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# Behaviour of grey seals (*Halichoerus grypus*) and their prey in and near set traps

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Front cover: Male grey seal near a pontoon trap. Photo: Linda Calamnius.
Back cover: Two fishers working by a lifted pontoon trap. Photo: Linda Calamnius.

## Abstract

The seal populations of the Baltic Sea Area were at historically low levels in the 1970's, due to two factors. The first was an extensive hunt and the second was emissions of organochlorines, which affected the reproductive abilities of the females. Laws and regulations were set in force to improve the marine environment and from the early 1990's the populations of the grey seal (*Halichoerus grypus*), the harbour seal (*Phoca vitulina*) and the ringed seal (*Pusa hispida*) have recovered. It is a success for the management of the Baltic Sea Area environment that the seal populations have increased. Coupled with the increase of the populations, is also an increase of conflicts with the inshore fisheries. The seals frequenting the fishing gear takes fish and damage gear. It is mainly the grey seal which is the culprit and it is predominantly males. These males have been proven to be specialists.

Two studies were conducted to learn more about the behaviour of seals and of their prey. The first study investigated the pattern of seal visits in the middle chamber of a herring pontoon trap. A camera filmed the seals which entered and the seals were identified. There were almost 1400 visits by 12 individuals. Of all visits, 84 % took place within 5 minutes of each other. Of all visits, 3.7 % were concurrent visits, i.e. two males inside the middle chamber at the same time. By studying these visits in detail, it could be concluded that there was a dominance hierarchy among the seals in the trap. A simulation of the visits was executed to examine whether the proportion of concurrent visits was random or non-random. The simulations used the same distribution pattern of the realized visits. If the visits had been random, then c 9.5 % of them would have been concurrent. This suggests that there is a pattern to their visits.

The second study investigated the effect of a Seal Exclusion Device (SED) on seal visits and on catch. The experiment was conducted during two years. In 2012, using a SED with a diamond mesh and in 2016 using two SEDs; the diamond mesh and a square mesh - with the entire frame rotated 45°. The expectation was that the SEDs would reduce the number of seal visits, increase the catch and possibly deter larger fish from entering. In 2012, the diamond mesh had an effect on the size of trout, with larger trout entering the control trap, whereas large salmon were not affected by the presence of the SED. In 2016, larger salmon were caught in the traps with a SED. There was no significant result regarding the catch of trout, possibly due to small samples. The number of seal visits in both sets of experiments were too low to be able to draw any conclusions regarding presence of seals. The SEDs did not have any effect on the quantity of caught fish.

*Keywords:* grey seal, inshore fisheries, mitigation means, Seal Exclusion Device, Baltic Sea Area

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# Glossary

(including abbreviations and acronyms)

| | |
|---|---|
| adapter | In pontoon traps*, the chambers between the wings* and the final parts of the pontoon trap. |
| Baltic Sea Area | The internal waters south and eastwards of the parallel at Skaw in Skagerrak, 57° 44.43'N. |
| blubber | A thick, fat layer which insulates certain marine mammals from cold. For example seals and whales. |
| BSAP | Baltic Sea Action Plan. A programme to restore good ecological status of the Baltic Sea Area. |
| bycatch | Discarded catch plus incidental catch. |
| carrying capacity | The number of individuals in a population(s) which the ecosystem can sustain. Often referred to as *K**. |
| cephalic | Referring to the head. |
| concurrent visit | In the current study; two seals in the middle chamber at the same time. |
| DDT | Dichloro-diphenyl-trichloroethane. An organochlorine*. Classified as a persistent organic pollutant. Accumulates in the food chain and causes, e.g. thin egg shells in birds and uterine occlusions in seals. It is banned in most countries. It is still used in some, as it is inexpensive and efficient in controlling malaria carrying mosquitoes. |
| discard | When used in fisheries; returning unwanted caught fish into the sea. |
| dyad | A group of two. |
| e.g. | Abbreviation of the Latin "exempli gratia." Used in English as an abbreviation for "for example." |
| endothermic | An organism relying on internal processes for heat production. |
| eutrophic | Rich in nutrients. |
| FAO | Food and Agriculture Organization of the United Nations. |
| fish chamber | The final part of the pontoon trap*. The pontoons are placed under this chamber. When they are filled with air from a compressor, the fish chamber is lifted to the surface. The fisher harvests the catch by opening a hatch in the bottom of the fish chamber. |
| HELCOM | The governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. |
| i.e. | Abbreviation of the Latin "id est." Used in English as an abbreviation for "which means" or "in other words." |
| inshore fisheries | Fishery conducted in the coastal waters. The boats are often under 12 m |
| *K* | Carrying capacity*. The maximum size of a population which can be sustained by the environment. |
| leading net | In pontoon traps*, the net which extends from land to the wings. Its purpose is to lead the migrating fish into the wings of the trap. |
| LIFE fishing | Low Impact Fuel Efficient. |
| Limit Reference Level | The biologically safe level necessary to maintain a viable population. |
| Mechanoreceptor | A sensory receptor which responds to mechanical pressure. |
| middle chamber | In pontoon traps*, the chamber preceding the fish chamber*. Compared to the previous "chambers" it is a restricted volume of water. |
| mystacial vibrissae | Whiskers of mammals, grows on the side of the nose of many mammals. |
| offshore fisheries | Fishery conducted further out at sea. The boats are often over 12 m. |
| oligotrophic | Poor in nutrients. |
| organochlorines | Group of compounds with a chemical structure which persists in the environment and in organisms. DDT* and PCB* are two examples. |
| otariid | Eared seals. One of three groups belonging to pinnipeds*. |

| | |
|---|---|
| PCB | Polychlorinated biphenyls. An organochlorine*. Classified as a persistent organic pollutant. |
| phocid | Earless seal or true seal. One of three groups belonging to pinnipeds*. |
| pinniped | Commonly known as seals. The word has Latin origin and means “finfoot.” |
| pontoon trap | A fishing trap developed by a Swedish commercial fisher and innovator in the early 2000’s, to mitigate the conflict between fishers and seals. It distances the seals from the catch. It can be used for fish of all sizes, from vendace to salmon. The trap works by a set of chambers becoming progressively smaller. The fish then becomes acclimated to the more and more restricted environment and thus swims further into the trap. |
| Precautionary Approach Level | The level where the population has its maximum growth. |
| psu | Practical Salinity Unit. Salt concentration in a liquid. Equivalent to permille (‰) or g/kg. |
| retention time | When used for a body of water, it is the time it takes for a total exchange of water. It can be calculated by dividing the total volume of the water by the volume of water flowing in or out of it. |
| seal finger | A condition caused by a mycoplasma. Transferred from seal to fisher by direct contact. If it is not treated promptly, it can cause stiff joints. Easily avoided by using rubber gloves. |
| sealworm | A parasitic worm which has its adult life stage in the stomach of seals. Can cause gastric pain if ingested by humans. |
| Swedish Agency for Marine and Water Management | In Swedish – Havs- och vattenmyndigheten. A government agency responsible for the use of Sweden’s marine and freshwater environments. Located in Gothenburg. |
| Swedish Board of Fisheries | In Swedish – Fiskeriverket. It was a government administrative authority for the management of and utilization of fishery resources. In 2011 there was an official change and the Swedish Board of Fisheries ceased to be an authority. The operation was transferred to the Swedish Agency for Marine and Water Management* and to the Department of Aquatic Resources at the Swedish University of Agricultural Sciences. |
| Swedish Environmental Protection Agency | In Swedish – Naturvårdsverket. Located in Stockholm. Public agency responsible for environmental issues. |
| Swedish Museum of Natural History | In Swedish – Naturhistoriska riksmuseet, located in Stockholm. It has the world’s oldest specimen bank for documenting and tracking pollutants. Responsible for the environmental monitoring of many organisms, including seals. Performs the dissections of bycaught and hunted seals from Swedish waters. |
| TAC | Total Allowable Catch. Set annually by the Common Fisheries Policy, which is the fisheries policy of the European Union. |
| Target Reference Level | The level where growth begins to level off and the population approaches the carrying capacity*. |
| Umwelt | Understanding organisms through their own senses. |
| wings | In pontoon traps*, the first “chamber” of the pontoon trap. |

** Word, abbreviation or acronym explained in the glossary*

# 1 The Baltic Sea Area

## 1.1 Brackish water, a young and sensitive ecosystem

The Baltic Sea is often used as a collective name for the sea area enclosed by Sweden, Finland, Estonia, Latvia, Lithuania, Russia, Poland, Germany and Denmark. The Baltic Sea Area is defined as the internal waters south and eastwards of the parallel at Skaw in Skagerrak, 57° 44.43'N (HELCOM, 2014). These waters consist of several sub-areas. They are the Kattegat, the Sound, the Western Baltic, Baltic Proper, the Bothnian Sea, the Bothnian Bay, the Gulf of Finland and the Gulf of Riga (Lääne, Kraav, & Titova, 2005). For practical purposes, I will hereinafter adopt HELCOMs definition and call this water mass, the "Baltic Sea Area" (HELCOM, 2014: Figure 1). The Baltic Sea Area is a shallow sea, with an average depth of 60 m and a maximum of 460 m (Lääne et al., 2005). Influx of saltwater is restricted to two straits in the south; through the Belt and through the Sound. The Baltic Drainage Basin is about 4 times the area of the sea itself and it is divided between 14 countries (Nilsson, 2006). The waters of the Baltic Sea Area are brackish, due to the inflow of the freshwater rivers. The salt content varies thus from 2 Practical Salinity Units (psu) in the northern part of the Gulf of Bothnia to 13 psu in Kattegat (Meier, Kjellström, & Graham, 2006).


*Figure 1. The Baltic Sea Area with surrounding countries and catchment area (Lääne et al., 2005).*

The Baltic Sea Area is a young ecosystem, approximately 8 000 years old (Elmgren, 2001). This is very young on an evolutionary time scale, compared to the Atlantic Ocean which is estimated to be 180 – 200 million years old (HELCOM, 2013b). The organisms inhabiting this inland sea have adapted to the brackish environment and are genetically different from their marine counterparts (Elmgren, 2001). An example is the Baltic cod which can breed at lower levels of salinity than their marine counterparts (Elmgren, 2001). Should the Baltic cod become extinct, it would not be possible to replace it with cod from the west coast of Sweden (Elmgren, 2001). Further adaptations to the brackish environment in the Baltic Sea Area can be found in the eggs and spermatozoa of Baltic flatfish. Their eggs have a lower egg specific gravity than their conspecifics in more marine environments (Lönning & Solemdal, 1972). The lower egg specific gravity allows the eggs to have a neutral buoyancy in the brackish water and thus avoid sinking to levels with low oxygen content (Nissling, Westin, & Hjerne, 2002). Salinity has probably been a major contributor to the evolutionary processes in the Baltic Sea Area (Nissling et al., 2002). Adaptation to a new environment has also occurred in the grey seal (*Halichoerus grypus;* Ukkonen, 2002). The breeding period for the Baltic grey seal is generally in February or March (Figure 2). In the eastern Atlantic they breed from September to December and in the western Atlantic their breeding period is from December until February (Boness & James, 1979).

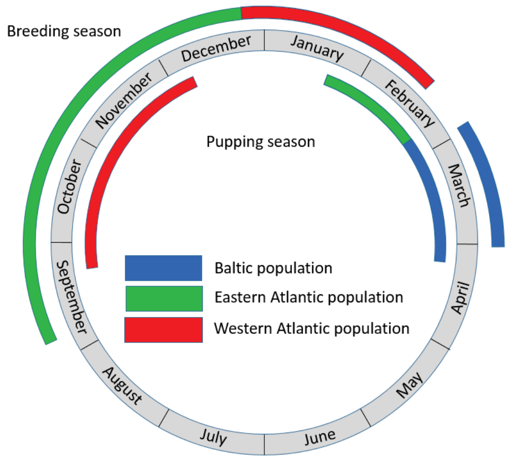


*Figure 2. Breeding and pupping seasons of the three populations of grey seals. The Baltic, the Eastern Atlantic and the Western Atlantic populations. Their respective breeding seasons are indicated outside of the grey circle and the pupping season is within the circle. Adapted from Boness & James (1979), Boyd (1991) and the Swedish Agency for Marine and Water Management (2012b).*

## 1.2 Marine mammals and fish

There are five species of marine mammals in the Baltic Sea Area. They are the grey seal, the ringed seal (*Pusa hispida*), the harbour seal (*Phoca vitulina*), the harbour porpoise (*Phocoena phocoena*) and the Eurasian otter (*Lutra lutra*). The number of seals counted in the Baltic Sea Area were in 2014, 32 000 grey seals, 10 000 ringed seals and around 10 000 harbour seals (Swedish Agency for Marine and Water Management, 2014). The majority of the harbour seals are in the Skagerak area. Around 1 000 of them are found in the Kalmar Strait area in the Baltic Proper (Swedish Agency for Marine and Water Management, 2014). The counted seals were estimated to be 60 to 80 % of the true population (Swedish Agency for Marine and Water Management, 2014). All three Baltic seal populations are increasing in numbers. The population of the grey seals has had an annual increase of 8 % from 2000 until 2014, the ringed seal has increased with 4.5 % per year since 1988 and the harbour seal has increased with 9 % per year (Bäcklin, Moraeus, Strömberg, Karlsson, & Härkönen, 2016). The current population status of the seals is that the grey seal and the southern Baltic population of the harbour seal are listed as least concern. The Baltic ringed seal and the harbour seal at Kalmar Strait are listed as vulnerable (HELCOM, 2013c).

