Size Selection of Fish in the Trap Fisheries of the Baltic and Bothnian Seas

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Abstract

A sustainable fishery in the Baltic Sea requires fishing gear that fishes selectively and at the same time excludes raiding seals. A successful type of trap recently developed in response to the seal problem is the pontoon fish chamber**,** which significantly decreases damage to gear and catch losses caused by grey seals. However, a common problem with traps is the bycatch of juvenile and non-marketable fish which constitutes a threat to the sustainability of the fishery and a time-consuming problem for the fishers.

This thesis deal with bycatch reduction of young herring, whitefish and perch in pontoon traps. Rigid grids and square mesh panels were installed in traps during commercial fishing operations and continuously monitored with underwater cameras. The selection efficiencies were calculated for different species and selection panel designs. The importance of abiotic and biotic factors for the selection efficiency, the diurnal activity levels of species, and the positions of escape through a selection panel were analysed. This thesis also addresses the survival changes of herring after being released from a trap and the potential size-structuring effects on the herring stock after a size-selective fishery.

The results showed that several tonnes of young fish were able to escape through selection panels from the traps during a season. 70-80% of young herring and whitefish escaped through an encircling selection panel while 90-100% of young perch and roach escaped through a rigid grid. Both biotic and abiotic factors were influencing the selection efficiency of herring. The factors which had most effect were the quantity of fish in the trap, the season of the year, the time of day, and the presence of seals. The diurnal activities were significantly different between species. Herring and roach preferred to escape during night while perch escaped mostly during dusk and dawn. The passing through a rigid grid did not affect the short term mortality of young herring and the risk that extensive use of traps will induce selection for phenotypic changes in mature herring, leading to an evolutionary change on the Bothnian Sea herring population is low.

The overall conclusion of this thesis is that bycatch can be reduced by equipping traps with selection panels. The appropriate design of the selection panel depends mainly on the behaviour and physiology of the fish. The survival changes of released fish seem high and the risk that extensive use of size-selective traps will induce evolutionary changes on the herring stock is low.

Keywords: Baltic Sea, Pontoon trap, Bycatch, Size-selection, Selection panel, Grid

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Dedication

To Sammy and Leo

Action is the foundational key to all success
Pablo Picasso

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Lundin, M., Calamnius, L., Hillström, L., Lunneryd, S.G. 2011. Size selection of herring (*Clupea harengus membras*) in a pontoon trap equipped with a rigid grid. Fisheries Research, 108: 81-87.

II Lundin, M., Ovegård, M., Calamnius, L., Hillström, L., Lunneryd, S.G. 2011. Selection efficiency of encircling grids in a herring pontoon trap. Fisheries Research, 111: 127-130.

III Lundin, M., Calamnius, L., Lunneryd, S.G. 2012. Survival of juvenile herring (*Clupea harengus membras*) after passing through a selection grid in a pontoon trap. Fisheries Research, 127-128: 83-87.

IV Lundin, M., Calamnius, L., Fjälling, A. Size-selection of whitefish (*Coregonus maraena*) in a pontoon trap equipped with a square mesh selection panel (manuscript).

V Lundin, M., Calamnius, L., Lunneryd, S.G., Magnhagen, C. The efficiency of selection grids in perch pontoon traps (manuscript).

VI Lundin, M., Östman, Ö., Hillström, L., Magnhagen, C., Larson, N. Effects of a size-selective trap fishery on the Bothnian Sea herring stock (manuscript).

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The contribution of Mikael Lundin to the papers included in this thesis was as follows:

I Participated in the planning of the study, performed field work, analysed the data and was mainly responsible for writing the manuscript.

II Participated in the planning of the study, performed field work, analysed the data and was mainly responsible for writing the manuscript.

III Mainly responsible for the experimental design, performed field work, analysed the data and was mainly responsible for writing the manuscript

IV Mainly responsible for the experimental design, performed field work, analysed the data and was mainly responsible for writing the manuscript

V Participated in the planning of the study, performed field work, analysed the data and was mainly responsible for writing the manuscript

VI Participated in the planning of the study, analysed the data and was mainly responsible for writing the manuscript

1 Introduction

1.1 The Baltic Sea trap fisheries

The increasing population of grey seals (*Halichoerus grypus*) over the last 20 years has caused serious problems for the small scale inshore trap fishery (Kauppinen et al., 2005; Westerberg et al., 2006). Seals plunder fish from the fishing gear and cause extensive material damage (Lunneryd and Westerberg, 1997; Lehtonen and Suuronen, 2004; Fjälling, 2005; Königson et al., 2007; He and Inoue, 2010; Königson et al., 2013).

