Seals and Fisheries
A Study of the Conflict and Some Possible Solutions

Abstract

List of Papers

Svensk sammanfattning

Introduction

Seals along the Swedish coast

The conflict between seals and fisheries
Seals → Fisheries
Direct interference
Competition for fish
Dispersal of parasites
Fisheries → Seals
Accidental by-catch
Food depletion through over-fishing
Disturbance in sensitive areas

The present thesis

Aims of the thesis

Interactions between harbour seals and coastal fisheries along the Swedish west coast Paper I, II and III

Interactions between grey seals and coastal fisheries in the Baltic Sea
Paper IV, V, VI and VII
Gillnet fisheries for herring in northern Baltic
Trap net fisheries in northern Baltic
Gillnet fisheries for cod in central Baltic

Conclusions and recommendations

Acknowledgements

References

Abstract

Interaction between seals and fisheries along the Swedish coast has serious environmental and economic consequences. This thesis describes the conflict as it affects four different small-scale coastal fisheries; the eel fisheries on the west coast, the herring fisheries and salmon fisheries in the northern Baltic and the cod fisheries in the central Baltic. Knowledge gained through studies of the interaction between seals and fisheries has been instrumental for the development of alternative seal-safe fishing gear and mitigation methods. For some fisheries the improved understanding has led to a resolution of certain parts of the conflict.

Certain coastal fisheries in the Baltic, such as the herring gillnet fishery, are at the point of collapse because of this conflict. Damage caused by grey seals to this fishery has been shown to be much more extensive than previously recognised. When seals raid nets, a significant part of the catch is lost without trace. Seals remove fish from nets without leaving any remains. This represents a hidden loss. Another hidden loss is caused by the presence of seals around fishing gear, which scares away fish from the area. The result is often a total loss of catch. Hidden losses are also evident in the gillnet fishery for cod in the central Baltic sea. In recent years damage by seals in the cod gillnet fishery has increased significantly. Due to the high value of cod the cod fishery is currently one of the fisheries that suffer the highest economic loss by seal damage.

Seal-safe fishing gear is at present the only long lasting solution which would meet the needs of both seals and fishermen. Mitigation of damage to catch and fishing gear as well as the prevention of accidental by-catch are two sides of the same problem; a solution to one is also a solution to the other. However, development of new fishing gear is challenging and time-consuming. It requires better knowledge of both fish and seal behaviour. At present suitable alternative fishing gear is not available for the herring fisheries carried out through the whole season. However, a herring trap has been developed as an alternative fishing gear for catching spawning herring in spring time. In the cod gillnet fishery, promising results have been achieved in trials of an alternative fishing gear - the two-chamber pot.

Another coastal fishery in the Baltic subjected to damage by grey seals, is the salmon trap net fishery in the North Baltic. A seal-safe salmon trap has been developed and is used by most of the salmon fishermen. This so called pontoon trap prevents the seal from reaching the catch by keeping the fish in an enclosed seal-safe fish chamber. However, in recent years there have been reports of damage by seals also in the pontoon trap. By filming the seals attacking traps it has been possible to identify 10 individual seals hunting in the traps and to determine that these same animals returned to the traps over a long period of time. It is possible therefore, to limit or decrease damage to the fisheries by limiting access for or by culling the individual seals specialized in raiding fishing gear.

On the west coast of Sweden the eel fyke net fishery suffers from damage by harbour seals. In order to find a lasting solution to the conflict, seal behaviour has been studied as well as the fyke nets' fishing efficiency. The issue of whether it is the eels or the by-caught species which motivate harbour seals to attack fyke nets was studied. It was shown that harbour seals raiding fyke nets have a preference for eel. Certain harbour seals that specialise in foraging at fyke nets, have developed different feeding preferences compared to those of most seals. Seal-safe fyke nets, which resisted attacks while still being efficient in terms of yield, have been developed. They are already in use in commercial fishery along the west coast.

List of Papers

The thesis is based on the following papers, henceforth referred to by their Roman numerals (I-VII)

I Königson, S., Lundström, K., Hemmingsson, M., Lunneryd S-G., and Westerberg, H. 2006. Feeding Preferences of Harbour Seals (*Phoca vitulina*) Specialised in Raiding Fishing Gear. Aquatic Mammals 32 (2):152-156

II Königson, S., Hemmingsson, M., Lunneryd S-G., and Lundström, K. 2007. Seals and fyke nets: An investigation of the problem and its possible solution. Marine Biology Research 3: 29-36

III Lundström, K., Lunneryd, S., Königson, S., and Hemmingsson, M. 2011. Interactions between harbour seals and coastal fisheries along the Swedish west coast: an overview. Accepted to NAMMCO Scientific Publications 8: in press

IV Königson, S., Fjälling, A., and Lunneryd, S-G. 2007. Grey seal induced catch losses in the herring gillnet fisheries in the northern. NAMMCO Scientific publications 6: 203-213

V Königson, S., Lunneryd, S-G., Berglind, M., and Fjälling, A. 2011. Male Grey seals specialize in raiding salmon traps. Manuscript

VI Königson, S., Lunneryd, S-G., Sundqvist, F., and Stridh, H. 2009. Grey Seal Predation in Cod Gillnet Fisheries in the Central Baltic Sea. Journal of Northwest Atlantic Fishery Science 42

VII Ovegård, M., Königson, S., Persson, A., and Lunneryd, S-G. 2010. Effects of escape windows on the capture of cod in floating pots. Fisheries Research 107, 1-3: 239-244

Svensk sammanfattning

Det småskaliga kustnära fisket i Sverige har under de senaste årtiondena utvecklats negativt. En av flera orsaker är att fisket drabbas skador på fångst och redskap orsakade av säl och detta problem ökar längs stora delar av Sveriges kust. I Östersjön, där gråsälen är den främsta skadegöraren, har fisket med fasta redskap efter lax och sik varit mest utsatt för sälens härjningar men de senaste åren är nätfisket ett av de fisken som drabbats allvarligast av den ökande sälpopulationen. Med en gråsälpopulation som under 2000-talet ökat till antal med mer än 10 % årligen, riskerar vi, om inte några direkta åtgärder vidtas inom en snar framtid, att flera mindre kustnära fisken längs kusten försvinner. Garnfisket är utsatt för sälskador då fångsten inte går att skydda. Fisken fastnat i garnen, som då blir likt ett dukat bord där sälen kan simma längs garnen och plocka fångsten. Ett av de hotade garnfiskena i norra Östersjön är fisket efter strömming med garnskötar. De ekonomiska förlusterna som syns i form av skadad fångst och förstörda redskap är endast en liten del av de totala förlusterna. När säl attackerar skötarna försvinner stora delar av fångsten utan att sälarna lämnar några spår efter sig. Detta kallas för dold förlust. Sälarna plockar ut hela fiskar ur näten och när sälarna patrullerar läng näten skrämmer de iväg fiskstimmet från redskapen. Om säl varit i närheten när skötarna lagts ut kommer skötarna upp tomma utan varken skadad eller hel fångst. Även fisket efter torsk med garn i centrala Östersjön är utsatt för sälskador. Sälskadorna har de senaste åren ökat markant i detta fiske i takt med att gråsälspopulationen ökat. Även här utgör de synliga skadorna endast en liten del av de reella skadorna orsakade av säl. För varje skadad torsk fiskaren får upp i sitt nät beräknar vi att minst 4 torskar försvunnit utan att sälen lämnat något spår i form av fiskrester efter sig.

Att sälsäkra redskap är den mest hållbara och långsiktiga lösningen på konflikten mellan säl och fiske är de flesta intressenter överens om. Om vi hittar alternativa redskap där sälarna inte kan skada varken fångsten eller redskapet så kan vi också minska bifångster av säl i redskap som även det är en del av konflikten. Att utveckla nya och alternativa redskap kräver ökad kunskap om både fiskens och sälens beteende i förhållande till redskapet. I skötfisket efter strömming finns det idag inga fungerande lösningar för att bedriva ett heltidsfiske under hela året men det pågår en utveckling av en strömmingsfälla som ska användas under vårfisket då strömmingen samlas nära kusten för att leka. Förhoppningsvis kan detta redskap bli en öppning för ett fortsatt småskaligt strömmingsfiske.

För torskgarnfisket i centrala Östersjön kan det däremot finnas en fungerande lösning i form av alternativa redskap. Fiskeriverket har under flera år provfiskat med torskburar betade med sill i ett kommersiellt fiske. Burarna är passiva redskap som består av två kammare. En ingångskammare med betespåse i och en fångst kammare. I och med att fångsten samlas i fångstkammaren finns det möjlighet att sälsäkra denna del av redskapet så att sälen inte kommer åt fångsten. Det är viktigt att ta tillvara all kunskap om konflikten i torskfisket samt kunskap om säl och torskbeteende i relation till redskap för att få fram ett så bra fungerande alternativ som möjligt och så snart som möjligt. Sälskadorna i torskfisket ökar och sprider sig snabbt längre söderut i Östersjön.

Fisket efter lax och sik längs norrlandskusten har länge varit det fiske i Sverige som varit hårdast drabbat av sälskador. Idag finns det ett fungerande sälsäkert redskap för lax, den så kallade push-up fällan. Fällan har ett sälsäkert fiskhus där fångsten samlas och där sälen inte kan komma åt den. Trots det sälsäkra redskapet har sälskadorna i laxfisket inte upphört helt. På senare år har fiskarna rapporterat att säl jagar fisk strax framför fiskhuset och tränger sig in i öppningen av fiskhuset för att komma åt fångsten. För att förstå hur sälen går till väga placerades flera filmkameror ut i push-up fällor. Vi kunde därmed identifiera 10 sälar som

specialiserat sig på att jaga i fällan och som återkom vid flera tillfällen under en längre tidsperiod. Denna kunskap är inte bara viktig för utvecklingen av nya sälsäkra metoder inom laxfisket. Vi vet nu att det är ett visst antal individer som specialiserat sig på att attackera redskap. Därmed finns en möjlighet att begränsa skadorna i ett område genom att ta bort de skadegörande individerna.