It is estimated that the population of harbour porpoises consists of 11 000 animals (SAMBAH, n.d.). The harbour porpoise is listed as vulnerable in the Western Baltic and as critically endangered in the Baltic Proper (HELCOM, 2015). The otter is included among the marine mammals of the Baltic Sea Area, as it is closely linked to the coastal environment (HELCOM, 2013a). The population is estimated to be around 2 500 animals, of which most occur in fresh water habitats. It is considered to be near threatened (HELCOM, 2013a).

There are approximately 230 different fish species in the Baltic Sea Area (HELCOM, n.d.). Of these around 50 fish species are commercially caught (Schroeer, Białaś, Paulomäki, & Abel, 2011). Scientific advice is given for ten of these species and there is a Total Allowable Catch limit (TAC) for five of them (Schroeer et al., 2011).

## 1.3 A shared resource

There are approximately 85 million people living in the countries within the Baltic Sea catchment area. The catchment area also includes Belarus, Czech Republic, Norway, Slovakia and Ukraine (Lääne et al., 2005). The management of the Baltic Sea Area is governed by HELCOM (Baltic Marine Environment Protection Commission), which was established in the early 1970's. In 1974 the first Convention of the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention) was signed by Sweden, Denmark, Finland, West Germany, East Germany, Poland,

and the USSR. The purpose of the convention was to reduce pollution and to improve the status of the marine environment through intergovernmental cooperation (HELCOM, 2010). Since then, the work has come to include protecting biodiversity, combating eutrophication and ensuring the environmental safety of maritime activities, through the Baltic Sea Action Plan (BSAP) which was adopted in 2007 (HELCOM, 2007). Before the Second World War (WWII) the Baltic was an oligotrophic sea (Thurow, 1997). It became eutrophic after effluents from industrialized farms with fertilized fields and waste from the increasing populations in the surrounding countries, found their way into the sea (Bonsdorff, Blomqvist, Mattila, & Norkko, 1997; Thurow, 1997). For a long time the Swedish Board of Fisheries did not view the eutrophication as a problem when the fish stocks increased (Elmgren, 2001). This view was strengthened in the early 1980s when the Baltic cod stock populations reached higher numbers than previously recorded. This positive opinion reversed when the cod stocks collapsed due to overexploitation and recruitment failure as a result of oxygen deficiency (Elmgren, 2001). Today eutrophication is one of the major challenges of managing the Baltic Sea Area (HELCOM, 2007; Lääne et al., 2005).

Limiting hazardous substances is another focal point in the management plan of the Baltic Sea Area (HELCOM, 2007). The sea is considered to be severely polluted (Elmgren, 1989; Kautsky & Kautsky, 2000; Muller, Dominik, & Reuther, 1980; Turner et al., 1999). The retention time for the Baltic Sea is estimated to be between 25 to 35 years. Nutrients and hazardous substances accumulate in the sediment and have a long residence time (Westing, 1989, as cited in Lääne et al., 2005).

One of the aims of the BSAP is to safeguard the long term viability of the seal populations (HELCOM, 2007). The seal populations should be managed mutually by the member countries (Swedish Agency for Marine and Water Management, 2012b). Further, each member country should have a national management plan (HELCOM, 2007). In 2013, five of the nine participating countries had a national management plan (HELCOM, 2013b). The responsibility for each member country is to coordinate the monitoring of the seal populations, to define reference levels and to harmonize the national management plans with the other member countries (Swedish Agency for Marine and Water Management, 2012b). Important parameters to monitor in the Swedish management plan is to investigate the structure of the populations referring to age and sex distribution and to follow up on the blubber thickness of the seals. The blubber thickness is an indicator of the nutritional status of the seal (Bäcklin, Moraeus, Kauhala, & Isomursu, 2013).

## 1.4 The Swedish Fisheries

The total catch of all species of fish, from both inshore and offshore fisheries, have decreased from 233 000 tonnes in 1999 to 123 000 tonnes in 2015 (Swedish Agency for Marine and Water Management, 2016). The overall trend is that the total number of fishing vessels and their capacity has decreased during the last decades (Popescu, 2010). The proportion of fish caught for human consumption in the Swedish fisheries was 64 % in 2003 (FAO, 2004). During the same year the proportion of catch from the inshore fisheries was 6.4 %. In 2015 this proportion had decreased to 3.7 % (Figure 3: Please see Appendix A for detailed catch statistics).

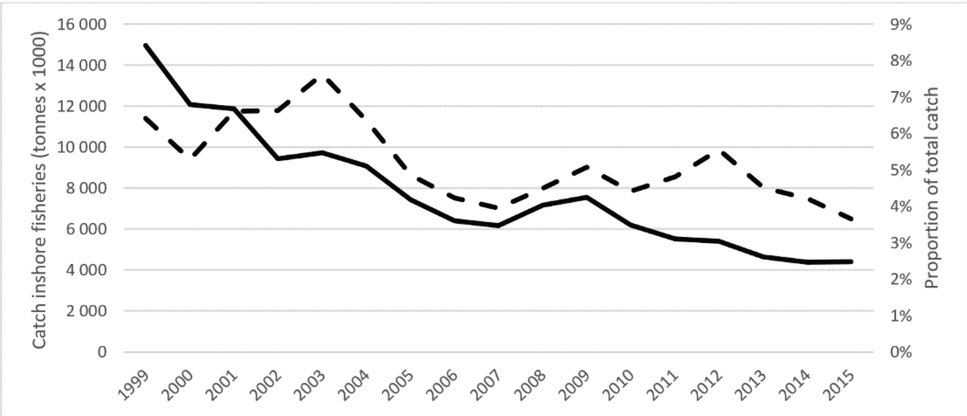


*Figure 3. Total catch of the inshore fisheries (solid line) and their proportion of the total catch of inshore and offshore fisheries (dashed line: Appendix A).*

The most commercially important species are herring (*Clupea harengus*), sprat (*Sprattus sprattus*), cod (*Gadhus morhua*) and vendace (*Coregonus albula*: Table 1). These species constituted 98.6 % of the total catch in 2015 (Swedish Agency for Marine and Water Management, 2016).

*Table 1. Swedish total catches from the Baltic Sea Area in 2015, of the most commercially valuable species (Swedish Agency for Water and Marine Management, 2016).*

| Species | Total catch in tonnes | Proportion of catch, Kattegat excluded |
|---|---|---|
| Herring (*Clupea harengus*) | 70 211 | 94,6 % |
| Sprat (*Sprattus sprattus*) | 44 501 | 99,2 % |
| Cod (*Gadhus morhua*) | 6 427 | 99,5 % |
| Vendace (*Coregonus albula*) | 1 890 | 100,0 % |
| Norway lobster (*Nephrops norvegicus*) | 329 | 0,0 % |
| Lumpfish (*Cyclopterus lumpus*) | 188 | 75,7 % |
| Salmon (*Salmo salar*) | 187 | 100,0 % |
| Eel (*Anguilla anguilla*) | 158 | 100,0 % |
| Whitefish (*Coregonidae*) | 152 | 100,0 % |
| European plaice (*Pleuronectes platessa*) | 134 | 36,4 % |
| European flounder (*Platichthys flesus*) | 126 | 97,7 % |
| Perch (*Perca fluviatilis*) | 122 | 100,0 % |

The trend is that catches of sprat and cod have decreased during the last decade (Figure 4). The herring catch has increased over the last years and for vendace it has doubled since 2006. The majority of the Swedish catches in the Baltic Sea Area are from the Baltic Proper, the Bothnian Sea and the Bothnian Bay (Swedish Agency for Marine and Water Management, 2016: Table 1).

Using the average of the auction prices received by the Stockholm Fish Auction in November 2016 and the total catches from 2015, assuming the catch is for human consumption, the total annual value of the herring catch would be in the vicinity of 2 800 million SEK. The corresponding values would be for sprat 1 700 million SEK, vendace 1 700 million SEK and for cod it would be 565 million SEK (http://www.stockholmsfiskauktion.se/). These figures are approximate as the price of fish varies with access and demand. They do however give an indication of their separate and total market values.

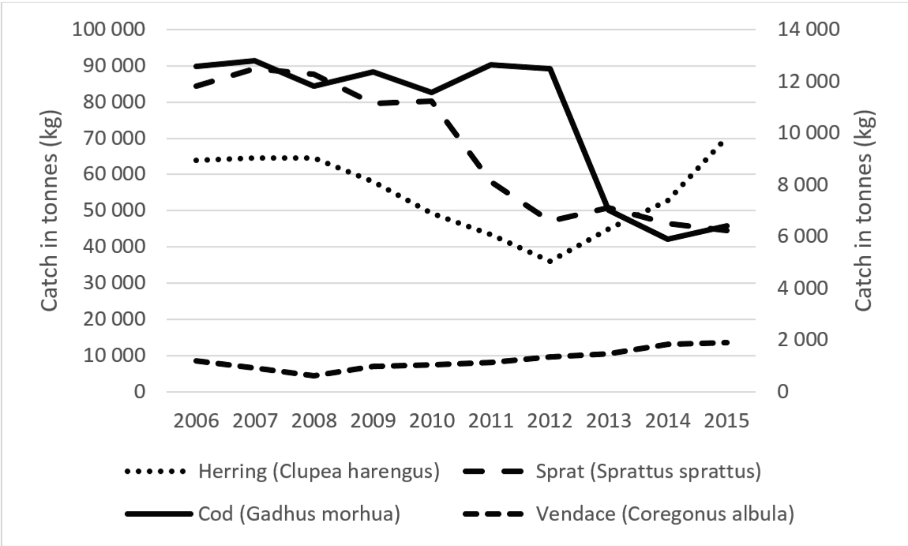


*Figure 4. Catches in the last decade of the four species with the highest commercial value. The catch of cod and vendace are indicated on the secondary y-axis (Swedish Agency for Marine and Water Management, 2016)*

Before the caught fish lands on the dinner plate of a consumer, it goes through three links in the trade chain; (1) from fisher to distributor/reseller (e.g. fish auction), (2) from distributor/reseller to processor (e.g. packaging/distributor or restaurant) and (3) to the consumer. The price of the product increases through each link in the chain. By the time it is served on the dinner table, as fillet, pickled herring or roe, the price has augmented with 115 to 125 % (Please see Appendix A).

The most commonly found prey found in the stomach content of grey seals was herring and sprat, 81 % and 27 % respectively (Lundström, Hjerne, Alexandersson, & Karlsson, 2007). Fisheries and seals both have herring and sprat at the top of their most caught fish and are thus competitors for the same resource.

A fish which is not used for human consumption, but should not be forgotten, is the three-spined stickleback (*Gasterosteus aculeatus*). It is a planktivorous fish and can have an effect on the mortality of other species by predating on their eggs and larvae. Its biomass was in the mid 1990's estimated to be 25 000 tonnes (Jurvelius, Leinikki, Mamylov, & Pushkin, 1996). In the approximate same period, the estimated biomass of herring was 5 000 000 tonnes and for sprat it was around 3 200 000 tonnes (Thurow, 1997). Herring and sprat are also planktivorous fish. Their annual total consumption of zooplankton was for herring estimated to be 45 000 tonnes and for sprat it was 24 000 tonnes (Arrhenius & Hansson, 1993). Herring and mainly sprat, can cause a high mortality on cod eggs (Köster & Schnack, 1994).

There are many positive aspects of maintaining the inshore fisheries. They provide more job opportunities than large offshore commercial enterprises (Schroeer et al., 2012). Further, they are more environmentally friendly (using passive gear and producing less discards), more selective, land a high value of fresh fish, deliver locally produced food and have a high touristic value (Schroeer et al., 2012). The fisheries in particular focus here, i.e. the pontoon traps, conforms to LIFE fishing (Low Impact Fuel Efficient: Suuronen et al., 2012). Catches by inshore coastal fisheries are almost exclusively for human consumption, compared to catches from offshore fisheries which is used for industrial purposes, e.g. to produce animal feed (Yodzis, 2001).