However, by using the recently developed pontoon fish chamber, damage to gear and catch losses caused by grey seals have been significantly reduced in this fishery (Lunneryd et al., 2003; Suuronen et al., 2006; Hemmingsson et al., 2008; Lehtonen and Suuronen, 2010). A fish trap with this type of fish chamber, which is emptied by raising the trap to the surface using compressed air, is referred to as a pontoon trap (Suuronen et al., 2006; Hemmingsson et al., 2008). The chamber is a fixed construction consisting of strong netting attached to rings of aluminium. Until 2009, the pontoon fish chamber was almost exclusively used for salmon (*Salmo salar*) and whitefish (*Coregonus maraena*). However, in 2009, the development of pontoon traps for herring (*Clupea harengus membras*) and perch (*Perca fluviatilis*) was begun (Harmångers Maskin & Marin AB in collaboration with the Seals & Fisheries Programme of SLU, dept. of Aquatic Resources).

Suuronen et al. (2012) included pontoon traps in a compilation of LIFE fishing gear (Low Impact and Fuel Efficient) as a type of gear that possesses several attractive characteristics compared to many alternatives: low energy use, minimal habitat impact and high quality of the fish landed. However, one drawback with all types of pontoon traps is the bycatch of young non-commercial fish and non-target species. This bycatch is often sorted manually and discarded by fishermen at sea, which leads to a high mortality of the fish and a time-consuming task for the fishermen. The catching and discarding of young fish before they have reproduced is a serious threat to fish stocks and a waste of a valuable natural resource.

1.2 Trap function

As passive fishing gear, traps are set in a suitable location and left there for the whole season (Fig. 1). They are secured with anchors and marked with buoys and flags. Standard depths are 6-14 m. The trapping process begins with the fish finding their passage parallel to the shore interrupted by a leading net stretching out from the shore to the trap. Wanting to continue forwards, the fish follow the leader out into deeper water, where they encounter the V-shaped 'wings', which constitute the first and largest enclosure within the trap itself. As the wings narrow, the fish still want to swim forwards and so they end up in the 'adapters'. Overhead video recordings show that fish sometimes turn around and try to swim back, but as the entrances get narrower, it gets difficult for them to find the way out. Instead they usually end up in the blind corners, where they are stopped by the net and forced to continue on forwards again towards the fish chamber.

The pontoon fish chamber itself has two entrances. One of them is equipped with a seal net or a frame crossed by a steel wire, which stops seals from following the fish into the fish chamber. The final entrance is fitted with nylon threads which reach from the entrance frame to a common point ahead of the entrance. On their way in, the fish pass these nylon threads fairly smoothly as they are travelling at speed and are eager to continue forwards. Once in the fish chamber itself, however, the nylon threads makes it difficult for the fish from swimming back out through the entrance, so they are now trapped.

The traps are designed in different ways depending on the target species (Fig. 2), often on the basis of the experience and observations of commercial fishermen. The biggest traps are those for salmon and whitefish. The leading nets are often between 150 m and 200 m long and the openings into the wings are 6 m on each side of the leading net. Fishermen say that whitefish need lots of space and wide entrances to persuade them to swim in to a trap. They also keep well away from the leading nets on their way in to the wings, even in total darkness. This was confirmed in a study by Lunneryd et al. (2002).

The whole salmon/whitefish trap is positioned at the surface. Sometimes bottom-set traps are used, in which the wings hang right down from the water surface to the sea bed, but floating traps for use in deeper water are just as common. These leave a gap between the sea bed and the bottom rope but the salmon still swim into the fish chamber. However catches of whitefish tend to be smaller in floating traps compared to bottom-set traps, presumably because whitefish swim close to the bottom when following the leader net. Salmon and whitefish traps have rounded corners inside the wings and adapters. The reason for that is so that the fish don't get caught in the corners. This is particularly important if there are seals chasing the fish inside the wings.