På västkusten är det knubbsäl som dominerar och även den orsakar stora ekonomiska förluster för det småskaliga fisket. Ålfisket med ryssjor är det fiske som drabbats värst av sälskador och i detta fiske har det skett en riktad insats för att minska skadorna. Sälsäkra ålryssjor har utvecklats där både sälens beteende och redskapens fiskeeffektivitet tagits i beaktande för ryssjornas utformning. Ålryssjor med starkt material i fiskhuset, där ålen samlas, används idag i det kommersiella yrkesfisket. Det diskuterades under lång tid vilken fisk i ryssjorna som attraherar sälarna. Var det ål eller var det den bifångade torsken? Det visade sig att sälar som attackerar ålryssjor föredrar ål framför torsk, tånglake och plattfisk. Trots detta visar flera studier att ål är ytterst sällsynt i sälarnas diet. Även detta talar för att vissa knubbsälar specialiserar sig på att attackera redskap och att de sälarna utvecklat en preferens för ål. Filmer, tagna med en undervattenskamera placerad bredvid en ryssja betad med ål, visade också att samma knubbsäl återkom flera gånger till ryssjan för att söka föda.

Introduction

Seals along the Swedish coast

There are three species of seals along the Swedish coast; the grey seal (*Halichoerus grypus*), the ringed seal *(Phoca hispida)* and the harbour seal (*Phoca vitulina*). On the west coast of Sweden the prevalent species is the harbour seal. Grey seals occur in the area, but only rarely (Härkönen and Lunneryd, 1990). In the early 20th century, the harbour seal population in the entire Kattegat-Skagerrak was seen as a competitor to the commercial fisheries. A bounty system for hunting was introduced in 1902. During the 1960s the population was estimated at 2-3,000 animals and harbour seals were considered endangered (Härkönen and Lunneryd, 1990). Hunting ceased in 1967 and after that the population increased dramatically of about 12% per year over the period 1979–1986 (Heide-Jørgensen and Härkönen, 1988; Teilman et al., 2010). In 1988 an epizootic occurred and a large part of the population died. After the epizootic, harbour seal numbers increased from around 5,000 to 19,000 animals, when in summer of 2002 another severe epizootic hit the west coast population. The number of deaths of harbour porpoises was expected according to Harding et al., 2002 to be 10 000 in Kattegat and Skagerrak. The recovery of the population after the second epizootic is thought to have proceeded on the same lines as after the first, with an annual increase in numbers of over 10 %. Today the counted number of harbour seals in Skagerrak and Kattegat is around 11 500 (Havet, 2010) so the actual number of seals is well above that.

All three species of seals are present in the Baltic. Ringed seals are found mainly in the northern Baltic. In 2009 around 6 500 ringed seals were counted in the Gulf of Bothnia (Havet, 2010). There is a small population of harbour seals south of Öland. This population is considered endangered and was estimated at 390 individuals in 2004 (Härkönen et al., 2005). However, the population is increasing at the rate of 9 % annually. Grey seals are the dominant species in the Baltic. It is mainly grey seal that cause damage and losses for commercial fisheries, although it is reported that damage caused by ringed seals also occur along the northern coast of Sweden (Hemmingsson and Lunneryd, 2005). In the middle of the 20th century high levels of organochlorines were found in both grey seals and ringed seals. These

compounds caused damage to the reproductive organs of females, which led to a strong decline in the grey seal population (Helle et al., 1976; Bergman and Olsson, 1986; Olsson et al., 1994). Since around 1980, organochlorine pollution in the Baltic has been reduced and this has allowed the grey seal population to recover (Hårding and Härkönen, 1999; Halkka et al., 2005; Karlsson and Helander, 2005). In the seal census carried out in 2004, the number of grey seals counted in the Baltic was 17,640 (Halkka et al., 2005). In 2009 the number of counted grey seals in the Baltic was 20,400 (RKTL). Hiby et al., (2007) indicated that the counted number of seals during a photo ID study represents approximately 80 % of the total population. This means that the population is now well over 25,000 animals.

The conflict between seals and fisheries

The conflict between marine mammals and the fishing industry is multifaceted and complex. The conflict is reciprocal in that seals affect the fisheries and the fisheries affect the seals. The negative impact on the fisheries include direct effects, which can be further divided according to if they act on individual or on population or ecosystem level, as well as indirect effects. Fisheries also have a negative impact on seals. Accidental by-catch directly affects individual seals and occurs in many different fisheries. Food depletion through over-fishing could also have a negative effect on seals. Fishing can also disturb seals in sensitive areas. The above mentioned interferences can be divided into direct and indirect effects as is described in table 1.

Table 1. Interactions between fisheries and seals.

Interaction		**Seals → Fisheries**	**Fisheries → seals**
Direct	Individual level	Damage to catch and fishing gear	Accidental by-catch
	Ecosystem level	Competition for fish	Food-depletion through over-fishing
Indirect		Dispersal of parasites	Disturbance in sensitive areas

From a management point of view, the direct interaction on an individual level, such as damage to catch and fishing gear, is the main problem area in Swedish waters. Here it is possible to study the magnitude of the problem and also to find non-lethal mitigation methods such as alternative seal-safe fishing gear. The prevention of by-catch of seals and the mitigation of damage will usually be achieved by the same means.

The grey seal population in the Baltic has increased dramatically during the last decade (Karlsson and Helander, 2005). The direct seals-fisheries conflict on a individual level in the Baltic has escalated in parallel with the population explosion (Baltscheffsky, 1997; Kauppinen et al., 2005; Westerberg et al., 2000; Lunneryd, 2001; Fjälling, 2004). However, with all seal populations increasing rapidly, the direct ecosystem effect of competition for fish is gradually becoming more common. With a rapid increase of grey seals in the central and southern Baltic the dispersal of parasitic seal worms (*Pseudoterranova decipens)* in the Baltic fisheries for cod *(Gadus morhua)* has become a growing problem.

Seals → Fisheries

Damage to catch and fishing gear

Small-scale and coastal fisheries are the fisheries most subjected to the direct interaction on an individual level such as damage to catch and gear caused by seals. Coastal fisheries are widely scattered around the Swedish coastline. They are of great importance to the local

population in many villages. Coastal fishery is often carried out by single fishermen who make daily fishing trips and return every night to harbour. In addition to damage caused by seals these fisheries tend to suffer from diminishing fish stocks and structural problems such as difficulties distributing the catch.
There are two centres of the grey seal distribution range, in the northern part of the Baltic proper and in the Åland Sea. The fisheries that are among the most severely affected by damage to catch and gear is the set trap fishery for salmonids (*Salmo salar, Salmo trutta, Coregonus lavaretus*) in the northern Baltic (Westerberg et al., 2006). Westerberg et al. (2000) estimated that in these fisheries, at least half of the potential total catch is lost to seals. Seals cause damage to set traps by tearing large holes in the net panels and chasing fish into the netting, and then tearing them loose for consumption. In recent years the direct damage to catch and gear has increased also in the cod fisheries (Swedish Board of Fisheries, 2008, Paper VI). Cod is fished with bottom set gillnets and hooks. Seals pick the catch from the nets or hooks, leaving only remains of fish. They also tear holes in the nets. Many other fisheries mentioned below are also subjected to direct damage to catch and fishing gear.

When a seal attacks fishing gear, such as gillnets or set trap, both fish remains and damaged fishing gear are sometimes left as evidence of the direct interference. In several reports concerning the seals-fisheries conflict, the loss of catch caused by seals has been estimated by measuring the percentage of fish remains found in the catch, see (Wickens, 1995). However, the visible direct loss such as fish remains only represents a minor part of the catch loss caused by seals. In addition to the visible catch loss, there is a direct invisible catch loss. This is the part of the catch which is completely removed from the fishing gear i.e seals leaving no trace of fish remains (Fjälling, 2005; Paper IV and VI; Sundqvist, 2005; Stridh, 2006). Seals can also scare away fish away from the fishing area, creating additional invisible losses (Paper IV).
Damage to fishing gear is an economic loss for the fishermen. The visible gear damage such as holes and tears also creates further indirect economic loss. Indirect expenses include costs for new material, time for repairing fishing gear and reduction in gear durability. Additional costs such as increased time and fuel consumption due to emptying the gear more often should also be taken in consideration.
Altogether, the economic losses due to seal attacks in the fisheries include direct visible and invisible losses. In turn these losses create further additional indirect losses. The total economic losses including direct and indirect losses for fishermen as a result of seal attack are listed in table 2. Direct catch losses and indirect losses together amounted to at least 15-20 % of the total catch value in the inshore fisheries in 1997 (Westerberg et al., 2006). Seal interference is an important reason for the current poor viability of the fisheries concerned, and for the ongoing low recruitment and gradual decline in the number of active fishermen (Swedish Board of Fisheries, 2001). If no effective mitigation measures for seal-induced damage are developed, the conflict between the seal stocks and the coastal fisheries will become very serious (Suuronen et al., 2006).

Table 2. The direct visible losses to catch and gear are only a small part of the total losses fishermen are subjected to. Invisible and indirect losses also need to be taken into account when estimating total losses.