A large part of the professional small-scale fishery is part-time, with farming or other supplemental livelihoods. They are important for maintaining flourishing coastal communities (Bruckmeier and Höj Larsen, 2008). Buying fish from local commercial fishers contributes to a more environmental friendly food production and increases the self-sufficiency of foods (FAO, 2000). The advice from the United Nations to governments is that food for schools, hospitals and other public administrations should be supplied by local producers (United Nations, 2014).

The inshore fisheries are adversely affected by seals both directly and indirectly (Westerberg, Lunneryd, Fjalling, & Wahlberg, 2007). The direct effects are fisheries competing with seals over the same resource and that seals damage catch and fishing gear (Westerberg et al., 2007). The indirect effects is a possible increase of the prevalence of sealworm (*Pseudoterranova decipiens*), due to the increased seal populations. Another indirect effect is that fisheries are not able to fish in marine areas set aside for the seals (Westerberg et al., 2007).

In the coastal fisheries, particularly in the trapnets, both gear and catch is often damaged by seals (Lehtonen & Suuronen, 2004). In the inshore gillnet fishing, it is not possible to mechanically protect the nets from the seals (Westerberg et al., 2007). In the late 1990's, gillnet fishing for salmonids stopped in the Bothnian Bay due to the frequent raiding by the seals (Neuman & Píriz, 2000). Since then, there has been a shift towards "seal-safe" fishing gear. For example to pontoon traps adapted for different species of fish; salmon and whitefish (Lunneryd, Fjälling, & Westerberg, 2003), herring (Lundin, Calamnius, Hillström, & Lunneryd, 2011), perch (Lundin, Calamnius, Lunneryd, & Magnhagen, 2015) or to cod pots (Königson et al., 2015). The latter is still under evaluation and has not yet been implemented. Pontoon traps for salmon and whitefish have been successful. Fishers are content with their function and the pontoon trap now dominate the coastal commercial fisheries (Hemmingsson, Fjälling, & Lunneryd, 2008). The pontoon trap was officially approved as a seal-safe fishing gear by the Swedish Environmental Protection Agency in 2001 (Hemmingsson et al., 2008) and it became eligible for investment subsidies. A commercial fisher stated that if it was not for the pontoon trap, there would be no inshore fisheries (K-Å Wallin, personal communication, May, 2015).

# 2 The grey seal in the Baltic

## 2.1 The history of seals and man in the Baltic

The history of seals in the Baltic is closely interlinked with the human populations in the countries surrounding the sea. The seals have been used as a resource, we are competitors for fish, we are both at the top of the food chain and we are exposed to the same pollutants. From the early history in the Stone Age and until the late 19th century, seals were considered to be a valuable resource (Eriksson, 2004; Schmölcke, 2008). Bones and teeth of seals have been found in human graves from the early Stone Age (Haglund, 1961). They were hunted for their fur, meat and blubber. The skin was used for clothing and by Sami people it was used to make fire, by grinding two pieces of fur against each other (Ryd, 2005). The blubber was turned into oil, which was a prized export product. It was shipped to other European countries from the late middle ages until the end of the 19th century (Edlund, 2000). The oil was used for waterproofing leather goods, boats and outdoor timber. It was also used to provide light, by burning it in oil lamps (Edlund, 2000). In the 18th century, the seal's body was deemed to have healing abilities which could cure any internal of exterior disease in both animal and man (Tengström, 1747, as cited in Edlund, 2000).

Historic accounts of how seals affect fisheries, dates back to the early 18th century (Broman, 1720/1911). Broman gave a detailed account of a diverse multitude of animals, including seals. He mentions that seals stole salmon and other fish off the nets and that they caused damage to fish and nets. Another early account dates back to 1732, when Carl von Linné undertook a journey to Lapland (Linné, 1732/1977). During his travels around the Bothnian Bay, he mentions that seals damage both gear and fish. Linné probably gave one of the first accounts of bycatch of seals, when seals got caught in the nets with their rear flipper (Linné,1732/1977). He also briefly described that seals were caught in many ways, either by using different types of nets or by shooting (Linné, 1732/1977). Other methods for hunting seals included using harpoons (Figure 5), cages, clubbing, a submerged spring trap or spears (Gustafsson, 1971).

*Figure 5. Hunting seals with spears in the 16th century in the Bothnian Bay. Detail of Carta Marina by Olaus Magnus (1572).*

At the turn of the 20th century it was estimated that the populations of seals in the Baltic, was in excess of 90 000 for the grey seal (Harding, Härkönen, Helander, & Karlsson, 2007), between 190 000 to 220 000 for the Baltic ringed seal (Hårding & Härkönen, 1999) and 5 000 for the harbour seal (Härkönen, Harding, Goodman, & Johannesson, 2005). The total annual consumption of fish by seals was approximately 320 000 tonnes (Thurow, 1997). Seals as a resource were still highly valued and favoured haul-outs of seals were a valuable asset. In the 1920's an airplane route had to change the course so as not to disturb the haul-out at Harstena (Haglund, 1961). Eventually, the previously valued seal oil was replaced by cheaper alternatives and the seals lost their value as a resource. Instead they gradually came to be viewed as a competitor for fish (Hårding & Härkönen, 1999) and as vermin (Bergman, Bignert, & Olsson, 2002). Seal bounties were introduced by the Nordic countries surrounding the Baltic and were collectively in effect from 1889 when they were first introduced in Denmark, to 1975 when they last ended in Finland (Hårding & Härkönen, 1999). It is estimated that 8 000 grey seals and 16 000 ringed seals were annually harvested by seal hunters in Denmark, Finland and Sweden in the early 1910s (Kokko et al., 1999). This led to a depletion of the collective seal populations, due to both subsistence hunting and government induced bounties

(Johnston et al., 2015). By 1920 seal hunters were complaining about smaller harvests (Hårding & Härkönen, 1999). The subsistence and bounty hunting resulted in a rapid decline of the grey seal population to around 20 000 animals in the 1940's (Harding et al., 2007).

In the 1960's the seal populations faced a new type of threat. It was environmental pollution in the form of organochlorines, more precisely the pesticides DDT and PCB (Kokko et al., 1999). Towards the end of the 1960's it was discovered that two apex predators, the white tailed eagle (*Haliaeetus albicilla*) and the grey seal had high levels of PCB and DDT (Elmgren, 2001; Olsson & Reutergårdh, 1986). In seals, DDT and PCB affects the reproductive abilities in the females, by partial or complete occlusion of the uterine horns (Helle, 1980). It was estimated that 90 % of the female ringed seals were sterile. Occlusion of the uterine horns also affected the grey seal and the harbour seal (Helle, Olsson, & Jensen, 1976). The reproductive rate of the seals thus sank dramatically and caused a population crash in the 1970's (Harding et al., 2007). After WWII and until the 1970's the main reason for the decrease of the seal populations in the Baltic were the organochlorines (Bergman et al., 2002).

The decline of seal and eagle populations alerted the general public that there were environmental issues in Baltic Sea Area (Elmgren, 2001). Laws and regulations were designed to diminish the emissions of pollutants. In 1974 the first Convention of the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention) was signed by Sweden, Denmark, Finland, West Germany, East Germany, Poland, and the USSR. The purpose of the convention was to reduce pollution and to improve the status of the marine environment (HELCOM, 2010). In the same period the failing reproductive abilities of the female seals was considered to be so severe, that protecting measures should be taken for the conservation of the seals (Westerberg, Fjälling, & Martinsson, 2000). The seals were by now low in abundance. In 1972 there were no seal inflicted damage in the entire salmon fishery in the Bothnian Bay (Westerberg et al., 2000). The bounty systems were discontinued in the late 1970's as a means to protect the diminishing numbers of seals. It also became forbidden to hunt them. The problem with the declining seal stocks had become acute and it was deemed that they were near extinction. There now remained around 3 000 grey seals, 5 000 ringed seals (Harding et al., 2007) and around 1 900 harbour seals (Karlsson, Bäcklin, & Härkönen, 2008; Karlsson, Härkönen, & Bäcklin, 2007). The absolute majority of the harbour seals were in Kattegat. A small remnant of 10 to 20 reproducing females remained in the Baltic Sea Area, more specifically at Kalmar Strait (Karlsson et al., 2007).

By 1980 the amount of fish eaten by seals had decreased to around 6 000 tonnes per year, as a result of the decreasing seal populations (Thurow, 1997). In the same period the fishing yield for human consumption had grown to approximately

100 000 tonnes per year (Thurow, 1997). In 1985, the total compensation for seal inflicted damage to fishers was 100 000 SEK (Westerberg et al., 2000).

By the 1990's, the gradual decline of the organochlorines and the ban on seal hunting, led to a population recovery (Harding et al., 2007; Varjopuro & Salmi, 2006). The seal populations had now increased and fishers' organizations in Sweden were lobbying to allow hunting again (Hårding & Härkönen, 1999). Coastal fishers in Finland started reporting more frequent encounters with seals (Varjopuro & Salmi, 2006). The compensation to fishers had in 1993 increased to 6.3 million (Westerberg et al., 2000). In 2007 it was estimated that the total costs for direct and indirect seal inflicted damage were 50 million SEK (Westerberg et al., 2007). The total compensation to commercial fishers for seal inflected damage the same year was 17 million SEK (Swedish Environmental Protection Agency, 2007). There are numerous papers which illuminate the increasing problem in the Baltic with raiding seals and the possible solutions. One of the earliest was an unpublished report from 1997 (Sand & Westerberg, 1997). Other articles addressing the conflict between seals and small-scale coastal fisheries or trying to find mitigating means are Fjälling, Wahlberg, & Westerberg (2006), Kauhala et al. (2015), Kauppinen, Siira, & Suuronen (2005), Lehtonen & Suuronen (2010), Lundin et al. (2011), Lunneryd et al. (2003), Oksanen, Ahola, Oikarinen, & Kunnasranta (2015) and Westerberg et al. (2000). Please see Appendix B for a comprehensive reference list.

## 2.2 The Umwelt of a Baltic grey seal

To better understand the grey seal, we shall first take a holistic approach by entering its *Umwelt*. The term *Umwelt* was coined by (von Uexküll, 1934/1992) and implies understanding the studied organisms through its perceptual world (de Waal, 2016). The *Umwelt* of aquatic animals is inherently different from that of terrestrial animals. Water is almost 800 times denser and 60 times more viscous than air. These physiological characteristics of water affects the skeleton, the locomotion and the buoyancy of organisms living in this medium (Dejours, 1987). It is therefore important to be as energy conserving as possible when swimming. The bodies of pinnipeds (as for most fish and whales) have evolved to minimize drag (Fish, 1993). The method of propulsion is different between the different groups of pinnipeds. Otariids move through the water by primarily using their fore flippers and phocids primarily use their hind flippers (Fish, 1993). Both pinniped groups have a high degree of flexibility in their axial skeleton which allows undulatory propulsion (Williams, 1999). The transport costs for phocids and otariids are 2.3 to 4 times higher than for fish (Williams, 1999). The pinnipeds have, from an evolutionary point of view, sacrificed energetic efficiency for versatility, being able to spend their time in both water and on land (Williams, 1999).

Water has a high thermal conductivity and incurs large maintenance costs for marine mammals (Williams, 1999). In this highly heat conductive medium, it is necessary to be well insulated for endothermic animals. The Baltic grey seal has therefore an insulating layer of blubber. In a healthy seal, the thickness of the blubber layer is around 50 mm (Karlsson & Bäcklin, 2009). This varies between male and female, the age of the seal and what time of the year it is (Bäcklin et al., 2013).

Sound is propagated more than four times faster in water than in air. The ear of the pinniped is adapted to both water- and airborne sounds but is better adapted to the aquatic environment (Schusterman, Kastak, Levenson, Reichmuth, & Southall, 2000). Pinnipeds produce a wide variety of underwater signals. The vocalizations are used for a variety of social contexts; to attract mates, in male-male aggressive interactions, to establish hierarchies, for territorial defence and for coordinating social and reproductive behaviour (Götz, 2008; Hanggi & Schusterman, 1994; Schusterman et al., 2000). The vocalizations have individual characteristics (Insley, Phillips, & Charrier, 2003) and male harbour seals are able to identify others by their vocalizations and to recognize dominant individuals (Hanggi & Schusterman, 1994). The types of underwater sounds emitted by grey seals are clicks, rups, growls, knocks and roars (Asselin, Hammill, & Barrette, 1993). Wahlberg, Lunneryd, & Westerberg (2002) suggested that understanding acoustic signals, e.g. fin slaps by harbour seals, could be used for developing mitigating measures in the conflict between pinnipeds and fisheries.