Figure 1. Complete salmon/whitefish trap during fishing. Photo: Mikael Lundin

Herring traps are smaller than salmon/whitefish traps and are often set at known spawning sites in the spring. The fish chambers are often positioned a few meters under the surface as experience shows that herring tend to swim at greater depths than salmon or whitefish. As a result the adapter needs to have a 'roof'. Perch traps are the smallest traps. Perch stick close to the shore and are thought to be unwilling to follow the leading nets too far out, so these are usually restricted to just 60 m in length. As perch generally swim close to the sea bed, the whole trap is fixed to the bottom, typically at a depth of about 6 meters. The whole adapter and sometimes the wings are also covered with a net roof. It is said to be very important that the whole of the net is firmly weighted to the bottom so that the perch do not escape. They also tend to be very sensitive to folds or other irregularities in the net walls, so it's common to use divers to check that the nets are sitting nicely in the water.

Some of the perch traps manufactured by Harmångers Maskin & Marin AB have been equipped with a raft fitted with pontoons. The raft is attached to the fish chamber and facilitates the work with setting the trap or taking up the trap from the water, making the trap more portable so that it easily can be moved between fishing spots (Fig. 5). The raft has enough room for the entire trap and the leading net which are otherwise transported in the boat. The leading net and the wings can be tied to each other and attached to the fish chamber on land, before the raft is loaded. When on the fishing spot, one person can be standing on the raft behind the fish chamber and put the netting in to the water while the entire equipage is towed with a motor boat.

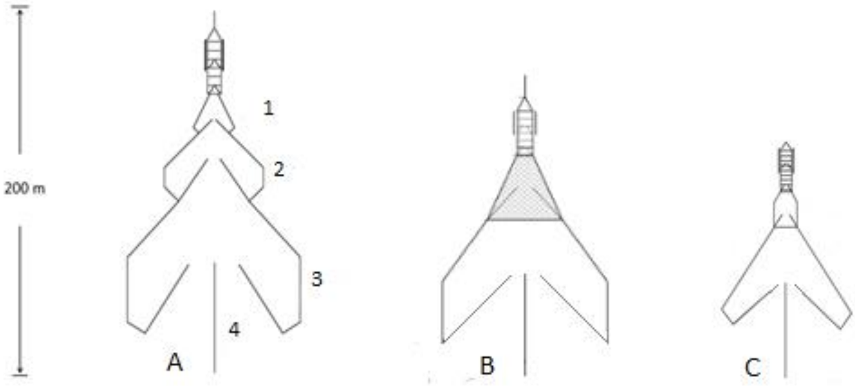

Figure 2. The different types of traps used in the studies (above view). A: Salmon/whitefish trap, B: Herring trap, C: Perch trap. Apart from the fish chambers the traps consist of 1: Second adapter, 2: Adapter, 3: Wings, 4 Leading net. Traps B and C lack the second adapter.

The fish chambers are made differently for the different target species and are adapted to the fishes' behaviour and physiology (Fig. 3,4,5). From the point of view of fishing efficiency, the entrances to the fish chamber are the most crucial parts. Based on what the commercial fishermen say, for whitefish the first entrance should be rectangular and tall, extending right up to the roof of the fish chamber. For a herring trap's fish chamber, which can quickly fill with several tonnes of fish when they are spawning, larger and longer entrances are needed. The smaller perch traps have narrower entrances than other fish traps.

Salmon and whitefish traps have double wall nets for the fish chambers, with a gap of 30 cm between them. The outer net prevents the seals from reaching through the mesh into the chamber. For the herring and perch fisheries, a single wall net is sufficient as the mesh size usually prevents the seals to do any damage.

The procedure for emptying the fish chambers is different for the different fisheries. All are raised to the surface using compressed air to inflate the pontoons. For salmon, whitefish and perch the fish chambers are equipped with fish boxes in the bottom, and all the fish collect there as the fish chamber is lifted out of the water. The fish box is emptied into the boat by opening a hatch. Instead of a fish box, herring fish chambers are equipped with a long sock-shaped net which fills with fish as the chamber is lifted. Larger fishing boats equipped with cranes are used to lift the catch aboard, making it easy to handle catches of several tonnes.

Figure 3. The pontoon fish chamber of a salmon/whitefish trap. Photo: Maria Boström.