Total losses due to seal attacks in the coastal fisheries	
Direct visible catch losses	-Damaged catch
	-Damage to fishing gear
Direct invisible catch losses	-Catch removed completely from the fishing gear
	-Fish scared away from the fishing area
Indirect losses due to damaged fishing gear	-Loss of catch due to damaged fishing gear
	-Costs of new material
	-Time spent repairing fishing gear
	-Reduced life durability of fishing gear
Indirect additional losses	-Increased time and fuel consumption due to checking and hauling the fishing gear more often
	-Longer fishing trips to areas where there is less seal interference
	-Lost fishing opportunities, due to both fishing grounds and fishing gear not being worth using any more as a result of seal interference

Competition for fish

It has been suggested that some marine mammals, which are at the top of the marine food webs (Pauly et al., 1998), can have considerable impact on the structure of pelagic ecosystems (Merrick, 1997). This could lead to resource competition with humans such as that marine mammals consuming commercially interesting fish and thereby decreasing fishermen´s catches. Studies of the competition between fisheries and marine mammals in the North Atlantic, the Pacific and for the world ocean as a whole have shown that marine mammals consume three times the amount of fish as the amount of fish caught through fisheries (Kaschner et al., 2001; Trites, 1997; Tamura and Oshumi, 1999; 2000). However, there are important differences between marine mammal groups with respect to consumption. All marine mammals do not feed on the same prey as humans exploit and several mammal groups with high consumption do actually not consume fish exploited by fisheries. However, Etnier and Fowler, 2010 argue that the targeted size composition of commercial fish populations taken by fisheries should match the size compostion of the same populations taken by marine mammals. Fisheries should catch the same size of fish which the marine mammals catch. This would reduce the not normal selectivity pressure imposed by fisheries. On the other hand, would create direct competition for certain species. Pinnipeds, have the highest overlap with fisheries in both the North Atlantic as well as the Pacific Ocean (Trites 1997; Kaschner et al., 2001). It is, however, hard to predict the outcome of such competition due to the complexity of marine food webs. Interactions between seals, fisheries and fish stocks depend not only on

factors associated with the seal population but also on sizes, structures and inter-species interactions of the prey populations. However, there are concerns over the impact of pinnipeds on fisheries. Björge et al., 2002 showed that on the west coast of Norway the harbour seals exploit the same areas as certain fisheries. The seals in this area have had an effect on fish species, also targeted by a seine fishery. Seals therefore have a negative influence on catches in the case of this specific fishery. However, the removal of one species of fish by predation by seals might be favourable for another species targeted by another fishery.
The effects of seal predation might be large even if the overall consumption is small. An example is the concentrated predation on migrating salmon at river mouths (Yurk and Trites, 2000). Seal predation has been identified as a potential factor that may worsen declines or impede recovery of depressed salmonid stocks (Wright 2007). Carter et al., (2001) estimated the number of adult salmon in Scottish rivers predated by seals to be lower than the rod fisheries in the same area. Butler et al., 2006 modelled how removal of seals in Scottish rivers could affect the protected prey, Atlantic salmon. In certain medium sized rivers the increase of the stock was small (<1%) when seals were removed. However, in small rivers the removal of one individual seal could increase the stock population with up to 17% during certain time of the year.

If an ecosystem is considered to be a "top-down" ecosystem the consumers such as seals control the abundance and diversity of species at lower trophic levels. In such a system there is competition between fisheries and apex predators for the food resource. Reducing the apex predators is likely to increase the availability of fish biomass for the commercial fisheries. Österblom (2006) has indicated that the Baltic Sea is indeed one of only a few areas in the world where a reduced top-down control (a reduction of seals in the early century) resulted in a change in the fish population and composition of species. Kaschner and Pauly (2004) also indicated that competition between marine mammals and fisheries is likely in the Baltic. If we look at an individual prey species level in the Baltic, there most likely is a competition. The seals´ consumption per fish species in the Baltic was compared to the combined commercial and leisure fishery in the same area. This was done by using diet data of hunted and bycaught greyseals (Lundström et al., 2007; Lundström et al., 2010). The comparison shows that seal consumption of flounder (*Platichthys flesus*), eel (*Anguilla anguilla*), and whitefish (*Coregonus lavaretus*) exceeded the human catch and it was approximately equal for salmon (*Salmo salar*) and cod (*Gadus morhua*). However, the overall catch of the fishery is larger than the seal consumption due to the large proportion of herring *(Clupea Harengus)* and sprat *(Sprattus Sprattus*) in the fishery (Bruckmeier et al., 2010).

Österblom (2006) has described the changes in the Baltic ecosystem over time. In the early 20th century the seal population in the Baltic was high, which Österblom (2006) suggests resulted in low prey abundance of cod. When the seal population decreased the Baltic changed from a seal to a cod-dominated state. After that it changed from an oligotrophic to a eutrophic state, and finally from a cod-dominated to a sprat-dominated state. We are now at the clupeid-dominated state where the seals' prey species are low and seal numbers are increasing. Even though the decline of the cod population cannot be correlated with the increase in the seal population, it is nevertheless likely that the recovery of the fish stock will be affected by that increase. Chouinard et al., 2005 have also suggested that grey seal predation increase natural mortality of prey species. Natural mortality played a role in the collapse of fish stocks and their failure to recover in the North West Atlantic. Jounela et al. (2006) suggests that because of the

growing grey seal population it would be useful to assess the effect of natural predation by seals on salmon stocks in the Baltic.
Österblom (2006) also suggests that an ecosystem approach should be used for fisheries management to integrate knowledge of seabird consumption requirements with the ICES definitions of "safe biological limits" for the Baltic Sea clupeid stocks, and thereby take account of the role which common guillemot play in clupeid consumption. Also Tyrrell (2011) pointed out the importance of considering predation when estimating abundance of fish species. Therefore maybe fish consumption by grey seals should be taken into account in the same way in the management of these fisheries.

Dispersal of parasites
Three parasitic nematodes are found in the stomachs of Swedish seals. Two of these, Seal worm (*Pseudoterranova decipiens)* and *Contracaecum osculatum* have seals as a true final host, the third one Whale worm (*Anisakis simplex*) has cetaceans as main final host. The seal worm occurs in the flesh of the fish and is therefore a problem for the commercial fisheries. Both harbour seals and grey seals can be infected by seal worms but the latter commonly have larger infestations. They are therefore a more important vector for the parasite. The seal worm is now commonly found both in benthic fish species and grey seals from the Baltic (Lunneryd, pers. Com; Perdiguero-Alonso et al., 2008). With the increasing grey seal population this could become a serious problem for the fishing industry. The seal worm has a complex lifecycle including intermediate hosts such as crustaceans and fish. The seal worm could infect humans if raw or marinated fresh fish were ingested, although the likelihood of infection is low (Adams, 1997). The main problem is that infected fish look unattractive to consumers. This brings added costs for the processing industry but also for the small-scale fishermen who prepare their catch for market.

Fisheries → Seals
Accidental by-catch
Lunneryd et al. (2004) suggest that about 450 grey seals were by-caught in the Swedish commercial fisheries in northern Baltic in the year 2001. In the Gulf of Bothnia, about 50 ringed seals were by-caught, while more than 400 harbour seals were by-caught off the west coast of Sweden. This study was based on a telephone survey of 16 % of all Swedish commercial fishermen. The fisheries for cod and flatfish with bottom-set nets are the fisheries where most seals get by-caught, and the species most affected is the grey seal. Many grey seals are also by-caught in various traps used to catch salmon and whitefish. Harbour seals, on the other hand, are often by-caught in fyke nets, used by the eel fishery as well as the flatfish fisheries with large mesh nets. The current levels of by-catch cannot be considered a serious threat to the Swedish seal populations, as all three seal species have demonstrated strong population growth in recent years. Nevertheless, by-catch of seals is not considered ethical and fishermen do have a problem handling the by-caught animals. By-caught seals are part of the seals-fisheries conflict. A way to solve the by-catch problem is to develop seal-safe fishing gear which should be unattractive for seals and reduces seal presence in the area. A decreased presence of seals around the gear would naturally reduce the amount of by-catch.

Food depletion through over-fishing
There is little conclusive evidence that prey depletion caused by human activities such as fishing can reduce marine mammal stocks, although Trites et al. (2006) suggest that intensive

fishing may lead to large and long-lasting ecosystem changes. Heavily fished ecosystems do not always have the ability to support abundant, healthy populations of apex predators. Fisheries can affect marine mammals also when prey and caught species do not overlap. They indirectly compete for the primary production required to sustain the prey and species caught, so-called food-web competition (Trites, 1997). However, food depletion can also create responses such as migration, with predators moving from an area where fish stocks are depleted to other areas. In turn, shifting their distribution can subject the animals to increased incidental mortality such as by-catch in bottom set gillnets. This occurred in the 1980s in Barents Sea when the capelin *(Mallotus villosus)* stock collapsed due to over-fishing in offshore waters. Harp seals (*Phoca groenlandica*) migrated towards the Norwegian coast and got by-caught in inshore fishing nets (Nilssen et al., 1992; Haug and Nilsson, 1995). Another of the few documented cases of commercial fisheries impacting on pinniped populations is the large reduction in the Barents sea´s stocks of herring in the 1960`s and capelin in the 1980´s which produced observed changes in the harp seal population (Haug and Nilsson, 1995). However, there is no evidence that depletion of fish stocks by commercial fisheries affects the survival rate of seals in Swedish waters.

Disturbance in sensitive areas

Today seal sanctuaries protect the most important haul-out sites for grey seals and harbour seals along the Swedish coast. Disturbance in sensitive areas is not a major problem in Swedish waters and to the extent that it exists, it relates more to pleasure boating than to fishing boats.

The present thesis

Aims of the thesis

In Swedish waters there are many fisheries where active management of the seal fisheries conflict is needed. For this purpose there are management tools such as: technical mitigation, economic compensation and lethal removal of seals. The aim of my work at the Swedish Board of Fisheries and the Department of Marine Ecology at the University of Gothenburg is to find methods for mitigating the conflict through any of these three management tools. The development of seal-proof fishing gear (technical mitigation) is the most important component of the Swedish mitigation strategy It is also considered to be the most durable solution to the problem. Knowledge about seal and fish behaviour in relation to fishing gear in the concerned fishery is needed in order to develop seal-safe fishing gear. The seal fisheries conflict has grown rapidly in many different fisheries along the coast. This has created an urgent need for suitable mitigation methods. It is not only important to gather information that will facilitate the development of fishing gear. Detailed knowledge of the extent to which seal damage affect the different fisheries is also important with regard to the economic management tool. This would give us a perspective on the fisheries concerned and would be useful in any future grey seal management work.

The aim of this thesis is to study the seal fisheries interaction in different fisheries along the coast both with regard to fish and seal behaviour as well as development of new fishing gear. These studies have been a base for implemented management tools used to relieve the conflict. Harbour seal behaviour in relation to fishing gear has been of importance in the search for a lasting mitigation method in the eel fishery along the west coast. Papers I and II presents some aspects of harbour seal behaviour around eel fyke nets - how they affect the eel fishery negatively and finally a solution to the conflict. Paper III provides an overview of both the

operational and ecological aspects of interaction between harbour seals and coastal fisheries along the Swedish west coast. Operational interaction include damage to catch and fishing gear as well as by-catch of seals and the ecological part of the interaction including the consumption of prey and predators of commercial species by seals and the dispersal of seal-borne fish parasites.