Most aquatic and semiaquatic animals have developed hydrodynamic detection systems to be able to detect conspecifics, prey or predators (Wieskotten, Dehnhardt, Mauck, Miersch, & Hanke, 2010). The seal's vibrissae have been adapted to be a finely tuned aquatic instrument (Schulte-Pelkum, Wieskotten, Hanke, Dehnhardt, & Mauck, 2007). The fat at the base of the vibrissae has a low melting point, resulting in a capacity of maintaining a high degree of flexibility at cold temperatures (Erdsack et al., 2015). The blood flow supplying the vibrissal pads is not affected by low temperatures (Dehnhardt, Mauck, & Hyvärinen, 1998). The seal is the mammal with the highest density of mechanoreceptors at the base of the vibrissae, indicating that a substantial amount of information is received through this tactile sense (Miersch et al., 2011). It is considered to be the most sophisticated vibrissae among mammals (Dehnhardt, 2001; Prescott, Diamond, & Wing, 2011; Schusterman et al., 2000; Sven Wieskotten, Mauck, Miersch, Dehnhardt, & Hanke, 2011). The hydrodynamic trail of a herring can be detected by a seal from a distance of 180 m, provided that the seal at some point crosses the wake of the fish (Dehnhardt, 2001). It is further suggested that seals use their vibrissae to bring them within sight of their prey and that they use their eyes for the final closing in (Schulte-Pelkum et al., 2007). They can also use their vibrissae for underwater orientation and for foraging (Dehnhardt et al., 1998). It is suggested that visual cues are not essential for grey seals when navigating (McConnell, Fedak, Lovell, & Hammond, 1999), due to the often turbid waters. A blind seal was found to have the same travel pattern as seeing seals (McConnell et al., 1999). Instead seals may rely on acoustic communication (Shapiro, Slater, & Janik, 2004) and on tactile information through their mystacial vibrissae (Dehnhardt et al., 1998). The Baltic waters are turbid with visibilities ranging from 0 to around 10 m. Using vision is instead important when the seals have elevated their heads out of the water. For example, when navigating by using stars (Mauck, Gläser, Schlosser, & Dehnhardt, 2008) or when locating baited buoys (Fjälling, Kleiner, & Beszczyńska, 2007).

In the male grey seal, the snout is a constantly growing cephalic structure. It has probably evolved through sexual selection (Miller & Boness, 1979). Male seals can use it as a visual cue to determine the status of a competitor during the breeding season or when contesting for a food resource. The most obvious visual determinant for social rank is body size (Arnould & Duck, 1997). Other visual cues are threat displays, such as averting the head, approaching with closed or open mouth, retracting the head which broadens the neck or a rapid approach – these are all different degrees of threats on land (Miller & Boness, 1979).

There are three possible ways which seals can communicate under water; it is vocally, tactilely or visually. There are reasons for the seals to evaluate each other during the mating season (Hanggi & Schusterman, 1994). There is also reason to believe that they might need to assess each other in contexts concerning other resources, e.g. for food. Considering that seals are aquatic mammals it would be surprising if they do not use the senses available for underwater communication or assessment of conspecifics.

# 3 Interactions between seals and man in the Baltic

## 3.1 Human influence on seals

Human activities might affect the seal populations through bycatch. This is valid for the critically endangered Saimaa ringed seal (*Phoca hispida saimensis:* Niemi, Auttila, Viljanen, & Kunnasranta, 2012), the Hawaiian and Mediterranean monk seals (*Monachus schauinslandi* and *M. monachus:* Kovacs et al., 2012). The Caribbean monk seal (*M. tropicalis*) is extinct, largely due to hunting and loss of breeding grounds (Kovacs et al., 2012). Bycatch of seals has become a cause for concern during the last decades as it poses both ethical and practical problems for the fishers (Lunneryd, Königson, & Sjöberg, 2004; Westerberg et al., 2007). In 2001 around 1 000 seals per year drowned in fishing gear in the Swedish waters (Swedish Board of Fisheries, 2005). In Estonia and Latvia the bycatches of seals were estimated to be 280 and 180 animals respectively (Dagys et al., 2009). The total bycatch in the Baltic waters could exceed 10 % of the censused population (Westerberg et al., 2007). In a more recent study the total bycatch was estimated to be c 2 280 animals for Sweden, Finland and Estonia (Vanhatalo, Vetemaa, Herrero, Aho, & Tiilikainen, 2014). This figure does not include bycatches of the other countries around the Baltic Sea Area (Latvia, Lithuania, Russia, Poland and Denmark). It is therefore not possible to make a comparison with the earlier study. The seal populations have increased and it is possible that the numbers of seals which are bycaught has also increased (Vanhatalo et al., 2014).

## 3.2 Seal influence on humans

Since the 1990's the increase of the seal populations in the Baltic has led to an increase of seal induced damage to fishing gear and catch for the coastal fisheries (Fjälling et al., 2006; Hemmingsson et al., 2008; Königson, Fjälling, Berglind, & Lunneryd, 2013; Lehtonen & Suuronen, 2010; Lunneryd et al., 2003; Westerberg et al., 2007). The cost for the damage caused by seals was in 2014 estimated to be 33 million SEK (Swedish Agency for Marine and Water Management, 2014). The so called "hidden losses" are not included in this estimate. They can amount to as much as 61 % of the potential catch (Fjälling, 2005). Examples of hidden losses are; fish which are deterred by the presence of seal, catch which is lost due to damaged fishing gear, costs to replace damaged material, increased fuel costs as a result of more frequent checking or moving the gear (Swedish Agency for Marine and Water Management, 2014). It is in the category of fish traps for salmon, brown trout and whitefish (*Coregonus maraena*) that the major economic losses caused by seals have occurred in the Swedish coastal fisheries (Westerberg et al., 2007). Developing seal-safe fishing gear is a highly prioritized solution to mitigate the conflict between seals and fishers (Westerberg et al., 2007). This is in line with the strategy of the BSAP, whose aim is to implement non-lethal mitigation methods (HELCOM, 2007).

It is considered to be mainly the grey seal which causes most of the damage to catch and gear (Königson et al., 2013; Neuman & Píriz, 2000; Suuronen et al., 2006). The grey seal has been regarded as a factor causing the decrease on whitefish catches during last decades (Jokikokko & Huhmarniemi, 2014). Certain individuals, most often males, becomes 'specialists', i.e. some individuals frequent fishing gears or fish farms to a greater extent than the general population. These animals are considered to be problem individuals or 'rogue' seals (Graham, Harris, Matejusová, & Middlemas, 2011). This was later corroborated by Königson et al. (2013). Another example of specialist behaviour in pinnipeds has been observed in leopard seals (*Hydrurga leptonyx*). They frequently eat other seals (Hiruki, Schwartz, & Boveng, 1999). There are two recent developments in the foraging behaviours of grey seals. An adult male grey seal was observed to predate on grey seal pups (Brownlow, Onoufriou, Bishop, Davison, & Thompson, 2016). There is also proof that grey seals have predated on harbour porpoises (Haelters, Kerckhof, Jauniaux, & Degraer, 2012; Stringell et al., 2015). Whether this behaviour is exhibited by specialist seals or not, remains to be seen. What can be concluded is that the grey seal is an opportunistic predator, feeding on what is most readily available (Varjopuro & Salmi, 2006).

The patterns of certain specific seals which raid fishing gear resemble the terrestrial situation where certain predator individuals kill livestock (Linnell, Odden, Smith, Aanes, & Swenson, 1999). This pattern fits solitary species like cougar (*Puma concolor*), jaguar (*Panthera onca*), leopard (*Panthera pardus*), grizzly bear (*Ursus arctos*) and black bear (*Ursus americanus*). It does not fit social animals like wolves (*Canis Lupus*: Linnell et al., 1999). It has been suggested that it is the larger home ranges of males which explains why they more often become problem individuals. They then come more frequently into contact with farms or fisheries. This results in a potential for formation of problem individuals (Linnell et al., 1999). Their chances of encountering prey are greater than for the females. Predation on livestock requires specialization. The terrestrial predator needs to cross physical barriers and sometimes bypass both shepherds and dogs (Linnell et al., 1999). The seal needs to find its way in and out of the trap, without becoming entangled in any of the netting. A high degree of risk is therefore associated with raiding a fish trap. Females, on the other hand, appear to be risk-averse. They commit to and prepare for reproduction at an earlier stage in the annual cycle, than males (Beck, Bowen, & Iverson, 2003).

*Table 2. Proportion of male versus female pinnipeds, which frequent fishing gear.*

| Species | Male | Female | Undeter-mined | Proportion male (%) | References |
|---|---|---|---|---|---|
| Australian fur seal (*Arctocephalus pusillus*) | 485 | 44 | 0 | 95 % | Hume, Pemberton, Gales, Brothers, & Greenwood, 2002; Marine and Marine Industries Council, 2002; Pemberton & Shaughnessy, 1993; Tilzey et al., 2002 |
| Grey seal (*Halichoerus grypus*) | 246 | 113 | 4 | 68 % | Bäcklin et al., 2011; Calamnius et al., n.d.; Calamnius et al., unpub. results; Fjälling et al., 2006; Harris, 2012; Kauhala et al., 2015; Königson et al., 2013b; Lehtonen et al., 2013; Lehtonen & Suuronen, 2010; Oksanen et al., 2015; Sand & Westerberg, 1997; Stenman & Pöyhönen, 2005 |
| Ringed seal (*Pusa hispida*) | 21 | 22 | 0 | 49 % | Oksanen et al., 2015; Stenman & Pöyhönen, 2005 |

In the southern hemisphere, it is generally the male of the Australian fur seal (*Arctocephalus pusillus*), which is more predisposed to raid fishing gear and fish farms than other present pinnipeds. On the other hand, for the New Zealand fur seal (*Arctocephalus forsteri)*, it was predominantly females which were caught in the trawling operations (Chilvers, 2008). This is highly unfortunate as this fur seal is one of the rarest species of pinnipeds in the world (Chilvers, 2008).

Comparing data of raiding vs hunted grey seals, the ratio between males and females becomes inverted, tipping the scale towards the females. After the protective hunt was introduced in 2001 (Bäcklin, Moraeus, Strömberg, Stenström, & Neimanis, 2015), a higher proportion of females (60 %) were hunted between 2002 and 2007 (Bäcklin & Moraeus, 2013). There are two possible explanations for this. The first is that there was a preference among hunters, for shooting female seals. The females are lighter in colour, the quality of their meat is better and their skins have less lesions and scars (J. Bohlin, personal comment, September 2016). The second explanation is that it is easier for the hunter to target the female seals when they moult on the ice in May (Bäcklin et al., 2011). In the Arctic harbour seal, the moulting period is differentiated between the sexes, with females moulting earlier than males (Reder, Lydersen, Arnold, & Kovacs, 2003). If the same pattern applies to the grey seal, the ice would be in poorer condition when the males moult. The preference for a hunter to aim for an individual of a specific sex is a complicated question and other forces might be at play. In 2011, the proportion of hunted male seals was 63 % (Bäcklin & Moraeus, 2013). In 2013/2014 the proportion was 39 % (Bäcklin et al., 2015).

### 3.2.1 Seal finger and sealworm - seals influencing humans

Seals can also influence humans through the so called "seal finger" and the sealworm (*Pseudoterranova decipiens*). The sealworm is a parasitic nematode.

Seal hunters who have been in direct contact with seals, can be afflicted with a condition called "seal finger" (Ståby, 2004). The condition is also known as "seal gangrene, "seal redness" or "blubber finger." It is a bacterial infection caused by a mycoplasma. Unless adequate treatment is initiated early, there is a risk that the joint in the affected finger will be severely damaged, possibly resulting in a rigid joint. The affliction is easily prevented by using rubber gloves (Ståby, 2004).

Some seals are hosts to the sealworm (Lunneryd, Ugland, & Aspholm, 2001). The life cycle of the sealworm passes through three hosts; crustaceans which eats eggs, fish which eats crustaceans and seals which eats fish (U.S. Centers for Disease Control, 2013). The sealworm reaches its adult stage in the seal, where it reproduces and emits eggs in the faeces of the seal (Clers & Andersen, 1995). When larvae of the sealworm are found in the flesh of fish, it is mainly a cosmetic problem (McClelland, 2002), incurring costly detection and removal costs in the production of fish as a consumer product (Bowen, 1990). Humans can be infected by the sealworm by eating raw or uncooked seafood. It can then cause gastric pain and nausea (Margolis, 1977, as cited in McClelland, 2002). The presence of sealworm in fish, is directly related to the proximity of seal haul-outs (Jensen & Idås, 1992).