Figure 4. The pontoon fish chamber of a herring trap. Photo: Mikael Lundin

Figure 5. The pontoon fish chamber of a perch trap with raft. Photo: Sven-Gunnar Lunneryd

1.3 Size-selection

Bycatches, whether they are of undesirable sizes of the target fish or of other species, are a threat to sustainable fisheries all over the world (Alverson et al., 1994; Hall et al., 2000; Pitcher et al., 2013). Two main actions are used to reduce bycatch in world´s fisheries; input/output controls and technical management (Pope, 2002). Input control means that restrictions are put on the number of vessels and fishing gears used, the amount of time to fish, the number of fishers allowed to fish etc. Output control means that restrictions are put on the catch, e.g. the amount of fish allowed to be caught or landed or minimum sizes (Pope, 2002). Technical management includes the regulation of mesh sizes and installation of selection panels in fishing gears.

Several studies have been conducted on size-selection of fish in trawls (Suuronen et al., 1996a,b; Armstrong et al., 1998; Madsen and Stær, 2004; Herrman and O'Neill, 2006; Bahamon et al., 2007). Various modifications such as the fitting of square mesh panels are commonly used to improve the selectivity of trawl codends. There has also been a substantial amount of research into using rigid sorting grids to improve the selectivity (Graham et al., 2004; Madsen, 2007). In a trawl, the fish are often sieved out more or less involuntarily through the selection device. The effectiveness of the selection depends not only on the shape and size of the fish, but also on many other factors, including the placement and design of the device (Armstrong et al., 1998; Madsen, 2007), towing duration and towing speed, and the amount of fish held in the codend (Dahm et al., 2002).

Only a few studies on selective release have been done for fixed fishing gear such as large- sized traps and pound-nets (Laarman and Ryckman, 1982; Brothers and Hollett, 1991; Tschernij et al., 1993; He and Inoue, 2010). With passive gear, fish are not forced out physically and any capture or possible escape requires their active behaviour (Hubert, 1996). Small details in the design of the gear and the selection device can dramatically affect the selection efficiency. Hence, there is a need for detailed knowledge of the behaviour of the fish during the selection process to be able to optimize the conditions.

Several factors can be assumed to affect the degree of selection: (1) environmental conditions, such as currents, winds, light intensity and temperature; (2) behavioural characteristics of the fish, such as flight disposition, school cohesion, boldness/shyness and reactions to predators; and (3) physical characteristics of the fish, such as visual acuity and tactile sense.

Among environmental factors, studies have shown that current speeds as low as 1 to 2 cm/s are enough to affect herring so that they orient with their heads against the current, so called rheotaxis (Harden Jones, 1963). A selection device should be placed where the fish spend most time and thus are most likely to detect the escape route. In the pontoon traps used in the Gulf of Bothnia and the Baltic Sea, the fish are confined in a cylindrical space and the selection device is often mounted on one side of the fish chamber by the fishermen themselves. Whether this is optimal or not is unknown.

Flight disposition varies between fish species. Even within a species, different individuals might have different flight dispositions. Sneddon (2003) has shown that rainbow trout (*Oncorhynchus mykiss*) differ in how they act and she categorizes individuals as either shy or bold. Schooling species such as herring are expected to be more difficult to select from the catch than more solitary species, as their whole survival strategy is based on staying in the school. The presence of predators and changes in temperatures can be expected to induce changes in the activity level of the fish.

1.4 How to measure the selectivity of a fishing gear?

Three main methods have been used in attempts to measure the selectivity of trawl nets: the covered codend method (Madsen et al., 2001), the alternate haul method and the trouser trawl method (Millar and Walsh, 1992). Variants of these methods can also be used for measuring the selectivity of pots and traps (Stewart and Ferrell, 2003). The covered codend method involves enclosing the whole trawl with a finer mesh net. The fish which escape from the trawl are then caught by the second net and can be compared with those remaining inside. Alternate haul means that one fishes with a normal fine meshed trawl net and a selective trawl net on alternate hauls, while trouser trawl requires fishing with a standard trawl and a selective trawl simultaneously. Common for all these methods is that the length distribution of fish taken by the selective gear is compared to the length distribution of the fish encountering the standard gear.

The usual procedure is to measure the lengths of the fish caught, assign them to length classes and present graphically the likelihood of each length class being retained by the selective gear, known as the retention length r(l) (Millar, 1992). From the selection graph, commonly called the selection curve, we derive a useful parameter known as L50, which is the length of fish which has a 50% chance of being retained or released by a certain net. Similarly L25 and L75 tell us which length classes have 25% and 75% probabilities to be retained, and the difference between these gives us the selection range (SR), which is a measure of how finely the net selects. The most widely used method for estimating the selection curve is the SELECT-method (Share Each LEngth's Catch Total)(Millar and Walsh, 1992; Millar and Fryer, 1999) which uses maximum likelihood for the fitting of a symmetric logistic selection curve to the data.