In the gillnet fisheries along the Baltic coast, fish caught in gillnets cannot be protected against grey seals. Many methods to reduce losses and damage in these fisheries have been tried – so far with poor results. In order to find a solution, the conflict in the Baltic herring gillnet fisheries has been studied in detail as has grey seal behaviour around herring gillnets .The conclusions are presented in paper IV. An issue of great importance for solving or limiting the conflict in all coastal fisheries is that of whether seals raiding fishing gears are specialists or not. It is believed that certain seals have specialized in attacking fishing gear and return to the fishing gear to hunt the catch. This issue has been reviewed in paper V.

The gillnet fishery for cod in the central Baltic is, as is the herring gillnet fishery, impossible to protect from grey seals. The damage by seals has increased significantly recent years. The conflict in the cod gillnet fishery has been studied in detail in paper VI. Currently there is an alternative fishing gear under development for the cod fisheries, the two-chambered cod pot. The pots selectivity and potential as an alternative fishing gear is described in paper VII.

Interactions between harbour seals and coastal fisheries along the Swedish west coast Paper I, II and III

On the west coast of Sweden it is the eel fishery which suffers the greatest losses due to seals. Harbour seals are responsible for the bulk of the damage (Paper I; Königson et al., 2003; 2006; Lundström et al., 2010). The west coast eel fishery has been one of the most economically important segments of the Swedish small-scale fishing industry. However, at this time the future of the Swedish west coast eel fisheries is uncertain. This is due to regulations of the fisheries due to the fact that eel is a threatened species. Fyke nets, pound nets and eelpots are the types of fishing gear commonly used, with fyke nets being the principal gear in use and also the fishing gear most subjected to damage. Damage consists of tears or small holes in the net, mainly in the fish bag where the fish gather. Eels are also dragged through the mesh itself and bitten in half.

Seals that attack fyke nets prefer eels, in other words eels are the main reason why the fyke nets are attacked, even though the fish bags of a fyke net often contain many fish species that could be tempting to a seal (Paper I). A consequence of this is that the frequency of damage will intensify with increasing eel catches, which in turn will increase fishermen's economic losses. During an experimental cull in 2001, eight seals were killed in two areas with high incidents of net damage in order to see if gear damage decreased thereafter. Stomach contents from two of the seals culled in close proximity to the fyke net consisted mostly of eel (11 undigested eels from one of the seals' stomachs, figure 1).

Figure 1. The stomach contents of a seal consisting of 11 undigested eels. The seal was shot near to an eel fyke net in an area where fishing with fyke nets is common.

Several studies have shown that harbour seals feed on a variety of prey. The main prey species are herring, codfish and flatfish. A scat or faeces analysis during a three-year study in the Skagerrak identified 40 different species, but eels were rarely found (Härkönen, 1987; Härkönen and Heide- Jørgensen, 1991). It was concluded that eels are not normally part of a typical harbour seal's diet. This raised the question as to whether there were a few seals that had developed this feeding preference and were returning repeatedly to the same area to forage. Many studies have concluded that individual seals have a regular pattern of visiting the same feeding areas and then returning to their haul-out sites (Bjørge et al., 1995; Tollit et al., 1998). Tollit et al. (1998) also found that individual seals had different foraging habitats. They suggested that this might indicate an individual specialisation in certain predation and foraging techniques. The preference for eels in fyke nets and the results from the experimental cull showing stomach contents with eels as the dominant species, indicate that certain individuals have indeed specialised in this way.
In order to study seal behaviour around fyke nets and to determine if it might be the same seal or seals attacking the fyke nets repeatedly, we placed an underwater camera next to a fyke net containing eels to tempt the seal (Königson et al., 2003). Seals were observed on six occasions out of 521 filmed hours both night and day. On five of these occasions, the same seal was identified as the visitor (figure 2) repeatedly coming back to the fyke net during a period of almost two months.

Figure 2. Pictures of two of the five occasions when seals were identified attacking the baited fyke net. The pattern circled makes it possible to identify the seal.

How did this conflict intensify to the level that it is at today? Researchers have suggested that declining fish stocks might be one of the reasons why the conflict has intensified. However, the abundance of juvenile cod, which is one of the harbour seals' main prey on the west coast, did not decrease during the 1990s (Lagenfeldt and Svedäng, 1999), the period when seal damage increased rapidly. Herring, another prey which is highly significant in the harbour seals' diet, actually increased. Therefore declining fish populations is not a probable explanation for the increased conflict. It is more likely that certain seals have developed the behaviour of raiding fyke nets because it is energy saving and easy for the seal to find food in the fishing gear. The population has increased after the two epizootics and an increasing proportion of the population of seals might have developed this specialized behaviour.

In recent years the focus has been on the direct interaction including damage to catch and fishing gear. However, with an increasing population of harbour seals also the indirect interaction, such as competition for resource and dispersal of parasites, are of concern. The information on food habits of harbour seals in the Kattegat-Skagerrak area is outdated and does not reflect the present diet. There has been a significant change in fish populations in Kattegat and Skagerrak. Therefore it is not possible to evaluate the level of overlap and ecological interactions between the seals and fisheries. However, the predation on eel of a small number of seals may account for a large part of the mortality in the local eel stock (Paper I; Lundström et al., 2010).

Interactions between grey seals and coastal fisheries in the Baltic Sea
Paper IV, V, VI and VII
The longest history of seal interaction in Swedish fisheries since the late eighties is reported from the Gulf of Bothnia, where grey seals are responsible for most of the destruction. The fisheries most affected are the trap net fishery for salmon, sea-trout and whitefish and the gillnet fisheries for herring and whitefish.

Gillnet fisheries for herring in northern Baltic
This herring fishery is one of the fisheries with the highest frequency of seal damage along the Swedish coast. Fishing for herring with gillnets in the northern Baltic is carried out both in the spring and the autumn. It is often carried out with small boats handled by a single fisherman.

Small meshed gillnets in links up to 400 meters are set out in coastal areas during spring and further offshore during the fall. Fishermen have reported that damage by seals is most severe in the autumn when the accessibility of herring has decreased.

We have used the EU logbook, as well as voluntary reports, where fishermen report their catch, effort and seal interactions to study the amount of damage in the herring fisheries over the season. Our studies showed that level of damage increased in early spring and in the autumn. Seal interference was at its lowest during May to July, and reached a maximum by the end of the year (figure 3). This reflects the life histories of both the herring and the seal (Paper IV). In the late spring, herring spawn and aggregate in shallow waters near the coastline. This provides seals with an abundant food source, thus decreasing their motivation for visiting fishing gear. In the early spring, adult Baltic grey seals focus on mating - beginning right after weaning the pups in February-March. During this time the males do not eat at all (Bonner, 1972). Somewhat later, in May and June, the Baltic grey seals moult and spend most of their time on land (Söderberg, 1974).

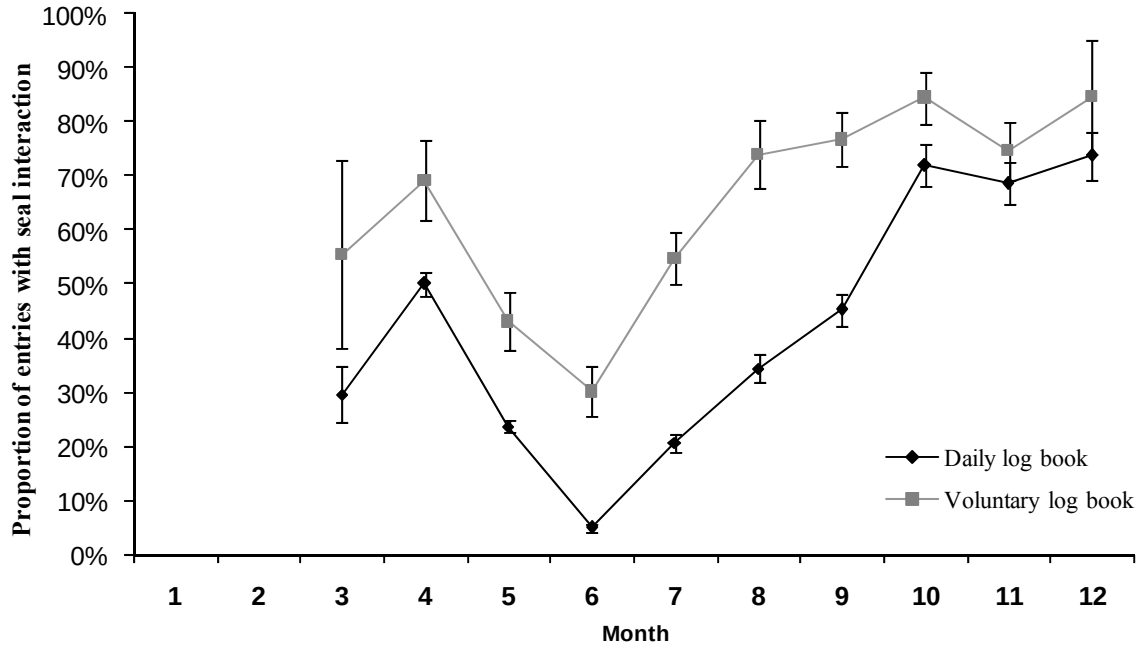

Figure 3. Relative frequency of seal interactions in the herring gill-net fisheries throughout the year, based on entries in the voluntary log-books (mean per month for 2003 and 2004), and in the daily log-books (mean per month for 2000 to 2005) in the northern Baltic, north of 60º00´N were use. Error bars showing s.e. For January and February, data from the daily log-books were excluded since there were no data in the voluntary log-books to compare with.

Damage by seals includes visible damage such as damaged fish and fishing gear as well as hidden losses. The latter include fish that are removed completely from the fishing gear, leaving no traces, and losses of fish that are scared away from the fishing area by seals patrolling the nets. These hidden losses are of great significance in the herring gillnet fisheries (Paper IV). Placing a net in an area where there are seals around is pointless, according to the fishermen. When this happens by mischance, in most cases the nets are retrieved with no catch at all, or only a few damaged fish remaining in the net.