# 4 Mitigating methods for pinnipeds in a global perspective

The problem with raiding pinnipeds is global. They raid fish farms, fishing gear of various types and place themselves strategically by fish ladders at hydro-electrical power dams (Brown, Jeffries, Hatch, Wright, & Jonker, 2011; Lunneryd et al., 2003; Quick, 2002; Sepúlveda & Oliva, 2005). Their learning abilities have been known since the days of Pliny (77AD). Pliny was of the opinion that phocids can be trained. Today, their learning ability is well documented. Pinnipeds have learned to open doors in fish traps (Lehtonen & Suuronen, 2010), to associate sounds of fishing boats, Acoustic Harassment Devices (AHD), Acoustic Deterrent Devices (ADD) or from acoustic fish tags with food (Königson, Fjälling, & Lunneryd, 2007; Stansbury, Gotz, Deecke, & Janik, 2015), to associate buoys with fishing gear and thus finding a potential foraging ground (Fjälling et al., 2007), to associate gill nets with food (Jokikokko & Huhmarniemi, 2014), to quickly exploit weaknesses in various protective systems (Marine and Marine Industries Council, 2002; Nelson, Gilbert, & Boyle, 2006), to keep their heads out of the water while an AHD is emitting pings (Fjälling, 2006) and that fish farms provide feeding opportunities (Gordon & Northridge, 2002). This learning ability is considered to be the main obstacle in achieving a perfect solution in finding mitigation measures (Varjopuro, 2011). It is a continuous arms race between fisheries, fish farms and the raiding pinnipeds. Their adaptability of finding new ways of getting to the fish, has led to many diverse means of mitigation.

The methods of keeping pinnipeds from fish, range from e.g. killer whale decoys (Jamieson & Olesiuk, 2001; Sepúlveda & Oliva, 2005), bubble curtains (Würsig & Gailey, 2002), culling problematic seals (Königson et al., 2013; Lehtonen & Suuronen, 2010; Mate & Harvey, 1986; Sand & Westerberg, 1997); to decimating the population by shooting non-specified individuals (Jounela, Suuronen, Millar, & Koljonen, 2006; Varjopuro, 2011; Westerberg et al., 2007: Appendix C).

## 4.1 A review of mitigation methods – perceived degree of severity coupled with success rate

The various devices and methods which are used to lessen the conflict between fisheries and raiding pinnipeds have different success rates. In an effort to find out which method is the most favoured in the fishing and fish farm industry, I collected data from 50 articles.

### 4.1.1 Method

I searched for peer-reviewed articles by using the search words; pinniped predation, pinniped depredation, exclusion device, mitigating fishery conflicts, pinniped prevention, seal-safe fishing gear, pinniped interactions fishing gear, pinniped deterrent devices, interactions between fisheries and pinnipeds. The same search was performed by exchanging the word “pinniped” with “seal.”

The mitigation methods were categorized into two main groups; non-lethal and lethal. They were then grouped into nine general methods; acoustic deterrent, aversive stimuli, capture, exclusion, management, shooting, tactile harassment, vessel handling and visual deterrent. There were a total of 40 different mitigation methods. Some of the methods were more infrequent than others, i.e. they were mentioned in one article. For example, capture and killing, scent deterrent and bean bag loads. Three mitigation methods were mentioned in 10 or more articles. They were AHD (14 articles), physical barriers (12 articles) and culling (10 articles). The articles were then categorized into whether the author(s) were positively or negatively inclined to the mitigation method. The method was awarded one point if the author(s) were positively disposed and one point if they were negatively disposed. If the article was neutral or did not come to a clear conclusion, the method was awarded 0.5 points. The percentage of papers in favour was calculated. Methods which had been addressed by only one paper were excluded.

The next step was to make an assessment of the degree of severity. More specifically, I made an assessment of how potentially harmful the method was to (1) the individual seal, (2) to other organisms in the near vicinity (including conspecifics) and (3) to the local environment. The scale which I used was from 0 to 5. The potential of damage was graded “0” for no damage, “1” for slight, “2” for moderate, “3” to a certain extent, “4” for severe and “5” for very severe damage. The total severity of each mitigation method was then calculated.

### 4.1.2 Results and discussion

The mitigations means which were favoured to a high degree, with a proportion of positive papers of 80 % or above, were electrical deterrents (Forrest, Cave, Michielsens, Haulena, & Smith, 2009; Marine and Marine Industries Council, 2002; Schakner & Blumstein, 2013), SED – preventing from entering (Calamnius et al., n.d.; Königson et al., 2015), trawlers avoiding seals – by driving away at high speed (National Seal Strategy Group & Stewardson, 2007; Tilzey et al., 2002), pontoon traps (Hemmingsson et al., 2008; Lehtonen & Suuronen, 2004; Lunneryd et al., 2003; Varjopuro, 2011; Varjopuro & Salmi, 2006; Westerberg et al., 2007) and culling (Bruckmeier & Höj Larsen, 2008; Jamieson & Olesiuk, 2001; Königson et al., 2013a; Lehtonen & Suuronen, 2010; Marine and Marine Industries Council, 2002; Mate, Brown, Greenlaw, Harvey, & Temte, 1986; Quick, Middlemas, & Armstrong, 2004; Sand & Westerberg, 1997; Würsig & Gailey, 2002). The results are visualized in Figure 6. For the three first mentioned methods (electrical deterrents, trawlers and SEDs) the numbers of papers reporting the method was low (two or three). Whether this is a reliable result for these papers or not, is a matter of opinion. It is by no means an exact science. It does give an indication of how the various mitigation methods are perceived by the author(s). All 50 papers are listed in Appendix C.

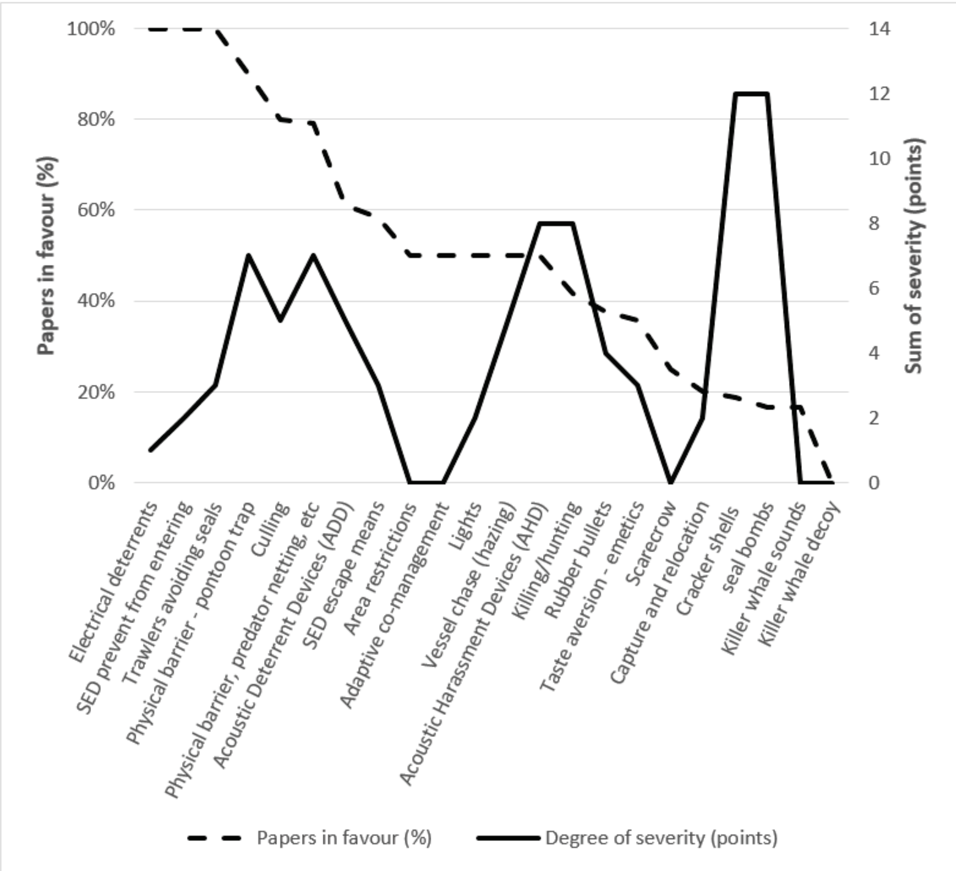

*Figure 6. Proportion of papers in favour for a certain mitigation method, coupled with perceived degree of severity. The mitigation methods are arranged in descending order of proportion of papers in favour. Where two or more methods received the same percentage, the sum of severity was arranged in ascending order.*

Culling of a specific problem individual had a high degree of severity for the seal involved. Culling removes the individual interacting with the fishery (Mate & Harvey, 1986). It is suggested that culling is a multispecies problem, also affecting other species. It should therefore be conducted as a long term experiment of at least 10 years and that mathematical models needs to be applied to understand its effects on the trophic system (Yodzis, 2001). The type of culling Yodzis (2001) refers to, is culling of non-discreet individuals. The culling under scrutiny here, is the removal of specific problem individuals. Culling of discreet animals does not affect any other organisms than the targeted. The total degree of perceived severity was thus low. The risk of accidentally culling another animal than the targeted is low. Any form of culling (selective control) is preferable to a widespread reduction of a population by indiscriminately killing or hunting them (Linnell et al., 1999). The effect culling specific problem individuals (animals taking higher risks) has on a population is not known and warrants further studies.

Seal bombs and cracker shells were not only considered to be rather inefficient, they can also cause harm to other organisms and the environment (Jamieson & Olesiuk, 2001; National Seal Strategy Group et al., 2007; Stewardson & Cawthorn, 2004). This resulted in a high degree of perceived severity.

The most frequently reported methods, were AHD, culling and physical barriers – e.g. predator netting and bag enclosures (Please see Appendix C for a complete list of references). The AHD received a rather low percentage of papers in favour (50 %). This is according to the papers cited, due to the conditioning of the seals. The AHD seemed to have a short time effect and that the seals over time became habituated to the sound. A few papers referred to AHDs or ADDs as "dinner bells" (Stansbury et al., 2015; Westerberg et al., 2007).

The seals which were exposed to the AHDs or ADDs in the cited papers were not identified. It would therefore be difficult to conclude if it were a certain individual which became habituated or not. The avoidance responses of seals to sound is coupled with previous experience, foraging opportunity, learning processes, the level of the sound emitted and their hearing ability (Götz & Janik, 2010). As age advances, impaired hearing becomes common in many mammal species, including seals (Mate et al., 1986). Young and old seals would therefore be expected to respond differently to sounds emitted by AHDs or ADDs (A. Fjälling, personal comment, November 2016). Certain individuals have little or no response to the sounds emitted by an ADD/AHD. The probable cause is impaired hearing (Götz & Janik, 2010; Mate et al., 1986).

Another factor which influences their response to ADDs/AHDs it the adult seals spatial behaviour and foraging tactics. It is complex and vary between the sexes, prey availability and where in the annual cycle the animal is (Breed, Bowen, & Leonard, 2011; Breed, Jonsen, Myers, Don Bowen, & Leonard, 2009). Commercial fishers have reported a pattern of increased seal activities by fishing gear in late autumn/early winter (D. Bergman, personal comment, May 2016). This is substantiated by a study with fish traps equipped with AHDs, where it was observed that presence of seals was not uncommon late in the fishing season, despite sounds emitted by an AHD (Fjälling, 2006). After the seals moulting period (May/June), an intense period of foraging activities begins. The seals need to replenish their energy reserves and their insulating layer of blubber (Sjöberg, 1999) before the oncoming winter with colder temperatures.

A previous study, regarding the efficiency of AHDs, showed that its effect lasted over and between fishing seasons, suggesting that habituation probably did not occur (Fjälling, 2006). This is supported by a recent study which found that wild seals were not habituated to sounds emitted by an ADD and that it instead maintained a deterring effect over a period of more than 40 days (Götz & Janik, 2015).

## 4.2 The pontoon trap – a successful means of mitigation in the Baltic Sea Area

According to Korpinen & Braeger (2013), it is a priority in the management plan of the fisheries to mitigate the conflict between the coastal fisheries and the growing seal populations in the Baltic. The most successful mitigation means used in these waters is the non-lethal pontoon trap (Hemmingsson et al., 2008), which excludes the seals from the catch. The pontoon trap is described by Lunneryd et al. (2003), Varjopuro & Salmi (2006) and Hemmingsson et al. (2008). It works by leading the fish into gradually smaller chambers, ending in the fish chamber, from where the fish subsequently is harvested (Figure 7).