Selection efficiencies may also be quantified by using underwater cameras (e.g. Grant et al., 2004). This will probably become more common in the future as camera technology steadily improves. Currently it is difficult to estimate the sizes of the escaping fish purely by viewing video recordings. It is usually necessary to collect the escapees to be able to measure them. The collection of escapees under fishing conditions demands some kind of collecting bag or netting on the other side of the selection panel. A problem may then be that escaping fish decide to swim back and forth through the grid, which will confuse the results. The collecting bag itself might also be darker than the trap (as it is more fine meshed) and frightening for the fish to swim into, thereby reducing the selection efficiency. There are, however, many benefits of using underwater cameras. Other species than the target species can be detected and the behaviour of the fish in connection to the capture and escape can be studied.

1.5 Survival of escaping fish

Several studies have been conducted to examine the survival rates of fish released from fishing gear. (e.g. Chopin and Arimoto, 1995; Suuronen et al., 1996a, 1996b; Suuronen and Erickson, 2010). Most of these studies have been on active gear such as trawls and the mortality among escapees has in general been variable and highly species dependent (Suuronen, 2005). The herring is one of the species showing the highest mortality rates. In a study by Suuronen et al. (1996b) the mortality of herring, selectively released from the codend of a pelagic trawl, was as high as 70-100% for fish smaller than 12 cm in length and 44-83% in the size range 12-17 cm. Suuronen et al. (1996a) and (1996b) argued that the high mortality of herring escaping from trawls is largely due to the exhaustion and physical damage experienced inside the trawl. The passage through a selection device was not the primary cause of injury and death.

There are few studies on the survival of fish escaping or released from traps. A large review of the existing mortality studies on passive gear such as traps and pots has recently been conducted by Uhlmann and Broadhurst (2013), but it only included reviews of two studies relating to the larger traps used in the Baltic Sea. One of them was paper III in this thesis. The other one was (Siira et al., 2006), which showed an average of only 7% mortality among adult Atlantic salmon released from large floating salmon traps along the northern Baltic coast. Fish are not forced to swim into or out of the traps, as both capture and escape requires active behaviour. Therefore, it is unlikely that these fish sustain as much damage and stress during the capture and escape processes as fish that are forced to struggle in order to escape (e.g. from a trawl). However, in a stationary trap, caught fish are exposed to environmental stressors before they can escape through a selection device, and it may take some time to find their way out. A key environmental stressor is water temperature, which directly influences the metabolic rates of the organism (Hirst and Bunker, 2004; Folkvord, 2005) and plays a critically important role in the mortality rates of escapees (Suuronen, 2005; Gale et al., 2011). One other important stressor is the presence of predators, for example grey seals (Lunneryd et al., 2003).

Some general questions in survival studies of fish escaping from fishing gear are how to collect them without causing any further injury, where to study them and how to measure their mortality rates after escaping (Suuronen, 2005). However, in order to ensure a sustainable fishery, the question is whether allowing the escape of undersized fish is enough. An important question to resolve is whether the fish that could escape would be in a fit state to survive and grow to maturity.

1.6 Potential negative effects of a size-selective fishery

It is clear that excessive fishing pressure has caused numerous collapses in fish populations all around the globe (Jacksson et al., 2001). A famous example is the 1992 collapse of the North-West Atlantic cod stocks that have failed to recover even after decades of reduced mortality rates (Olsen et al., 2004; Olsen et al., 2005). It has also been shown that a size-selective fishery (targeting the larger individuals) often leads to a fisheries-induced evolution causing a reduction in fish size and maturation at smaller size and lower age among the entire population (Law, 2000; Heikinheimo and Mikkola, 2004; Hutchings and Reynolds, 2004; Kuparinen and Merilä, 2007; Kuparinen et al., 2009), which in turn may affect ecosystem processes (Belgrano and Fowler, 2013). The benefits of practising a size-selective fishery are therefore questioned by some authors (e.g. Rochet et al., 2011). A common fact in these populations where evolutionary changes have occurred is that the fishing mortality is higher than the natural mortality rates, in some cases two or three times as high (Swain et al., 2007).