Many solutions have been tried in order to reduce the negative impact of seals on the herring gillnet fisheries. The attempts have not been successful. However, the studies have added to our understanding of seal behaviour, which is important for further development of alternative fishing gear. One question among others was if seals use the marker buoys on the fishing gear to find the nets? Fishing grounds are often located in the open sea many nautical miles off the coast, where there are no landmarks to enable seals to find the fishing gear. Yet seals seem to arrive at the gear very quickly. Königson et al. (in prep) and Königson (2002) found that damage did not decrease when fishing gear was hidden under the surface with a submersible buoy, which surfaced when it was time to empty the nets. In another investigation, Fjälling et al. (2007) set out different sizes of buoys within a defined area, baited with herring underneath. A positive correlation between the buoy diameter and the proportion of missing bait was found. Most likely therefore, seals can, indeed, use their eyesight at short ranges for locating buoys above the surface. However, in the normal course of events it seems that seals locate the fishing gear without help from the surface marker buoys, so hiding the fishing gear is not an effective mitigation method for gillnet fisheries.

In another trial, an Acoustic Harassment Device (AHD) was submerged together with herring gillnets in the hope of keeping seals at a distance. AHDs have shown positive results when used in the trap net fishery in the Baltic (Fjälling et al., 2006). Catches increased and damage decreased when AHDs were in use next to the salmon traps. However, damage levels did not decrease when the AHD was used in the herring gillnet fishery. This could be because the device had many technical faults and did not always emit sound at the level it was supposed to. It is of great importance that AHDs emit sound at the right level. Otherwise there is no seal deterrent effect. With the herring gillnets set in deeper waters, we came to suspect that the device was working more as a dinner-bell than a harassment advice.

To test the dinner-bell theory, we placed an AHD close to the coast, with an observer on shore, to see if any seals having got used to associating this with the fishing gear in the earlier experiments would be attracted to the sound. On four out of five occasions seals did indeed approach the AHD after only half an hour. The AHD did work as a dinner-bell and we concluded that the seals had been using their hearing to locate the fishing gear more quickly than otherwise. Maybe seals can also learn to associate the noise of a fishing boat with a feeding opportunity and then follow the boat to the fishing area.

In order to distract the seals away from the fishing grounds large cages filled with herring were placed some distance from the fishing grounds. The results showed no apparent decrease in the damage of the catch and fishing gear. However, some interesting aspects of seal behaviour were revealed. By filming one of the cages we noticed that the same seals came back repeatedly every day for a week. Two seals were identified feeding from the cage (figure 4). By supplying a measured amount of herring in the morning, filming the two seals and then weighing the remains, we concluded that it was possible for the two seals to eat, on average, 32 kg of herring in 10 hours (Königson et al., in prep.). The cage was filmed and the remains weighed on three occasions. The amount of fish that a grey seal can eat has been much debated. The most common view is that grey seals consume between 3kg and 7kg per day (Rae, 1960; Innes et al*.,* 1987; Ronald et al., 1984 and Mansfield and Beck, 1977). Königson et al., (in prep.) showed that it is possible for a seal to eat as much as 16 kg per day during certain circumstances, which is a higher amount consumed fish than previously known.

The year after the feeding cage project was finished, a second experiment was carried out in the same location. Feeding cages were again filled with herring and a cull was carried out to eliminate the seals feeding from them. The hypothesis was that the seals that had specialised in

feeding from the provisioning cage might be the ones that were raiding the fishermen's nets. By eliminating these seals, damage to the fishery should consequently decrease. The experiment did not, in fact, produce any decrease in damage levels. However, it provided other interesting information. One previously identified seal did indeed return to the cage a year later and was then shot. The results from the feeding cage project provide the first indication that the same seals do return to a specific feeding site even after a long absence.

A. B.

Figure 4. A. The seal identified in 2004 at the feeding cage which returned every day to feed on herring. B. The same seal which returned to the feeding cage in the same area in 2005 and was culled. The pattern which made it possible to identify the seal is circled.

A development of a seal safe herring pontoon trap began in 2009. The traps can be used during the spring season when the herring aggregate in coastal areas. The herring pontoon trap is a promising alternative fishing gear for herring fisheries. The traps can be selective by releasing the undersized herring with the use of selection grids (Lundin, et al., 2011). A number of traps will be used in the commercial fisheries the spring 2011.

Trap net fisheries in northern Baltic

The trap net fishery in the Baltic is, in many respects a model fishery - being selective, energy saving and harmless to the benthic environment. The trap nets used in the fisheries are huge constructions that comprise a leader arm, a trap and a fish chamber where the fish gather. The trap nets are often placed in river mouths with the leader arm at a right angle to the shore line. The fisheries are carried out with small boats most often operated by one single man. Salmon, but also white fish follow the leader arm into the trap and finally get caught in the fish house. Seals have learnt to reach the catch in the fish chamber by entering the trap either via the main entrance, over the net panels or through a hole torn in the side of the fish chamber. They also use the net panels of the trap to hunt fish on their way into the fish chamber. Many measures have been tried to reduce the seal damage. However, the most successful measure has been the recently developed 'push-up' fish chamber, which keeps the caught fish protected from the seals (Suuronen et al., 2006; Lunneryd et al., 2003; Hemmingsson et al., 2008) (figure 5). This fish chamber, in combination with a large mesh trap that prevents seals from using the trap to hunt fish as it allows fish to escape through the net when being chased, is a successful development of seal-safe fishing gear (Lunneryd et al., 2003). The traps are now used by 86 % of the Swedish salmon trap fishermen along the northern Baltic coast (Hemmingsson and Lunneryd, 2007. However, during past years reports of damaged catch by seals in the pontoon

fish chamber are common. This indicates that there is still a problem in this fishery even though the pontoon chamber as well as the large mesh trap is used.

Figure 5. The pontoon' trap, here seen on its way up to be emptied, consists of a fish chamber connected to a large mesh trap.

Our earlier described studies on grey seals as well as harbour seals indicate that there are a few seals specializing in attacking fishing gear. However, we wanted to resolve this question also with regard to the grey seals in the Baltic. To get an answer to this, underwater cameras were placed on trap nets in areas where seal damage was common. Seals were filmed when they attacked fish caught in the trap net. This gave us pictures of individual seals from many directions. Each grey seal has an individual pattern, and this natural marking allows identification of a large subset of the population. Photo-identification techniques obtaining individual marking data of marine mammals have been developed and successfully applied for a number of species (Wursig and Wursig 1977; Hiby and Lovell 1990; Clapham and Mayo 1990; Jones 1990). Königson et al., (in prep.) and Paper V showed that recognition of individual seals is possible also through underwater photo-identification. By identifying individual seals raiding a salmon trap the question of whether seals specialized in raiding stationary fishing gear do return to the fishing gear to hunt was finally answered. In Paper V it was concluded that a number of seals do return to hunt in the traps and that many seals also return after a longer period of time. This knowledge has been crucial in the work of finding mitigation methods for the salmon trap fisheries. We now know that it is possible to limit the damage by limiting the number of individual seals raiding salmon traps. A salmon trap that also encloses seals attacking the catch has been developed and is available on the market. Care is taken to float the fish chamber where the seal is caught to secure free access to the water surface so trapped seal can breathe freely. When the seal is trapped an alarm is activated and sent to the fishermen. When the trap is lifted the seal is still alive and can be put to death in a

humane way. This method is also used in Finland to selectively remove nuisance seals as well as capturing live seals for scientific studies (Lethonen and Suuronen, 2010).

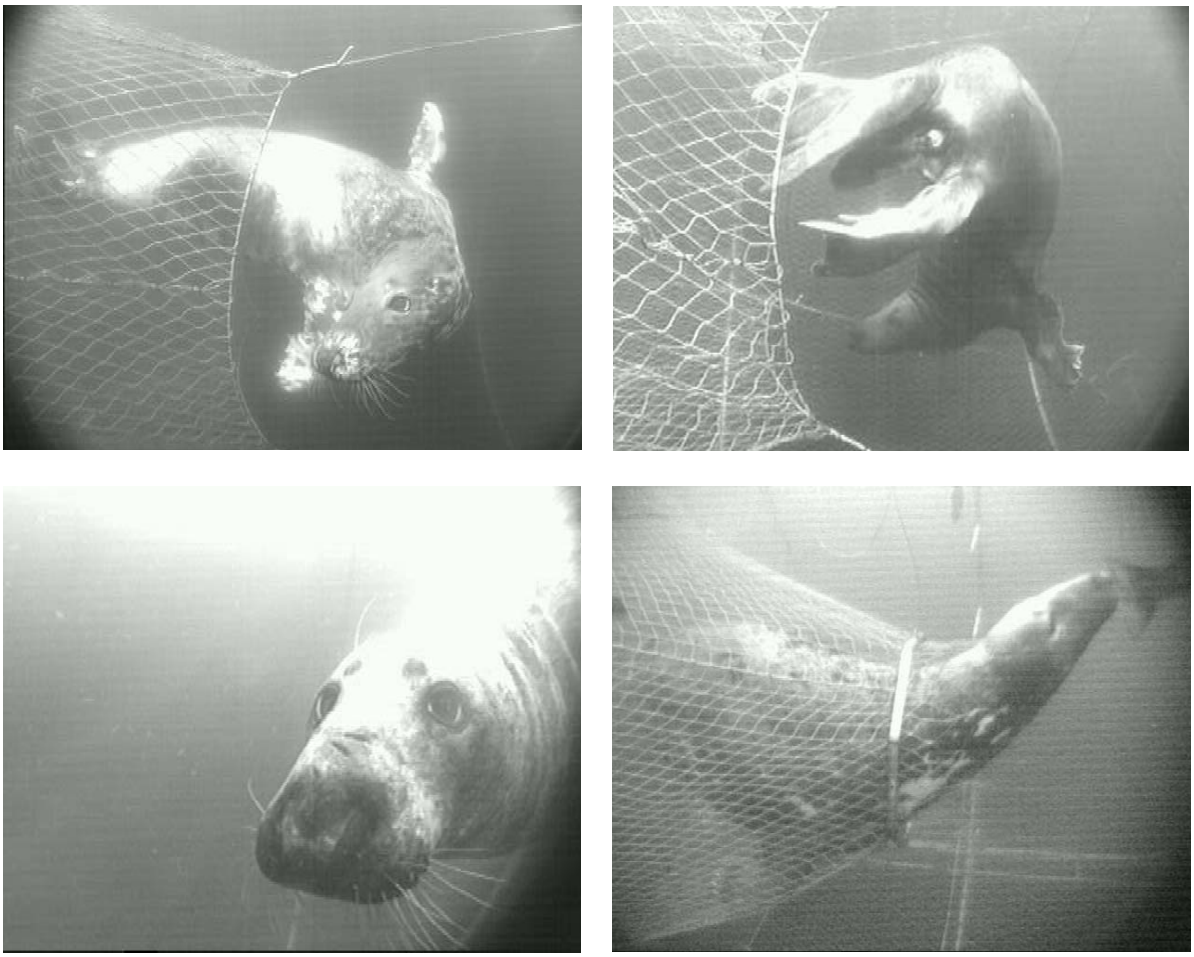

Figure 6. Four seals with individual characteristic markings all identified when raiding a salmon trap.