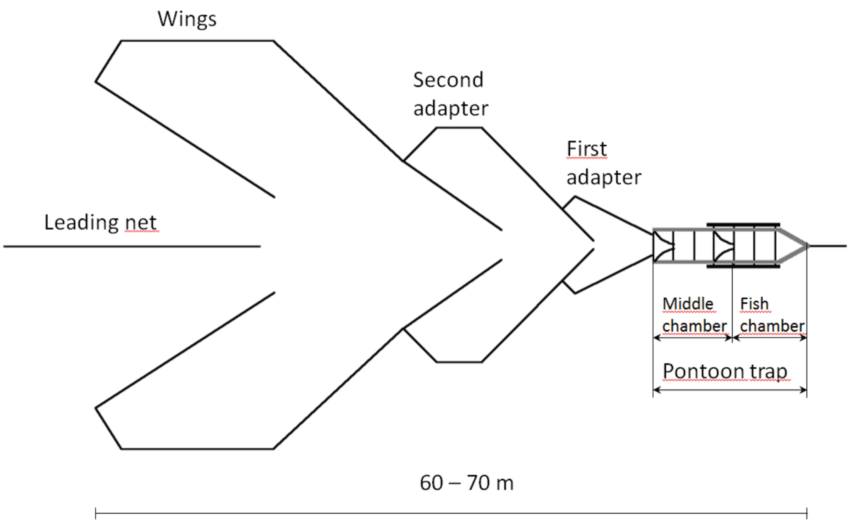


*Figure 7. Schematic of pontoon trap for salmonids, without anchoring ropes and set lines.*

Pontoon traps have been in use since the early 2000's and are today used by a majority of the commercial fishers along the east coast of Sweden (Königson, 2011). Pontoon traps have been developed for salmonids (*Salmonidae*) and whitefish (*Coregonus maraena*), herring (*Clupea harengus membras*) and vendace (*Coregonus albula*), perch (*Perca fluviatilis*) and pikeperch (*Sander lucioperca*). Even though seals are not able to gain access to fish in the fish chamber, it is possible for them to raid in the middle chamber (Figure 8). The incentive for the seals to enter the middle chamber is strong, as caught fish become a resource in form of easily caught prey. The grey seal is an opportunistic and resourceful predator (Gordon & Northridge, 2002; Lunneryd et al., 2003; Varjopuro, 2011; Varjopuro & Salmi, 2006) and will do what it can to get fish from the traps. Hence, the problem of mitigating the conflict between seals and fisheries is a ceaseless effort.

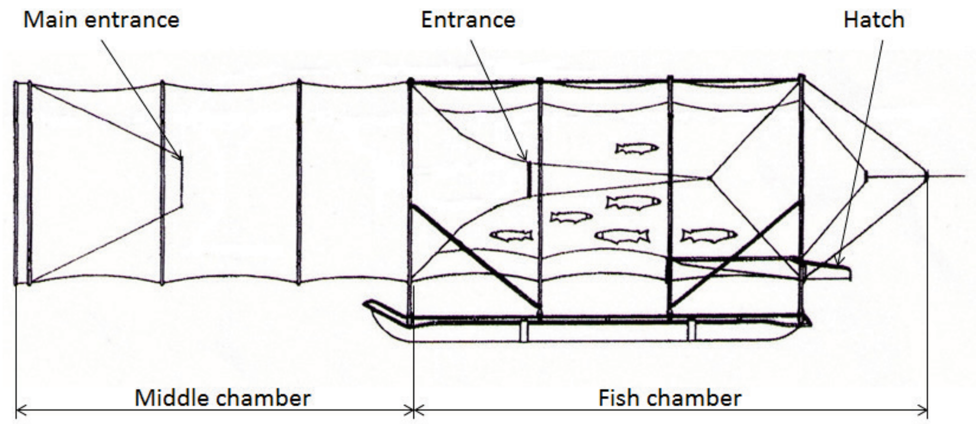


*Figure 8. The final parts of the trap. The middle chamber and the fish chamber. It is from the fish chamber that the fish is harvested by opening the hatch*

# 5 Present study: Seal and fish behaviour in pontoon traps

## 5.1 Seal exclusion device

The behaviour of the seal is dynamic. If one part of the traps is made inaccessible, it will try other ways of accessing the catch (Westerberg et al., 2007). A recurring problem which affects the inshore fisheries using pontoon traps is that grey seals are able to get into the middle chamber, where they capture, damage and stress the caught fish. In order to reduce the number of visiting seals, a seal exclusion device (SED; Lyle & Willcox, 2008) was placed in the entrance of the middle chamber. The expected objectives with the SED in this trial were; (i) to prevent access of seals and (ii) to increase the catch. A negative side effect of the SED was also expected; that it would deter large fish from swimming into the middle chamber and subsequently to be caught. Two sets of experiments were carried out. One in 2012, using a diamond mesh SED and one in 2016, using the diamond mesh SED and a square mesh SED, which was rotated 45°.

The seal visits were too few to be able to draw any conclusions. The SED did instead have an effect on the size of the caught fish. In 2012 larger trout were caught in the control trap, whereas large salmon appeared to be unaffected by the presence of the SED. In 2016 larger salmon were caught in the traps with a SED, whereas the differences in the individual sizes of trout were not significant. A plausible explanation for the non-significant results of the catch of trout in 2016, is that there were three treatments, resulting in small samples. The total catch was unaffected for both salmon and trout in both years.

## 5.2 Grey seals avoidance of conspecifics in a pontoon trap

During the breeding season male grey seals compete for females and the spacing between them is moderately consistent (Miller & Boness, 1979). It is a risk to be too close to a competitor as there is a potential for injuries. The spacing of competitors could possibly also be applied by seals in the aquatic environment, in this particular case in a set trap for herring.

In an experiment in a pontoon trap for herring in 2009, a camera was placed filming the entrance into the middle chamber. Seals visiting the trap were identified by their pelage patterns or scars. It is method previously used by e.g. Gerondeau, Barbraud, Ridoux, & Vincent (2007), Hiby et al. (2007) and Königson et al. (2013).

There were 1389 separate visits by 12 different seals. The majority of visits (84 %) took place within 0 to 5 minutes of the previous visit. There were two seals inside the middle chamber in 3.7 % of the visits. The concurrent visits were further investigated by looking at the realized and possible dyadic interactions. A dyad is defined as a group of two (Pinter-Wollman et al., 2014). A dominance matrix with a pairwise comparison was made. The seal in a pair which frequented the trap most often was considered to be the winner. A simulation of visits by seals was executed, with randomly selected times for when the seal swam in and for how long time it spent there. The randomization used the factual distribution patterns of when seals entered and the length of the visits as were realized during the study.

Given the many visits within 5 minutes of each other and the low proportion of concurrent visits, it suggests that the seals are informed of whether there is a seal already present in the trap, thus avoiding a potential conflict with a conspecific. There were a total of 28 possible dyads. Half of them were realized, i.e. with two seals concurrently in the middle chamber. The major part (86 %) of the realized dyads had a higher calculated probability of occurring than what actually happened. If the visits had been random, then c 9.5 % of all the visits would have been concurrent, with two seals inside the middle chamber at the same time.

By establishing a dominance matrix, it was possible to ascertain which of the seals was the most frequent winner. It was also possible to construct a social network (Figure 9). Certain dyads which were possible never occurred. This suggests that there might be an active avoidance between certain pairs of seals occurring concurrently in the middle chamber.

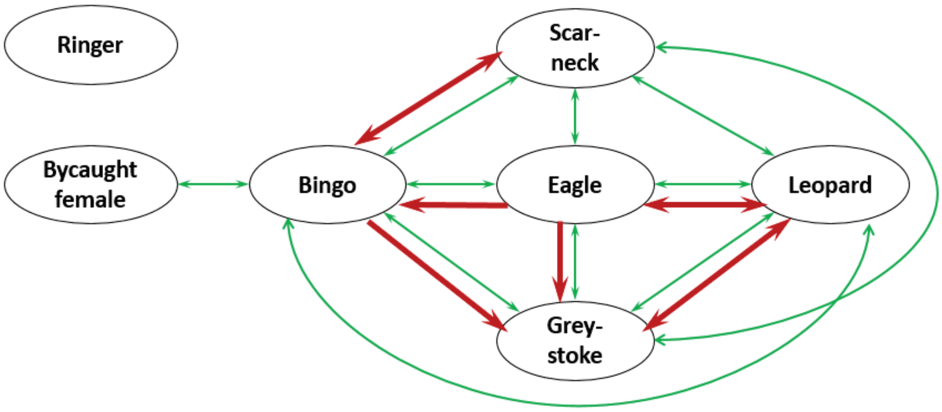


*Figure 9. Possible interactions (green line) and realized interactions (red line) between the seals. The arrows indicated the direction of the social interaction, i.e. which seal was the winner. Ringer was the only observed seal during the period he was present.*

The combined results indicate that the seals have a method of being informed of the presence of a conspecific and might choose to not enter the middle chamber, when a certain individual is present.

# 6 Maintaining a top predator – current and future management of the seals

Since the early 20th century, the seal has gone from being a valued resource (Hårding and Härkönen, 1999), to a vermin (Bignert et al., 2002), on the brink of extinction (Hårding and Härkönen, 1999) and causing substantial economic losses for fishers (Varjopuro, 2011). One way to mitigate the conflict might be to reconsider our opinion of whether the seals could be viewed as a resource instead of as problem to be solved. According to the Swedish Agency for Marine and Water Management (2012), a way to improve the relationship between man and seals and to motivate the compensations which are paid for the damage the seals causes, is to view the seals as a resource. The values which are provided to humans by wildlife are (from Conover, 2001):

- Ecological – maintaining the ecosystem
- Scientific – as indicator organism
- Recreational – hunting or viewing the animal (s)
- Physical utility – food and clothing
- Monetary – trade in products, hunters or tourists spend money to hunt or to view the animal(s)
- Existence – as a potential valuable asset in the future
- Historic values – humans feel at ease from knowing that we have healthy wildlife populations in healthy wilderness areas.

Today, some of the values stated above are untaxed or could be applied to a greater degree.

## 6.1 Ecological values

Top predators play an important role in the construction and maintenance of the food webs. The removal of a top trophic level will have an effect on the rest of the ecosystem (Elmgren, 2001). Fish predation is considered substantial in marine food webs. It does not mean that the abundance of prey is controlled or regulated by predators. Spatial and temporal variations can affect recruitment and determine adult abundance of prey (Pinnegar et al., 2000). Predator control has been practiced for almost 200 years, to benefit game and allow harvesting. It has severely reduced the abundance and distribution of many mammalian and avian species (Reynolds & Tapper, 1996). Humans and predators have previously co-existed for millennia. In recent decades, the frequency of conflicts has increased, due to the exponential increase in human population and expansion of human activity (Woodroffe, 2000). According to the BSAP, the management of the human activities in the Baltic Sea Area should have an ecosystem based approach (HELCOM, 2007). The objective of an ecosystem based management is to maintain a healthy marine ecosystem by taking into account the entire ecological community. i.e. all the trophic levels and their linkages and to remain adaptive and responsive to occurring changes (Dickey-Collas et al., 2014). For the grey seal, the management goal is that it should have a favourable conservation status and that its impact on human interests should be neutral or positive (Swedish Agency for Marine and Water Management, 2012b).

## 6.2 Scientific value

As a top predator, the seal accrues contaminants and is an indicator of the status of the Baltic Sea (Bäcklin et al., 2010). As an indicator organism, they are a valuable resource for the human populations around the Baltic. An example of how the health status of the grey seals has changed over the years can be seen in the prevalence of intestinal ulcers. From 1987 until a decade later, the prevalence of ulcers in the colon increased in young seals. The following decade it increased in older seals (Bäcklin et al., 2016). Since 2007, the prevalence of ulcers has decreased. Perforated intestinal ulcers was the third most common cause of death in seals sent to the Swedish Museum of Natural History in 2008 (Leidenberger & Bäcklin, 2008). The two most common causes were hunting and bycatch. There is a possible connection between the presence of the hookworm (*Corynosoma spp*.) and intestinal ulcers in grey seals (Bäcklin et al., 2016). The initial ulcer may start as a lesion, caused by a hookworm. The current hypothesis for the cause of the intestinal ulcers is that environmental contaminants are impairing the seal's ability to heal, thus contributing to the development of the ulcers (Bäcklin et al., 2016). Intestinal ulcers are today found in 10 % of the grey seals in the Baltic Proper and in 20 % of the seals in the Bothnian Bay (Bäcklin et al., 2016). Only one case of intestinal ulcer has been reported in seals from waters outside the Baltic Sea Area (Bäcklin et al., 2016).

It is important to continue to monitor known problem compounds and to be observant for possible new contaminants and pollutants. A recent discovery in the health status of Baltic seals is lacerations around their eyes, ears, noses and in their mouths (Moraeus, Bäcklin, Neimanis, & Östlin, 2016). The current theory is that these seals have been exposed to the chemical weapons which have previously been dumped in the deep areas of the Baltic (Moraeus et al., 2016).