Once an evolutionary response has happened, it may be difficult or even impossible to reverse (Law, 2000). However, an experimental study by Conover et al. (2009) showed that the reversal of evolutionary downsizing was possible and that populations have an intrinsic capacity to recover genetically from evolutionary changes caused by fishing. In fisheries management, it is important but difficult to assess whether shifts in fish population dynamics are due to an evolutionary response or to phenotypic plasticity (Kuparinen and Merilä, 2007). Rochet et al. (2011) concludes that eventual effects of a size-selective fishery will depend on the particular combination of gear selectivity, fishing intensity, and ecological settings in a given fishery. Hence, there is a need for further studies in this topic.

The trawl fishery for pelagic herring in the Baltic and Bothnian Seas does not target larger individuals and the fishing mortality is relatively low, so there is no evolutionary pressure here towards reduced growth rates (ICES, 2013). Total catches landed by Swedish and Finnish trawlers together in 2012 were 94,000 tonnes out of an estimated spawning stock biomass of 970,000 tonnes (ICES, 2013). The small scale inshore fishery for spring spawning herring using nets and traps is more size-selective, but the number of fishermen is low (a few hundred in the whole of Sweden and Finland), and the linking of fishing rights to ownership of the foreshore means that this fishery is traditionally managed in a sustainable fashion. In any case, the total catches in this fishery in 2012 were only about 5,000 tonnes, which represents less than 1% of the spawning stock biomass (ICES, 2013). Any risk of genetic selection for a slow-growing population as a result of fishing pressure from the trap fishery can, therefore, be discounted. Much more of an issue in terms of herring stock assessments is that grey seals are estimated to consume over 8,000 tonnes a year (Gårdmark et al., 2012) and that they prefer to take larger sized herring (Lundström et al., 2010).

2 Objectives

In order to develop a more sustainable and economically viable trap fishery in the Baltic and Bothnian Sea, this thesis assesses the use of rigid grids and square mesh net panels as methods for reducing the bycatch of young fish in pontoon traps. By using underwater video footage, it also assesses biotic and abiotic environmental factors which might influence the behaviour of fish and the size-selection process under commercial fishing conditions. The survival chance of released herring and the potential size-structuring effects by a size-selective trap fishery on the Bothnian Sea herring population is addressed.

I address the following questions:

- To what extent can bycatches of undersized herring, whitefish and perch in traps be reduced by using selection panels? (Paper I, II, IV, V)

- Is the herring behaviour and the efficiency of the size-selection process influenced by environmental factors? (Paper I)

- Does the passage through a rigid grid induce injuries or death among herring? (Paper III)

- Are certain areas or a certain placement of a selection panel more effective than others? (Paper IV)

- Does the diurnal escape pattern differ between species caught in traps? (Paper V)

- Does an intensive size-selective trap fishery for herring induce a shift toward shorter mean length of mature individuals? Will the consumption of herring by grey seal further add to this shift? (Paper VI)

3 Material and methods

3.1 Study species

3.1.1 Herring

The herring is the most common fish species in the Baltic and Bothnian Seas. Since medieval times the herring fishery has been the most important sector of the Swedish fishing industry in economic terms, and the herring is also an important component of the marine ecosystem (Lundmark, 2010). Its diet consists mainly of zooplankton, and it may consume over 50% of the total zooplankton production of the seas in question (Arrhenius and Hansson, 1993). Such a high consumption probably also has a major impact on nutrient dynamics in the marine ecosystem (Hjerne and Hansson, 2002).

Herring is an important food resource for many fish, birds and mammals, and particularly for the grey seal, for which they make up a significant part of the total diet: studies have suggested between 30% and 50% for adults and juveniles and even more for cubs (Lundström et al. 2007; Lundström et al. 2010). Another enthusiastic predator of herring is the cormorant (*Phalacrocorax carbo*); the diets of some colonies can consist of 32% herring, so cormorants might well have a big impact on some herring populations (Boström et al., 2009). The impact of cod (*Gadus morhua*) as a herring predator is considered of importance only in the southern Baltic, where the cod population is still viable (Lundström et al. 2010). To what extent the remaining cod there impact on the herring population is unknown. Other species which prey on herring are salmon, trout (*Salmo trutta*), pike (*Esox lucius*) and perch. The first named, however, appears to prefer sprat (*Sprattus sprattus*) (Karlsson et al., 1999) while predation by the other three has decreased with declining stocks.