Gillnet fisheries for cod in central Baltic

Another fishery where the economic losses due to seals are significant is the gillnet fishery for cod in central Baltic. It is one of the most economically important fisheries along the Swedish coast. The coastal cod fishery is often carried out with small boats handled by a single fisherman. The fishing gear used is bottom set gill nets about 100m long, linked together in rows of about seven to ten nets, creating a fleet. Several fleets, which together can be about 6000m long, are often set during one fishing trip. Longlines, which can include up to 2000 baited hooks, are also used when fishing for cod in coastal waters. In recent years, there have been an increased number of reports of seal damage in the cod fisheries of central Baltic. (Swedish Board of Fisheries, 2009). The seal population has also increased during this period, however, not as fast as the increase of reported damage in central Baltic. As in the case of the herring fishery, hidden losses are significant in the cod gillnet fishery. In Paper VI it was estimated that for each found fish remain at least 4.1 fish were lost to seals without a trace. The hidden losses can, in a fishery subjected to seal damage, account for as much as 36% of the total potential catches or 67% of the landed catches. In paper VI it was concluded that grey seals' impact on the cod gillnet fishery is negative and serious and should therefore

be taken into consideration in the management plans for cod as well as for grey seal. Seals represent a larger threat to the cod fishery in the Baltic than is commonly appreciated.

The knowledge gained from studies in the herring fisheries as well as the trap net fisheries for salmon will come to use when trying to find a solution to the increased damage in the cod gill net fisheries in the central Baltic. During the recent three years the Swedish Board of Fisheries has been studying cod pots as an alternative to the gillnet fisheries for cod in central Baltic and the results are promising (Paper VII; Königson et al., 2010). Pots are used in a variety of different fisheries and are known to use less energy in operation than active gears. They are less destructive to the benthic habitat compared with gear and they can be left in the water for long time periods. They also deliver the catch alive, increasing its commercial value. But equally importantly, the catch is gathered in a closed department which makes it possible to develop a seal-safe fishing gear. The Swedish Board of Fisheries has studied the fishing efficiency of the "two-chamber" pots in a commercial fishery for a few years. The results show that the pots can potentially be used in a commercial fishery (Paper VII; Ljungberg 2007; Ovegård, 2009) and that the catch in pots are comparable to the catch in gillnet fisheries (Königson et al., 2010.). However, the two-chamber pot is not seal-safe at this point in time and currently seal-safe alternatives are under development..

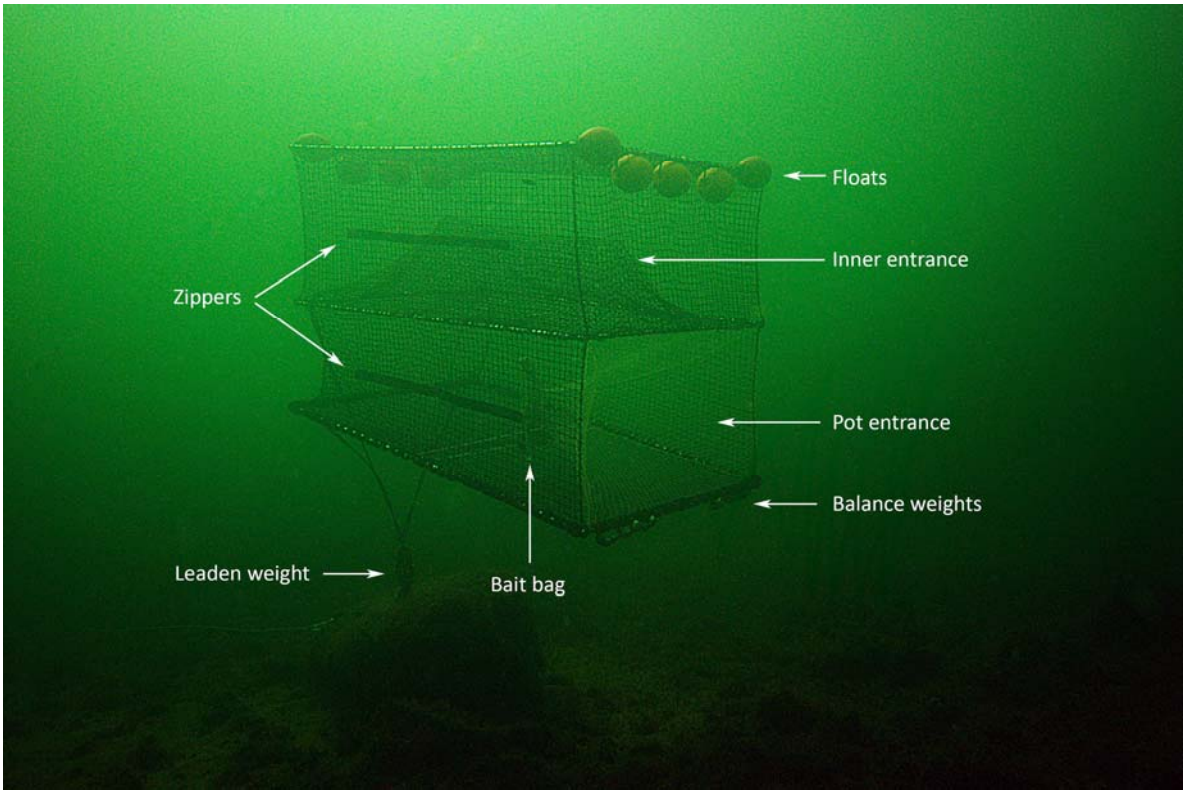

Figure 7. The two-chamber pot floating just above the bottom. When the pot is floating the entrance will be in the direction of the current. This enables for the cod to follow the scent from the bait bag into the pot. Usually eight pots are set in a link with a distance of 60 meters between them.

Conclusions and recommendations

The most successful method to-date for mitigating the seal-fishery conflict is the development of seal-safe fishing gear. It has proven to be possible to make passive fishing gear such as traps and fyke nets seal-safe. In the eel fishery along the west coast, seal-safe fyke nets have been

developed and successfully implemented in the fisheries. These fyke nets have a stronger material in the fish chamber where the fish gather. Replacing standard fyke nets with seal-safe fyke nets not only decreases damage by seals but can also lead to increased catches in areas where seal attacks are a problem. Seal-safe fyke nets is now an accepted measure for decreasing the damage caused by harbour seals. The cost of modifying fyke nets can be subsidised by local authorities, using funds from the Swedish Environmental Protection Agency. A general goal is that all fyke nets used along the coast will be replaced with seal-safe fyke nets in order to prevent seal damage in fishing areas. Filming has shown that seals put in a lot of effort when raiding a standard fyke net. In case of seal-safe fyke nets the energy cost for the seal when trying to tear through the strong material will be very high. This is likely to act as a disincentive for attacks and cause specialised seals to abandon the behaviour of attacking fishing gear.
Harbour seals, have specialized in attacking fyke nets and developed a certain feeding preference for eels. If hunting of seals is considered as a measure to reduce the levels of damage in the fisheries, it should be limited to areas close to fyke nets which have been attacked rather than random culling seals in a haul-out area.
Grey seals have, in common with harbour seals along the west coast, also specialized in raiding fishing gear. By limiting the number of "specialised" seals it is possible to limit damage if only to the extent of limiting its increase. This can been done in trap net fisheries. A salmon trap, which encloses attacking seals has been developed and is at this point available on the market.
In gillnet fisheries the nets are often placed far out in deep water and extend over long distances. In the long-term, mitigation methods, such as the development of new fishing gear, represent the most sustainable solution in these fisheries. However, in the herring gillnet fishery, as for many other gillnet fisheries, there is no simple solution to the conflict. Today the only reasonably seal-safe alternative fishing method available is trawling, which has several other negative consequences such as high energy consumption, reduced selectivity with regard to the size of herring, and a generally larger by-catch of unwanted fish species. However, a new alternative fishing gear, a large seal-safe herring trap to be used in the spring, are under development and will be implemented in the spring 2011.
For the cod gillnet fishery in central Baltic, where seal damage has increased rapidly over the past five years, there now exists a promising alternative to gillnets. Two-chamber cod pots have been tried out in commercial fisheries and results show that they have potential to catch a large amount of fish while at the same time reducing seal damage.

In conclusion; seals affect the small-scale coastal fisheries negatively and seriously and this fact needs to be taken into consideration in any management plans for both the grey seal and the harbour seal. Because of this, the conflict needs to be managed in three ways: alternative fishing gear, economic compensation and lethal removal of individual specialist seals.

Acknowledgements
This thesis has been written with course of my work at the Swedish Board of Fisheries. The people who have supervised and supported me through the whole process are my close colleagues. Some of them are unfortunately not working in our team anymore. However, they have during many years supported and contributed to the team with their loyalty, hard work, great ideas, knowledge and of course their stubbornness. Special thanks goes to Sven-Gunnar Lunneryd, Malin Hemmingsson, Arne Fjälling and Karl Lundström. Without your support I would not have been where I am today. I would also like to thank Håkan Westerberg, the initiator of Project Seals and Fisheries, and a mentor to all of us working with these questions.

In all our projects we have been working closely with fishermen. Their knowledge and help has been most vital. So I would like to thank all fishermen who participated in this project. Bengt Börjesson introduced me to the eel fishery on the west coast. Dennis Westlund taught me everything I know about the herring gillnet fisheries and showed us how to have a great time in a very small village. Magnus Sandin and his family showed my students and me great hospitality. Together with Tore Johnsson and Magnus Sandin, we went fishing for cod even thought seals were most often way ahead of us. Runo and Peter Nordin took an active interest when we caught seals raiding their fish traps. Also thank you, Göran and Kurt Olofsson, for starting a totally new fishery with cod pots and for having faith in this new method even though it must have felt as if no one believed in us.
Thank you, Malin Berglind for your commitment and hard work in identifying many individual seals. Thank you, David Börjesson, who put in hard work with good humour during too short time, I wish you could have stayed longer. Dan Tilander watched videos on seals and gave us inside information about off-shore fisheries. Fredrik Ljunghager is not only someone that I have relied upon during the past years - he is also highly committed to his work. This has been invaluable for the work we carried out in the cod pot fisheries. Thanks also to our volunteers and students, Irene Weinberger, Anna Söderlind, Marie Mårtensson, Heide Stridh, Frida Sundqvist, Peter Ljungberg and Mikael Ovegård for your devoted commitment and helping out during long hours at sea. Without your help many projects would never have been carried out. Graham Timmins have always giving me great advice on short notice and Britta Carlström who has with great enthusiasm helped me searching for and getting hold of articles and literature.
Since Project Seals and Fisheries has been a part of the Coastal laboratories everyone working in Öregrund, Ringhals and Simpevarp has welcomed us and made us feel as a part of their team. A special thought to Johan Modin, who is not with us today, for the encouragement you gave me. Johan described our work as simple and clear and actually leading to changes in fisheries. Thank you, Per Johnson, for seeing the possibility for me to finish my Ph D even if I am not “following the book”. Thank you all!

I would also like to thank my family for encouraging me, especially my father Lennart Königson, who helped out finalizing this thesis. Thanks also to my mother Eva Königson for always helping out with my beloved rascals when their mother needed time to write. Thanks to Lena Granhag the founder of “Blända kollektivet” for all your good advice, which has been very useful. Finally, if I am to dedicate this to anyone, it needs to be to Hjalmar and Vilgot. You rushed into my life, just like that, giving me everything in life worth living for. You are happy for the smallest things: cars (Blixten Mc Queen), candy, cookies and being together with us as a family. I love you endlessly. Henkan, who made me smile just by looking at me, I will be grateful to you for the rest of my life for bringing the two rascals into our lives. But besides that you are the most important person in my life and your support and judgement means a lot to me (so please start laughing at my jokes because I am really funny and it would make my heart jump). Thank you!
The projects described in the thesis were mainly funded by the Programme Seal and Fisheries who is funded by the Swedish Board of Fisheries and the Swedish Environmental Protection Agency. Other important contributors were the European Union Structural fund for fisheries (EFF) and the Nordic Council of Ministers.

Referenses

Adams, A., Murell, K. D. and Cross, J. H. 1997. Parasites of fish and risks to public health. Revue Scientifique et Technique de la Office International de Epizootics 16:652-660

Baltscheffsky, S. 1997. Seals in the Bothnian Sea: From endangered species to coastal nuisance. Enviro 23

Bergman, A., and Olsson, M. 1986. Pathology of Baltic grey seal and ringed seal females with special reference to adrenocortical huperplasia: is environmental pollution the cause of a widely distributed disease syndrome? Finnish Game Research 44:47-62

Bjørge, A., Thompson, D., Hammond, P., Fedak, M., Bryant, E., Aarefjord, H., Roen, R., and Olsen, M. 1995. Habitat use and diving behaviour of harbour seals in a coastal archipelago in Norway. In Whales, seals, fish and man. Edited by Blix, A.S., Walloe, L., and Walltang, O. Elsevier, Amsterdam 211-223

Bjørge A., Bekkby T., Bakkestuen V., and Framstad E. 2002. Interactions between harbour seals, Phoca vitulina, and fisheries in complex coastal waters explored by combined Geographic Information System (GIS) and energetics modelling. ICES Journal of Marine Science 59:29–42

Butler J., Middlemas S., Graham I., Thompson P., and Armstrong P. 2006. Modelling the impacts of removing seal predation from Atlantic salmon, Salmo salar, rivers in Scotland: a tool for targeting conflict resolution. Fisheries Management and Ecology 13:285–291

Bonner, W. 1972. The grey seal and common seal in European waters. Oceanography Marine Biology: An Annual Review 10:461-507

Bruckmeier K., Westerberg H., and Varjopuro, R. 2010. Findings from the case studies in the Baltic Sea, reconciliation in practice. In Human – Wildlife Conflicts in Europe. Eds. Klenke, R.A., Ring I., Kranz A., Jepsen N., Raushmayer F., and Henle K. Springer, Berlin.

Carter T., Pierce G., Hislop J., Houseman J., and Boyle P. 2001, Predation by seals on salmonids in two Scottish estuaries. Fisheries Management and Ecology 8:207-225

Chouinard, G., Swain, D., Hammill, M., and Poirier, G. 2005. Covariation between grey seal (Halichoerus grypus) abundance and natural mortality of cod (Gadus morhua) in the southern Gulf of St. Lawrence. Canadian Journal of Fisheries and Aquatic Sciences 62:1991-2000

Clapham, J., and Mayo, C. 1990. Reproduciton of humpback whales (Megaptera nwaeungliae) observed in the Gulf of Maine. Report of the International Whaling Commission 12:171-176

Etnier, M., and Fowler, C. 2010. Size Selectivity in Marine Mammal Diets as a Guide to Evolutionarily Enlightened Fisheries Management. North American Journal of Fisheries Management 30:588–603

Fjälling, A. 2004. Assessment and reduction of the conflicts between commercial fisheries and grey seals (Halichoerus grypus) in Swedish waters. Licentiate Thesis. Institute of Technology, Linköping University.

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

Fjälling, A., Wahlberg, M., and Westerberg, H. 2006. Acoustic harassment devices reduce seal interaction in the Baltic salmon-trap, net fishery. ICES Journal of Marine Science 63:1751-1758

Fjälling, A., Kleiner, J., and Beszyńska, M. 2007. Evidence that Grey seals (Halichoerus grypus) use above-water vision to locate baited buoys. NAMMCO Scientific Publication. 6:215-227.

Halkka, A., Helle E., Helander B., Jüssi I., Jüssi M., Karlsson O., Soikkeli M., Stenman O., and Verevkin M. 2005. Number of grey seals counted in censuses in the Baltic Sea, 2000 – 2004. In: Helle E., Stenman O., and Wikman M. (eds); Symposium on Biology and Management of Seals in the Baltic Sea Area, Helsingfors 12-13

Harding, C., Härkönen, T., and Caswell, H. 2002. The 2002 European seal plague: epidemiology and population consequences. Ecology letters 5:727-732

Haug, T., and Nilssen, K. 1995. Ecological implications of harp seal Phoca groenlandica invasions in northern Norway. In Whales, seals, fish and man. A .S. Blix, L. Walløe, and Ø. Ulltang (eds.). Proceedings of the International Symposium on the Biology of Marine Mammals in the Northeast Atlantic, Tromsø, 29 November–1 December 1994. Developments in Marine Biology, Elsevier 4:545–556

Havet 2010. Om miljötillståndet i svenska vatten. Ges ut av Naturvårdsverket och Havsmiljöinstitutet. www.havet.nu

Heide-Jörgensen, M-P., and Härkönen, T. 1988. Rebuilding seal stocks in the Kattegat-Skagerrak. Marine Mammal Science 4(3): 231-246

Helle, E., Olsson, M., and Jensen, S. 1976. Sälarna i Östersjön och miljögifterna. Fauna och Flora 71(2): 41-48

Hemmingsson, M., and Lunneryd, S.G. 2005. Inventering av sälskadesituationen i Västerbottens- och Norrbottens län. Report to the Project Seals and Fisheries.

Hemmingsson, M., and Lunneryd, S.G. 2007. Pushup-fällor i Sverige, Introduktionen av ett nytt sälsäkert fiskeredskap. (Push-up traps in Sweden, the introduction of a new seal-safe fishing gear). Finfo Fiskeriverket informerar 8 (in Swedish, with English summary).

Hemmingsson, M., Fjälling, A., and Lunneryd, S-G. 2008. The pontoon trap: Description and function of a seal-safe trap-net. Fisheries Research 93:357–359

Hiby, A., and Lovell, P. 1990. Computer aided matching of natural marks: A prototype system for gray seals. Report of the International Whaling Commission 12:57-62

Hiby, L., Lundberg, T., Karlsson, O., Watkins, J., Jüssi, M., Jüssi, I., and Helander, B. 2007. Estimates of the size of the Baltic grey seal population based on photo-identification data. NAMMCO Scientic Publication 6:163-175

Härkönen, T. 1987. Seasonal and regional variations in the feeding habits of the harbour seal, *Phoca vitulina*, in the Skagerrak and the Kattegat. Journal of Zoology 213:535-543

Härkönen, T., and Lunneryd, S.G. 1990. Knubb- och gråsälen i Kattegatt-Skagerrak. (Harbour and grey seals in the Kattegat and Skagerrak areas). Fauna och flora 85: 129-139

Härkönen, T., and Heide-Jørgensen, M. 1991. The harbour seal *Phoca vitulina* as a predator in the Skagerrak. Ophelia 34(3):191-207

Härkönen, T., Hårding, K., Goodman, S.J., and Johannesson, K. 2005. Colonization history of the Baltic Harbour seals: Integrating archaeological, behavioural and genetic data. Marine Mammal Science 21(4):695-716

Hårding, K., and Härkönen T. 1999. Developments in the Baltic grey seal (*Halichoerus grypus)* and ringed seal *(Phoca hispida)* populations during the 20th century. Ambio 28:619-627

Innes, S., Lavigne, D.M., Earle, W.M., and Kovacs, K. 1987. Feeding rates of seals and whales. Journal of Animal Ecology 56:115-130

Jones, M. 1990. The reproductive cycle in gray whales based on photographic resightings of females in the breeding grounds from 1977-82. Report of the International Whaling Commission 12:177-182

Jounela, P., Suuronen, P., Millar, R.B., and Koljonen, M-L. 2006. Interactions beteen grey seal (*Halichoerus grypus*), Atlantic salmon (*Salmo salar*) and harvest controls om the salmon fishery in the gulf of Bothnia. ICES Journal of Marine Science 63:936-945

Karlsson, O., and Helander B. 2005. Development of the Swedish Baltic grey seal stock 1990-2004. In: Helle E., Stenman O., and Wikman M. (eds); Symposium on Biology and Management of Seals in the Baltic Sea Area, Helsingfors 17

Kaschner, K., Watson, R., Christensen, V., Trites, A., and Pauly, D. 2001. Modeling and mapping trophic overlap between marine mammals and commercial fisheries in the North Atlantic. In: Impacts on North Atlantic Ecosystems: Catch, Effort & National/Regional Datasets. Eds. Zeller, D., Watson, R., and Pauly, D. Fisheries Centre Research Reports 9(3):35-45

Kaschner, K., and Pauly, D. 2004. Competition between Marine Mammals and fisheries: Food for thought. Report for the Human Society of the United States.

Kauppinen, T., Siira A., and Suuronen P. 2005. Temporal and regional patterns in seal-induced catch and gear damage in the coastal trap-net fishery in the northern Baltic Sea: effect of netting material on damage. Fisheries Research 73:99-109

Königson, S. 2002. Torsk och strömmingsfiske med pop-up boj som vakare. Report to the Project Seals and Fisheries.

Königson, S., Lunneryd, S.G., and Lundström, K. 2003. Sälskador i ålfisket på svenska västkusten. En studie av konflikten och dess eventuella lösningar. (The seal-fisheries conflict on the west coast of Sweden. An investigation of the problem and its possible solutions). Finfo Fiskeriverket informerar 9:1-24

Königson, S., Ljunghager, F., and Lunneryd, S-G. 2010. Torskburar - ett lovande alternativ till garnfisket. Report to the Swedish Board of Fisheries and the Project Seals and Fisheries.

Königson, S., Ljunghager, F., and Lunneryd, S-G. 2010. Lovande torskfiske med bur. Havsutsikt 3:8-9

Königson, S., Lunneryd, S.G.., Lundström, K., and Fjälling, A. 2011. (in prep.) Sälskador i skötfisket efter strömming i Bottenhavet.

Lagenfeldt, I., and Svedäng, H. 1999. Fisk och fiske i Västerhavet och Öresunds kustområden. Fiskeriverket rapport 99:7

Lethonen, E., and Suuronen, P. 2010. Live-capture of grey seals in a modified salmon trap. Fisheries Research 102: 214–216

Ljungberg, P. 2007. Evaluation of baited pots in the fishery for cod, (*Gadus morhua*) within the southeast Baltic. Master thesis at Lund University

Lundin, M., Calamnius, L., Hillström, L., and Lunneryd, S.G. 2011. Size selection of herring *(Clupea harengus membras)* in a pontoon trap equipped with a rigid grid. Accepted by Fisheries Research

Lundström, K., Hjerne, O., Alexandersson, K., and Karlsson, O. 2007. Estimation of grey seal (*Halichoerus grypus*) diet composition in the Baltic Sea. NAMMCO Scientific Publications 6: 177-196

Lundström, K., Hjerne, O., Lunneryd, S-G., and Karlsson, O. 2010. Understanding the diet composition of marine mammals: grey seals (Halichoerus grypus) in the Baltic Sea. ICES Journal of Marine Science 67: 1230–1239.

Lunneryd, S.G. 2001. Fish preference by harbour seal (*Phoca vitulina*), with implications for the control of damage to fishing gear. ICES Journal of Marine Science 58(4): 824-829

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

Lunneryd, S.G., Königson, S., and Sjöberg, N. 2004. Bifångst av säl, tumlare och fåglar i det svenska yrkesfisket. By-catch of seals, harbour porpoises and birds in the Swedish commercial fisheries. Finfo 2004:8

Mansfield, W., and Beck, B. 1977. The grey seal in eastern Canada. Fisheries and Marine Service. Technical Report 704

Merrick, R. 1997. Current and historical roles of apex predators in the Bering Sea ecosystem. Journal of Northwest Atlantic Fishery Science 22:343-356

Nilssen, K., Grotnes, P., and Haug, T. 1992. The effect of invading Harp seals (Phoca groenlandica) on coastal fish stocks of North Norway. Fisheries Research 13:25-37

Olsson, M., Karlsson, O., and Ahnland, E. 1994. Vad händer med sälarna. SNV Rapport 4254

Ovegård, M. 2009. The effect of selection windows on the capture of cod (Gadus morhua) in floated pots. Master thesis at Lund University

Pauly, D., Trites, A. W., Capuli, E., and Christensen, V. 1998. Diet composition and trophic levels of marine mammals. ICES Journal of Marine Science 55: 467–481

Perdiguero-Alonso D., Montero, F.E., and Juan Antonio Raga, J.A. 2008. Composition and structure of the parasite faunas of cod, Gadus morhua L. (Teleostei: Gadidae), in the North East Atlantic. Parasites & Vectors 1:23

Stridh, H. 2006. Can grey seal (*Halichoerus grupus)* learn to use acoustic deterrents to locate fishing gear? Master thesis at Stockholm University

Sundqvist, F. 2005. An Assessment of the True Damages caused by Grey Seals, *Halicoerus grypus*, in the Swedish Baltic Net Fishery after Atlantic Cod, *Gadus morhua.* Master thesis at Lund University

Rae, B. 1960. Seals and Scottish fisheries. Marine Research 2

RKTL. Finnish Game and Fisheries Research Institute. http://www.rktl.fi/svenska/

Ronald, K., Keiver, K., Beamish, F., and Frank, R. 1984. Energy requirements for maintenance and faecal and urinary losses of the grey seal (*Halichoerus grypu*s). Canadian Journal of Zoology 62:1101-1105

Suuronen, P., Siira, A., Kauppinen, T., Riikonen, R., Lethonen, E., and Harjunpää, H. 2006. Reduction of seal-induced catch and gear damage by modification of trap-net design: Design principles for a seal-safe trap-net. Fisheries Research 19:129-138

Swedish Board of Fisheries. 2001. Småskaligt kustfiske och insjöfiske - en analys. 146 p. https://www.fiskeriverket.se/download/18.1e7cbf241100bb6ff0b80001729/Kustfiskerapp_2001.pdf

Swedish Board of Fisheries. 2008. Fiskbestånd och miljö i sötvatten. Resurs och miljö-översikt. 180 p.
https://www.fiskeriverket.se/download/18.2cd9c4ad11a113f131a8000100/RoM2008-web.pdf

Swedish Board of Fisheries. 2009. Fish stocks and environment in marine and inland waters. Swedish Assessments 2009, 205 p.
https://www.fiskeriverket.se/download/18.7e2791921225aba85fa80001361/RoM_eng_web.pdf

Söderberg, S. 1974. Feeding habits and commercial damage of seals in the Baltic. In: Proceedings of the Symposium on the Seal in the Baltic. Swedish Environment Protection Agency, Lidingö, Sweden 66-78

Tamura, T. and Ohsumi, S. 1999. Estimation of total food consumption by cetaceans in the world's ocean. Institute of Cetacean Research, Tokyo, 15pp

Tamura, T. and Ohsumi, S. 2000. Regional assessments of prey consumption by marine cetaceans in the world. SC/52/E6. In: International Whaling Commission, Adelaide, Australia. 41pp

Teilmann, J., Rige´t, F., and Härkönen. T. 2010. Optimizing survey design for Scandinavian harbour seals: population trend as an ecological quality element. ICES Journal of Marine Science 67(5): 952-958

Tollit, D., Black, A., Thompson, P., Mackay, A., Corpe, H., Wilson, B., Parjis, S., Grellier, K., and Parlane, S. 1998. Variations in Harbour seal *Phoca vitulina* diet and dive-depths in relation to foraging habitat. Journal of Zoology 244, 209-222.

Trites, A. 1997. The role of pinnipeds in the ecosystem. In Pinniped populations, eastern north Pacific: Status, Trends and issues. Eds. Stone, G., Goebel, G., andWebster, S. Boston, MA: New England Aquarium, Conservation Department 31-9

Trites, A., Christensen, V., and Pauly, D 1997. Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. Journal of Northwest Atlantic Fisheries Science 22:173-187

Trites, A., Christensen V., and Pauly. D. 2006. In Top Predators in Marine ecosystems: their role in monitoring and management, eds. I. L. Boyd, S. Wanless and C. J. Camphuysen. Published by Cambridge University Press. Cambridge University Press 2006

Tyrrel, M.C., Link, J.S., and Moustahfid, H. 2011. The importance of including predation in fish population models: Implications for biological reference points. Fisheries Research 108 (1):1-8

Westerberg, H., Fjälling, A., and Martinsson, A. 2000. Sälskador i det svenska fisket. (Seal damage in the Swedish fishery). Fiskeriverket Rapport 3:4-38

Westerberg, H., Lunneryd, S-G., Fjälling, A., and Wahlberg, M. 2006. Reconciling Fisheries Activities with the Conservation of Seals throughout the Development of New Fishing Gear: A Case Study from the Baltic Fishery–Grey Seal Conflict. American Fisheries Society Symposium 587-598

Wickens, P. 1995. A review of operational interactions between pinnipeds and fisheries. FAO Fisheries Technical Paper 346

Wright, B., Riemer, S., Brown, R., Ougzin, A., and Bucklin, K. 2007. Assessment of harbour seal predation on adult salmonids in a Pacific Northwest eustary. Ecological applications 17(2):338-351

Wursig, B., and Wursig, M. 1977. The photographic determination of group size, composition, and stability of coastal porpoises (Tursiops truncates). Science 198(4318):755–776

Yurk, H., and Trites, A: W. 2000. Experimental Attempts to Reduce Predation by Harbor Seals on Out-Migrating Juvenile Salmonids. Transactions of the American Fisheries Society 129:1360–1366

Österblom, H. 2006. Complexity and change in a simple foodweb –Studies in the Baltic Sea (FAO Area 27.111.d) Ph D thesis at Stockholm University