Without indicator organisms, it would be difficult to monitor the effect of pollutants and the human impact on the environment. The indicators which are monitored in the seals are their distribution and abundancy, blubber thickness, pregnancy rate in the females and the growth rate in individual seals (Swedish Agency for Marine and Water Management, 2012).

## 6.3 Recreational value

### 6.3.1 Ecotourism

Ecotourism is a growing sector. There are several examples of wildlife safaris in Sweden. For example, of viewing moose, wolves, beavers and brown bears. There are also seal-safaris which are offered from Strömstad on the west coast to Haparanda in the Bothnian Bay (Swedish Agency for Marine and Water Management, 2012b). For the seal-safaris, it is beneficial to have a high density of seals. There is a substantial economic value in marine mammal ecotourism (Jamieson & Olesiuk, 2001) and it could be further exploited in the Baltic Sea Area.

### 6.3.2 Hunting

The population of grey seals today, surpasses the limit reference level (Swedish Agency for Marine and Water Management, 2012b). The limit reference level for the grey seal is 10 000 animals (HELCOM, 2016). There should thus be ample room for larger hunting quotas (Figure 10). Hunting for seals requires a high degree of skill and expertise. Special seal hunting safaris could be offered to hunters seeking an extra thrill. The grey seal has previously been considered to be a game species (Varjopuro, 2011) and it could become one again (Bruckmeier & Höj Larsen, 2008). When hunting of seals was introduced in Finland as a mitigation means, it had a temporal effect in the vicinity of fishing gear. Its long term effect on the population level is unknown (Varjopuro, 2011). A more open hunting would increase the hunting pressure on the seal population and lower the number of animals. This would be beneficial for the fisheries, but possibly detrimental for the low abundance areas of the Southern Baltic (Poland and Germany). There, the grey seal is considered to be a species which needs conservation measures (Schwarz, Harder, von Nordheim, & Dinter, 2003). The expectation is that some of the "surplus" of seals in the northern waters of the Baltic Sea Area will migrate to more southern latitudes (Schwarz et al., 2003).

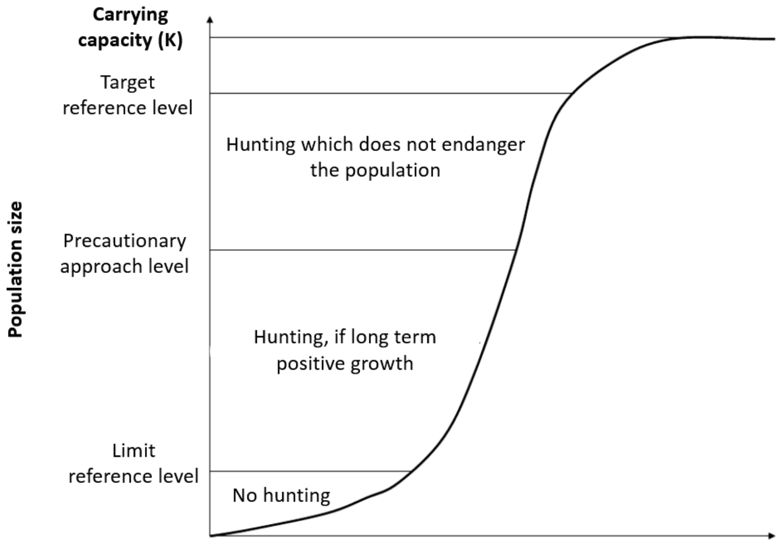


*Figure 10. The different reference levels for the Baltic grey seal population. Adapted from the Swedish Agency for Marine and Water Management (2012b).*

The type of hunting of seals, which today is allowed in Sweden, is the protective hunting. Protective hunt is the removal of the specific individual which caused damage to gear or assets (fish in the case of seals). The purpose of the protective hunt is to decrease seal induced damage on fishing gear and catch. In 2015, the total allowable protective hunt for the grey seal was 410. Of these, about 70 % were shot (Swedish Environmental Protection Agency, 2016). The quota is difficult to fill, due to the rules governing the hunt (Swedish Agency for Marine and Water Management, 2013). In 2016 a new law by the European Union (EU) took effect regarding the protective hunt for seals. Seals are only allowed to be hunted within 200 m from a place where fishing is conducted and where seals have caused damage to gear or taken fish (Swedish Environmental Protection Agency, 2016c). The new law has made it more complicated for the hunters to hunt seals.

The recommendation from HELCOM is that populations under the Limit Reference Level should not be exposed to hunting. Populations between the Limit Reference Level and the Precautionary Approach Level, can be hunted if the population has a long term positive trend. Populations between Precautionary Approach Level and Target Reference Level, or if they are over the Target Reference Level, can be hunted so long as they do not jeopardize the long term goals of the overall management (HELCOM, 2013b). The carrying capacity (K) for the seal populations have not yet been determined for the seal populations (HELCOM, 2013b). Without knowing the value of K, it is not possible to calculate the Target Reference, Level, which is 80 % of K (HELCOM, 2013b).

An alleviation of the rules governing the hunt would facilitate for the hunters and be a step in managing the increasing grey seal population. An increase of the hunting quota would increase the value of the seals, in form of tourism geared to hunters (Swedish Agency for Marine and Water Management, 2012b).

## 6.4 Physical utilities

Today, it is a small fraction of the human population in the EU, who can benefit from products stemming from hunted seals. It is the hunters and their families. The seal as a resource can, as previously stated, be used in many ways; the meat is rich in flavour, the skin is versatile and can be used for wide variety of products, seal-oil can be made from the blubber and used for a multitude of purposes. The Kvarken Council (2007) sees many potential possibilities for seal products in the future. There is for example a great interest in seal meat. The council further suggests that the time has come to limit the increasing seal populations.

## 6.5 Monetary values

Since 2009, there has been a general ban within the European Union (EU), on trade in seal products, except for products from Inuit or other indigenous communities (European Parliament and the Council of the European Union, 2009). The ban was set in force by the European Parliament, as a response to citizen concern regarding the killing and skinning of seals (European Parliament and the Council of the European Union, 2009). The laws governing the different member states differed between the countries and the goal of the European Parliament was to harmonize the laws of all its members. Some member states had already adopted the ban (European Parliament and the Council of the European Union, 2009). One of the goals of the ban, was that it should not adversely affect the subsistence of the Inuit or other indigenous people (European Parliament and the Council of the European Union, 2009). The ban excluded seal products which had been derived from hunts regulated by national laws. These products were thus allowed to be placed on the market. In Sweden, this applied to seals which were killed during the protective hunting. They were therefore part of the EUs aim to have a sustainable management of marine resources (European Parliament and the Council of the European Union, 2009). Since the introduction of the general ban in 2009, the export of seal derived products from Inuit communities on Greenland has plummeted with 90 % and it has had a catastrophic impact on the Inuit coastal communities (Brabant, 2015).

In 2015 the EU strengthened the ban on seal products. It is now only possible for Inuit or other indigenous communities to trade in seal products (European Parliament and the Council of the European Union, 2015), thus excluding products derived from seals shot during the protective hunt by non-indigenous communities.

According to the Habitats Directive, Annex 2 and 5 council directive (92/93/EEG), Sweden must ensure that the hunting of the seals is consistent with a favourable conservation status. According to the Helsinki Commission, the lower reference limit for both the grey and the harbour seal is a population of 10 000 each (Swedish Environmental Protection Agency, 2016a, 2016b). As mentioned earlier, the status of the grey seal and the southern Baltic harbour seal populations are of least concern (HELCOM, 2013c). The estimated populations have for both seal species passed the lower reference limit. In 2014, the grey seal population was estimated to be around 45 000 animals and for the harbour seal the estimated population was 14 000 animals (70 % of the true population; Swedish Agency for Marine and Water Management, 2014).

A regression to the previous EU law, when it was allowed for non-indigenous communities to sell and trade in seal products derived from the protective hunt, would increase the value of the seals. If the fisher can sell bycaught seals, or products derived thereof, the seal would then not only be viewed as a problem. It would serve a subsistence purpose and become a valuable asset, improving the fisher's attitude towards the seals. It would be a mitigation method that has not yet been tried in the Baltic Sea Area. The seals would be viewed as a resource as suggested by the Swedish Environmental Protection Agency (2013) and serve a subsistence purpose as they today are for the Inuit and other indigenous communities within the EU (European Commision, 2016).

## 6.6 Existence

Conover (2001) considers that wildlife has an existence value as a potential asset in the future of humans. This should not be the only reason to maintain and manage a certain species. There are many factors which should be considered before killing or decimating a population of predators. One of them is that removing or decimating a predator can have adverse effects on the entire ecosystem (Dulvy, Freckleton, & Polunin, 2004; Pinnegar et al., 2000).

## 6.7 Historic values

The recuperation of the Baltic seal populations is viewed as an international success for the management of the Baltic environment (Elmgren, 2001). It is the result of a mutual effort from the countries surrounding the Baltic, that the seal populations have recovered from near extinction. According to Conover (2001), the historic value of a species originates from the general view of mankind that there is a sense of satisfaction when there are healthy wilderness areas and wildlife populations.

# 7 Closing words

The inshore fisheries are a valuable asset. They provide locally produced, high quality fish, which almost exclusively is used for human consumption. They have a low impact on the environment and are part of a self-sufficient food production chain, thus decreasing the dependence on imported fish. It is therefore important that the development of mitigation means continues. The catch should be harvested by fishers. Learning more about the behaviour of the seals which frequent the fishing gear, might be a possible way of developing new non-lethal mitigation means as advised in the BSAP (HELCOM, 2007).

The seals are here to stay, irrespectively of whether we are in favour for them or not. If a nuisance has become permanent, there is no option other than to learn to live with it (Varjopuro, 2011). Whether this will be in the form of new or improved seal deterrents, physical barriers, an acceptance of their presence, an increase in the hunting pressure, or a combination of these mitigation means, remains to be seen. If seals were to be viewed as a resource again, there would be a common interest among the countries surrounding the Baltic Sea Area, in keeping the seal populations at sustainable levels and maintaining them.

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Appendix

# A – Offshore and inshore catch in the Baltic, from 1999 to 2015

Linda Calamnius

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**Method**

The source for the statistic on  the following spreadsheet "Offshore and inshore catch" is:

https://havbi.havochvatten.se/analytics/saw.dll?PortalPages

The values used was "Östersjön" (the Baltic) for the area fished.
The value used for "Redskapstyp (type of gear) was set to include all types of gear
The value used for "Fartygssegment" (type of vessel) was set to include all types of gear
The same procedure was performed for the Kattegat

I called Jarl Engqvist (administrative officer) at the Swedish Agency for Marine and Water Management to determine whether the various fishing gears were used by inshore or offshore fisheries. Please see the table to the right.