Herring mature at between 2 to 4 years of age, when they are around 14 cm in length (Vainikka et al., 2009). They are often separated into two different sub-populations depending on the time of spawning. Before the

1950s, the autumn spawning herring were the most common, and this spawning took place between August and September (Lundmark, 2010). More recently, the spring spawning herring (May to June) have become the dominant type. This change in spawning periods has occurred every 50-100 years, according to Lundmark, who speculates that the reason for the shift in patterns may be due to changes in salinity and that high salinity favours spring spawning (Lundmark, 2010). Herring spawn close to the coast and the spawning season goes on for about three months in the same area without interruption. The herring is a communal spawner with no pairing or parental care of the offspring. After spawning, the herring migrate back to deeper waters further out from the coast, where they stay for the rest of the year (Rajasilta et al., 1993). Norwegian spring spawning herring can spawn up to 15 times in their lifetime (Skaret et al., 2002). The spawning school includes individuals of different ages and sizes, in which individuals of similar sizes tend to swim side by side (Rajasilta et al., 1993), which gives them a hydrodynamic advantage (Pitcher et al., 1985).

The herring stocks as a whole are not threatened, but there is still a serious problem: for the last 20 years, the herring caught in the Baltic and Bothnian Seas fishery have been getting steadily smaller in size (Lundmark, 2010). Even more alarming is that they are smaller at a given age than they used to be: since 1974, the average weight of a five-year old herring has decreased from 70 g to 40 g. This may be due to competition for food with an increased population of sprat (Rönkkönen et al., 2004; Casini et al., 2006) or due to shifts in the plankton communities (Suikkanen et al., 2013).

3.1.2 Whitefish

The Baltic and Bothnian Sea whitefish exist in two forms: stationary and migrating (Svärdson, 1979). It has for a long time been debated whether these forms are separate species, but it is now widely accepted that they are ecotypes of the same species (Säisä et al., 2008). The biology among the ecotypes is markedly different. The stationary whitefish is smaller, stays in the same area and spawns in shallow bays in late October - early November. The migrating whitefish is larger, grows faster and migrates up in freshwater to spawn in August - September (Byström and Hudd, 2010). The stationary whitefish matures at ca 25 cm in length while the migrating whitefish matures at ca 35-40 cm in length. (Personal communication, Thomas Hasselborg).

The whitefish has for a long time been an important species in the fisheries of the Baltic and Bothnian Seas but the commercial catches in the Swedish part of the Baltic and Bothnian Seas have decreased significantly. During the late 1980s, the yearly commercial catch could reach 1,000 tonnes in the Bothnian Bay alone (Byström and Hudd, 2010). Since 2000, catches have decreased from 276 to 139 tonnes (Swedish Agency for Marine and Water Management (SwAM), 2013). Currently, the catches by the recreational fishery are believed to be larger than the catches by the commercial fishery (Swedish Board of Fisheries, 2011). Possible causes of the decreased catches of whitefish are overfishing, increased populations of grey seals (Karlsson and Helander, 2005) and cormorants (Östman et al., 2012; Östman et al., 2013), large scale environmental changes (Walther et al., 2002), destroyed reproduction areas, or a combination of these factors.

The stationary and migrating forms are difficult to distinguish by sight alone and are not separated in the commercial catch statistics. Therefore, it is difficult to estimate the population status for each form. Migrating whitefish are artificially fertilized, hatched and reared in hydropower compensation schemes and released as young in Finnish and Swedish rivers. On the Swedish side of the Bothnian Sea, management actions have been taken such as closed fishing seasons and establishment of protected areas. In 2011, the whitefish of the Gulf of Bothnia became red-listed by the World Wildlife Fund.

Whitefish are known to actively search for an escape while in captivity (Personal communication. Åke Andersson). They often swim into the trap in small shoals and can be observed swimming near the surface while inside of the trap.

3.1.3 Perch

Perch is a shoaling predatory fish. It is often located near the coast, in sheltered areas where the temperature is higher and the vegetation is more pronounced. It spawns in shallow waters during April - June. In some areas it migrates up in fresh water to spawn (Olsson et al., 2012). It matures at approximately 20 cm length, females normally later than males (Heibo and Magnhagen, 2005; