leaving them with little motivation to enter the ensonified area. The AHD was supplied with a mains connection from the shore. The results are promising so far, with minimal seal interference. Fishing with herring nets, which had not been feasible for several years, has now been resumed in the area. Fishing with fyke nets and eel traps in the test area has also experienced very little seal disturbance. During a few periods when the mains connection was lost (blown fuses) however, the seal interaction picked up quickly, demonstrating the need for an efficient operations monitoring system. The costs for the maintenance of the AHD were small and the power consumption negligible. Suitable sites (a limited number) along the coast, such as large bays with narrow entrances, have now been selected for expanded trials. If these areas can be made 'seal-free', this would be a great asset for the local fisheries. The same is true for the mouths and adjacent bays of several small rivers, where sea-trout gather before and after spawning. There are reports that grey seals increasingly often ravage these shallow areas, leaving a large number of fish carcasses behind. In one area (Åvaån, County of Stockholm) an AHD has been permanently installed and has seemingly solved this problem. In two rivers (the Lagan, County of Halland, and the Göta Älv, County of Västra Götaland), AHDs have successfully prevented seals from migrating upstream and disturbing spawning and sport fisheries.

Experiments with prey detection

An aquarium experiment was made to gather knowledge on which stimuli are the most important for harbour seals in detecting a prey item (Brembeck and Hultgren 2003, Brembeck et al. 2004). Live fish (cod) were released at random into one of two submerged boxes. The seals were able to access the interior of a box through a black neoprene curtain. The sides of the boxes were interchangeable and could, alternatively, block all sensory inputs (vision, hearing, vibrissae) for the seals, or all but one sense. The time was measured from the release of a fish into the box until the seal had discovered the fish and put its head into the box. It was found that in all trials the response time was shorter when the sense being tested was available, compared to when it was blocked. It was deduced that all three senses were important and helped to solve the task of detecting a prey. The rate of correct answers (if there was fish in the box when the seal put its head in) was 52% and did not differ significantly between treatments. When the visual sense was blocked, seals more often put their heads into the box at random. It should be noted that the seals, during their patrolling, passed by outside the boxes several times per fish that was put into the box. During the hours of darkness, the seals often pushed the box around, which startled the fish; this behaviour was not seen during daylight.

An interesting observation was made of seals trying to take a fish through the netted side panel of the box. The seal would rapidly thrust its head forward towards the fish, while its body remained completely still. This was repeated several times, but only as long as the fish was within a certain ‘near zone’ of about 250 mm. If the fish moved even a few millimetres out of this zone, the seal instantly lost interest and left. Interestingly, this distance was also found to be the minimum functional distance separating the inner and outer nets in the experimental salmon trap (Paper IV). It may be that seals use this sudden head thrust at close range to capture fish. The ability to extend the neck is evident from Figure 5 (a) and (b), and is explained by the pronounced S-form of the spine when the head is held in the typical resting position (Figure 6). This ability was also observed by Björnstad (2005) and Björnstad and Fjälling (2005) in an aquarium experiment with seal-safe entrances to fishing gear. The efficient protection of the fish contained in the fish chamber which we observed (Paper IV) was thus probably dependent on three factors: (a) the rigid frame structure prevented the seals from pushing the net into the fish chamber and so reaching the fish; (b) the taut net panels hindered the seals from grabbing and chewing fish through the net; and (c) the distance between the two nets was large enough to minimize the seals’ inclination to attack the captive fish.

Figure 5. Grey seal with the head in (a) typical and (b) forward thrusted position.

Figure 6. Longitudinal cross-section of a harbour seal with the head in the typical resting position. The spine is curved in an S-shape. Photo Per Klaesson.

Another observation during this experiment was that for extended periods seals patrolled and checked the boxes where fish were only occasionally available. Patrolling was also observed in the trials with the new salmon trap (Paper IV), where an under-water video camera, positioned at the entrance of the traditional trap, revealed that seals visited the trap about 200 times in 100 hours of recording. In most of these cases no salmon was taken.

Capturing 'specialist' seals, is it a realistic option?

In one study, a limited protective cull was not found to be an efficient method of reducing seal disturbance to fishing gear (Sand and Westerberg 1998), but another study presented contrary results (Königson et al. 2003). In yet another case, when protection culling was allowed again 2001 in Sweden, a fisherman lethally removed 11 grey seals (most of them large males) at a severely disturbed salmon trap in a river mouth, and during the following three to four years he experienced very little seal interference (Sjöström pers. comm. 2005). In this case however an AHD was in operation, which probably prevented the recruitment of new marauders. This case, and the Ballard Locks case described above (NOAA 1997), indicate that the removal of selected seals may be a useful tool in some situations. Such removal need not necessarily involve culling the animals. It could alternatively be a matter of capture and subsequent translocation, although seals do tend to return to where they were caught if they can (Hume et al. 2002). Today, methods for catching selected problem seals are not available. If such methods existed, important information on individual behaviour of marauding seals could be gathered by catching and equipping them with data loggers and transmitters. The present methods used for capturing grey seals are basically limited to juvenile seals at their haul out sites. Hence, new methods capable of capturing adults, especially large males, are needed. Such methods would also make culling more acceptable and efficient. In many areas hunting cannot take place at all since it is not possible to land the animals as required by law (the water is deep, turbid or fast flowing), making it impossible to fill the quotas. Hunting from boats is prohibited in Sweden. If animals could be caught irrespective of area, it would be efficient in terms of problem management. Also, if they were caught alive, decisions on which animals to put down and which to release could be made very precisely. In an attempt to develop such a new capturing method, a series of trials was performed (Lunneryd and Fjälling 2004). A large trap consisting of a net cylinder (a modified pushup fish chamber), was constructed and tested. It succeeded in catching harbour seals, but not grey seals. Based on these experiences and a thorough study of old records and books on sealing in the Baltic Sea, principles for a new seal trap was outlined and described in the same report. The suggested trap basically consists of a short net set in the shape of a narrow 'G', and is equipped with a baited and self-triggered scaring device in the centre. When seals are suddenly startled, they dart away at high speed and are then liable to be caught in the net (Ling 1915).

CONCLUDING DISCUSSION

It is possible to estimate most of the seal-induced catch losses in the fisheries investigated, including the hidden losses. The new tools described could be used in other fisheries apart from the ones discussed. The methods should be further improved and could be used to study the seal interaction process itself in more detail. For instance, data on the seals' basic food preferences could be gathered by noting which marked fish (species, size, sex, condition factor etc; Paper II) were taken from the nets, and which were not. A comparison could then be made with data derived from scats and stomach contents. The composition of the latter samples reflects not only preferences but also the availability (density, catchability) of different food items.

Efficient seal-safe fishing gear can be developed for at least some fisheries. Generally the possibility of protecting catches is largest for fishing gear where the catch is first concentrated (by a leader net, or bait), and then herded into and kept inside a fish chamber. This chamber can be constructed in such a way (using double net walls, strong materials, taut net) that the catch is safe from seals. The concentrating process may however in itself create a 'resource' for seals, i.e. spots with elevated densities of fish which seals will try to exploit. The possibility of protecting fishing gear where the catch is exposed and dispersed in the water mass (gill nets, long lines) is inherently limited. For this reason there is often a need for a change in fishing methods. Modifications must then be made specifically for each target fish species. The new designs must be based on a thorough knowledge of the natural behaviour of both seals and fish. It ought to be fruitful to involve specialized institutions in this work.

The fisheries sector does not have a well established tradition of scientific investigations and publication. Much valuable information may be found in old and in 'grey' literature, although it must be used with discretion. Mitigation methods and observations described in such literature may need further evaluation to reach a final conclusion. There is also a large accumulated body of observations and knowledge among fishermen, which preferably could be used in the design of scientific experiments. It is important and beneficial and highly recommended to involve the fisheries sector in the experiments and the development processes.

FUTURE PROSPECTS

Gear development

Much work remains to be done with the development of seal-safe fishing gear as more and more fisheries are becoming disturbed. One example is that the problems in the gillnet fishery for cod in the southern Baltic are becoming acute. Since gill nets are very difficult to protect, another fishing method must be considered. One such method would be to use traps. This will be a challenge since the construction needs to be fairly large and sturdy, and still must be easy to handle, even from the traditionally small boats and by their small crews. Cod traps of a convenient size have been tried with some good results in the Norwegian fisheries (Beltestad et al. 1996), but they were not designed to be seal-safe. An additional problem in the Baltic is that the density of the cod in the areas concerned is too low to make the use of leader nets feasible. Hence, some other way of concentrating the fish before capture must be developed. One possible alternative might be to use olfactory stimuli distributed by an automatic bait pump. Baited gill nets had higher catches of cod than non-baited ones (Engas et al. 2000), but the efficiency of such an approach in traps needs to be evaluated.

Conditioning

An attractive option for keeping seals away would be to induce in them a negative association to fishing gear. There are several difficulties in this undertaking, both in evaluating the effects of such stimuli, and in making them usable in a large scale field situation. To begin with, the conditioning must be made in relation to the correct context, i.e. to the fishing gear, and not only to a particular fish species or situation. The experiments must therefore be designed in collaboration with ethologists and performed under controlled conditions. The conditioning must also have long-lasting effects. There is evidence of a long term memory in pinnipeds; Kastak and Schusterman (2002) found that a sea lion reliably remembered and could apply conceptual rules after 10 years. It must also be possible to administer the imprinting in an efficient way (i.e. simple, inexpensive, reaching many seals) in the field. In addition to the methods used today (emetics, sound), it may also be possible to develop new ones. One such new method might be a mechanical device which would capture and pull out one of the seals' highly innervated whiskers as they took bait. This would certainly induce considerable pain, but should not be disabling. The root of the whisker could be used for DNA profiling, which in turn would reveal if this individual returned, or if it was by-caught later. Another new method one could imagine would be to offer bait at fishing gear which gave a mild electric chock when a seal bit into it. These methods could possibly also be used in connection with an olfactory cue designed to stimulate the Jacobson's organ. Information from this organ is handled by the primitive 'reptilian brain' and negative imprints are usually acute and life-long, according to Watson (1999) in a review of scientific and other publications on this topic.

Gathering crucial information

A detailed knowledge of how seals find and exploit fishing gear is crucial in the continued work on mitigation methods. In large terrestrial carnivores, tagging with radio transmitters has proved very useful in monitoring their movements, as well as gaining insights into their hunting techniques and strategies. In aquatic animals (seals, fish) ultrasonic transmitters and data loggers have served the same purpose. Such an approach, however, relies on effective capturing methods, inherently difficult with grey seals. It would be interesting to develop and evaluate an automated tagging station for grey seals, placed on a haul-out rock. If this were found feasible, several seals could then be tagged with active (ultrasonic) and/or passive (PIT) transmitters. Especially important would be to tag large males, which are notorious for raiding fishing gear, making it possible to monitor their activity near fishing gear using automated data logging devices. The tagging station could also be designed to collect other information (individual weight, DNA samples, and scats). Further field trials of the type described in Paper V (baited buoys) could also be suitable for gathering important information. Such trials should use improved technology; baits and cameras should all have a timer, a local weather station should be placed in the test area and the basic bait set-up should be unaffected by waves. Tests should also include decoy buoys, buoys with camouflage patterns and submerged buoys. All buoys should be deployed at precisely chosen distances to give information on the detection distances of seals.

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