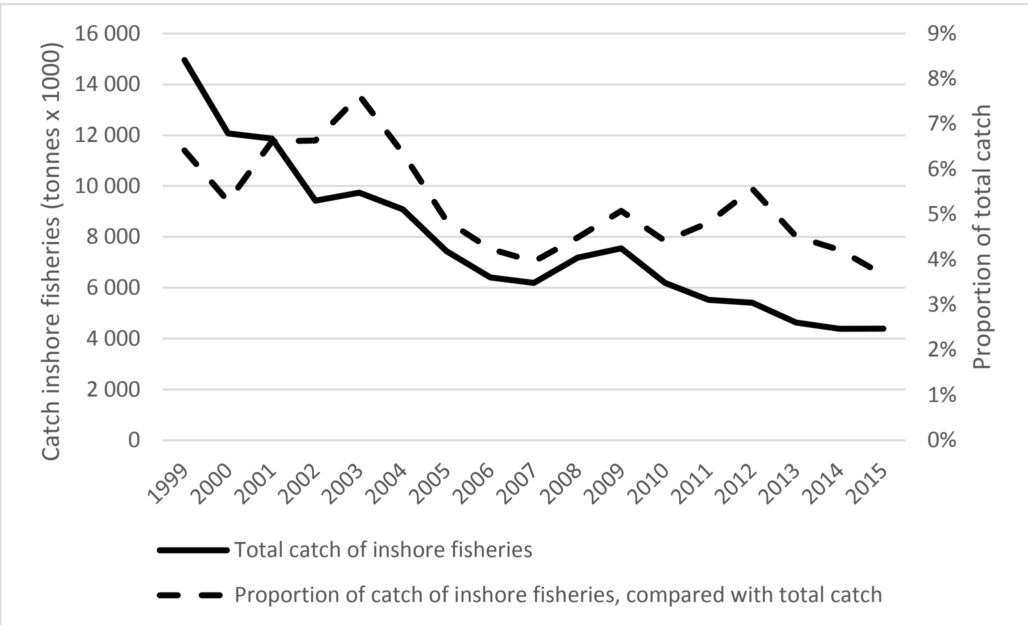
| Type of gear belongs to inshore or | | |
|---|---|---|
| **Type of gear** | **Inshore** | **Offshore** |
| Set traps and fyke nets | Yes | No |
| Pots | Yes | No |
| Nets | Yes | No |
| Hooking tools | Yes | No |
| Purse seines | Yes | No |
| Trawls | No | Yes |

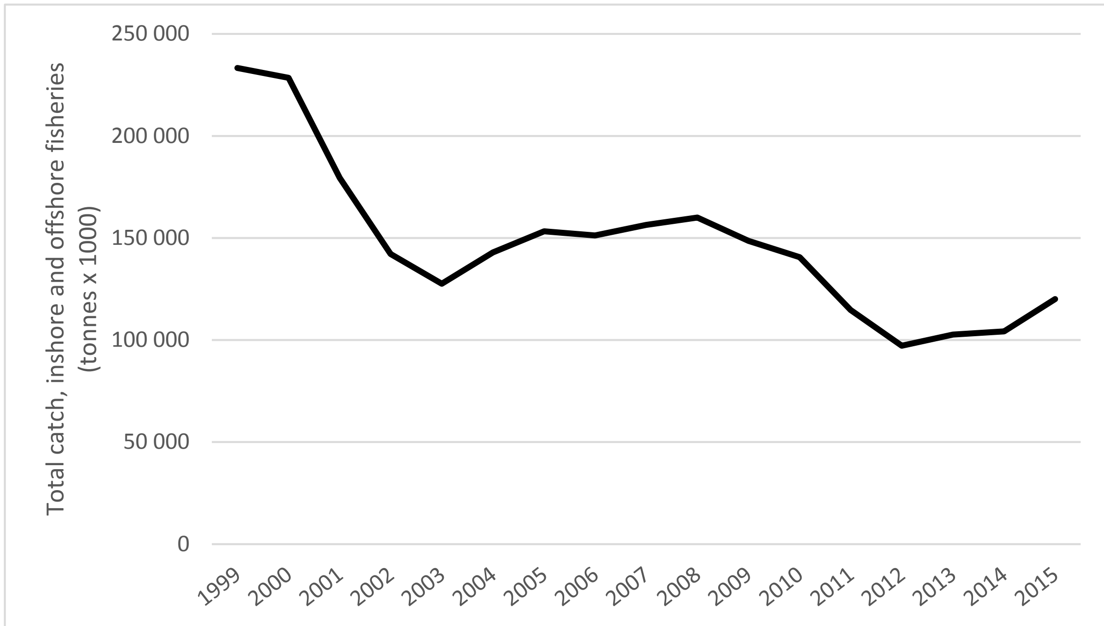
| Inshore fisheries | Quantity (kg) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type of fishing gear | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| Set traps and fyke nets | 757 926 | 638 625 | 694 517 | 640 236 | 726 631 | 837 608 | 849 803 | 705 996 | 722 622 | 730 688 | 670 225 | 590 235 | 580 115 | 526 092 | 586 977 | 510 200 | 472 799 | 440 171 |
| Pots | 42 377 | 27 114 | 30 548 | 38 205 | 27 094 | 16 067 | 16 611 | 11 828 | 7 957 | 6 192 | 13 695 | 14 777 | 7 676 | 7 665 | 9 268 | 10 105 | 16 013 | 20 140 |
| Nets | 10 567 483 | 9 881 186 | 9 453 323 | 7 680 648 | 7 821 958 | 6 628 941 | 5 127 331 | 4 543 768 | 4 721 070 | 5 354 489 | 5 420 308 | 4 378 489 | 3 689 218 | 3 631 850 | 3 005 015 | 3 109 444 | 2 889 560 | 2 663 333 |
| Hooking tools | 283 939 | 406 225 | 895 375 | 903 590 | 1 096 208 | 1 531 398 | 1 356 259 | 1 134 218 | 730 019 | 914 163 | 892 493 | 676 122 | 699 442 | 651 472 | 476 827 | 257 477 | 226 659 | 114 872 |
| Purse seines | 3 304 295 | 1 121 025 | 796 000 | 165 812 | 63 624 | 73 875 | 92 755 | 9 346 | 5 447 | 180 828 | 550 810 | 537 974 | 549 051 | 590 537 | 555 939 | 499 446 | 792 621 | 680 643 |
| TOTAL INSHORE | 14 956 020 | 12 074 174 | 11 869 762 | 9 428 490 | 9 735 515 | 9 087 888 | 7 442 760 | 6 405 156 | 6 187 115 | 7 186 359 | 7 547 531 | 6 197 596 | 5 525 503 | 5 407 616 | 4 634 025 | 4 386 673 | 4 397 653 | 3 919 159 |

| Offshore fisheries | Quantity (kg) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Redskapstyp | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| Trawl | 218 351 397 | 216 335 600 | 167 631 431 | 132 781 947 | 117 864 872 | 133 823 410 | 145 843 588 | 144 782 378 | 150 265 974 | 152 860 213 | 141 072 372 | 134 411 591 | 109 294 627 | 91 819 878 | 98 101 028 | 99 815 589 | 115 645 361 | 119 330 776 |
| TOTAL OFFSHORE | 218 351 397 | 216 335 600 | 167 631 431 | 132 781 947 | 117 864 872 | 133 823 410 | 145 843 588 | 144 782 378 | 150 265 974 | 152 860 213 | 141 072 372 | 134 411 591 | 109 294 627 | 91 819 878 | 98 101 028 | 99 815 589 | 115 645 361 | 119 330 776 |

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL INSHORE and OFFSHORE (tonnes) | 233 307 | 228 410 | 179 501 | 142 210 | 127 600 | 142 911 | 153 286 | 151 188 | 156 453 | 160 047 | 148 620 | 140 609 | 114 820 | 97 227 | 102 735 | 104 202 | 120 043 | 123 250 |

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proportion of catch of inshore fisheries, compared with total catch | 6,41% | 5,29% | 6,61% | 6,63% | 7,63% | 6,36% | 4,86% | 4,24% | 3,95% | 4,49% | 5,08% | 4,41% | 4,81% | 5,56% | 4,51% | 4,21% | 3,66% | 3,18% |
| Total catch of inshore fisheries | 14 956 | 12 074 | 11 870 | 9 428 | 9 736 | 9 088 | 7 443 | 6 405 | 6 187 | 7 186 | 7 548 | 6 198 | 5 526 | 5 408 | 4 634 | 4 387 | 4 398 | 3 919 |
| Offshore fisheries, times greater than inshore | 14,6 | 17,9 | 14,1 | 14,1 | 12,1 | 14,7 | 19,6 | 22,6 | 24,3 | 21,3 | 18,7 | 21,7 | 19,8 | 17,0 | 21,2 | 22,8 | 26,3 | 30,4 |



| Catch per species (tonnes) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | Proportion of total catch (%) | Trophic level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Herring (Clupea harengus)** | 53 165 | 64 591 | 64 468 | 58 073 | 49 272 | 43 515 | 36 104 | 44 887 | 52 751 | 70 211 | 56,3% | Planktivorous |
| **Sprat (Sprattus sprattus)** | 82 849 | 89 131 | 87 723 | 79 557 | 80 331 | 57 970 | 47 222 | 50 885 | 46 455 | 44 501 | 35,7% | Planktivorous |
| **Cod (Gadhus morhua)** | 12 253 | 12 806 | 11 804 | 12 359 | 11 585 | 12 647 | 12 491 | 7 033 | 5 909 | 6 427 | 5,2% | Predator |
| **Vendace (Coregonus albula)** | 1 195 | 914 | 628 | 982 | 1 042 | 1 145 | 1 349 | 1 481 | 1 825 | 1 890 | 1,5% | Planktivorous |
| **Norway lobster (Nephrops norvegicus)** | | 505 | 562 | 467 | 421 | 324 | 440 | 371 | 370 | 329 | 0,3% | Scavenger and predator |
| **Lumpfish (Cyclopterus lumpus)** | 94 | 122 | 138 | 73 | 128 | 128 | 34 | 55 | 170 | 188 | 0,2% | Predator |
| **Salmon (Salmo salar)** | 336 | 318 | 259 | 321 | 300 | 359 | 245 | 193 | 195 | 187 | 0,1% | Predator |
| **Eel (Anguilla anguilla)** | 317 | 437 | 410 | 324 | 321 | 287 | 236 | 268 | 210 | 158 | 0,1% | Scavenger and predator |
| **Whitefish (Coregonidae)** | 197 | 154 | 143 | 136 | 131 | 126 | 138 | 114 | 143 | 152 | 0,1% | Invertebrates and zooplankton |
| **European plaice (Pleuronectes platessa)** | 97 | 342 | 296 | 249 | 167 | 120 | 108 | 136 | 153 | 134 | 0,1% | |
| **European flounder (Platichthys flesus)** | 169 | 191 | 224 | 220 | 183 | 185 | 171 | 484 | 258 | 126 | 0,1% | |
| **Perch (Perca fluviatilis) small > 0,2 kg, < 0,4 kg** | 107 | 93 | 85 | 73 | 73 | 78 | 84 | 91 | 109 | 122 | 0,1% | Predator |
| **(Perch (Perca fluviatilis) medium >0,4 kg, <0,8)** | | | | | | | | | | 122 | 0,1% | Predator |
| **(Perch (Perca fluviatilis) large >0,8 kg)** | | | | | | | | | | 122 | 0,1% | Predator |
| **Stickleback (Gasterosteidae)** | | 4 | 31 | 15 | 0 | 162 | 5 | 43 | 12 | 83 | 0,1% | |
| **TOTAL** | | **169 608** | **166 772** | **152 849** | **143 955** | **117 047** | **98 626** | **106 041** | **108 560** | **124 751** | | |

| Catch per species (tonnes) | Price at distributor/ reseller (SEK/kg) | Source | Total value | Price for consumer (SEK/Kg) | Price increase | Product | Source |
|---|---|---|---|---|---|---|---|
| **Herring (Clupea harengus)** | 39,3 | http://www.stockholmsfiskauktion.se/ | 2 759 294 701 | 88,78 | 126% | Fillet | https://www.coop.se/handla-online/varor/fisk/fisk/farsk |
| **Sprat (Sprattus sprattus)** | 39,3 | http://www.stockholmsfiskauktion.se/ | 1 748 873 226 | 88,73 | 126% | Pickled herring | https://www.coop.se/handla-online/varor/fisk/fisk/farsk |
| **Cod (Gadhus morhua)** | 88 | http://www.stockholmsfiskauktion.se/ | 565 545 218 | 188,78 | 115% | Fillet | https://www.coop.se/handla-online/varor/fisk/fisk/farsk |
| **Vendace (Coregonus albula)** | 900 | http://www.stockholmsfiskauktion.se/ | 1 700 709 750 | 1937,5 | 115% | Roe | https://www.coop.se/handla-online/varor/fisk/fisk/farsk |
| **Norway lobster (Nephrops norvegicus)** | 289,5 | http://www.stockholmsfiskauktion.se/ | 95 375 949 | | | | |
| **Lumpfish (Cyclopterus lumpus)** | | | | | | | |
| **Salmon (Salmo salar)** | | | | 179 | | | https://www.coop.se/handla-online/varor/fisk/fisk/farsk |
| **Eel (Anguilla anguilla)** | | | | | | | |
| **Whitefish (Coregonidae)** | | | | | | | |
| **European plaice (Pleuronectes platessa)** | 28,8 | http://www.stockholmsfiskauktion.se/ | 3 858 011 | 189 | | | http://butik.fiskbilen.se/fisk |
| **European flounder (Platichthys flesus)** | | | | | | | |
| **Perch (Perca fluviatilis) small > 0,2 kg, < 0,4 kg** | 8,2 | http://www.stockholmsfiskauktion.se/ | 1 002 773 | Price if all perch small | | | |
| **(Perch (Perca fluviatilis) medium >0,4 kg, <0,8)** | 51,2 | http://www.stockholmsfiskauktion.se/ | 6 246 400 | Price if all perch medium | | | |
| **(Perch (Perca fluviatilis) large >0,8 kg)** | 70 | http://www.stockholmsfiskauktion.se/ | 8 540 000 | Price if all perch large | | | |
| **Stickleback (Gasterosteidae)** | NA | | | | | | |
| **TOTAL** | | | | | | | |

Appendix

# B – References Baltic pinniped mitigation methods

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Appendix

# C – References Global pinniped mitigation methods

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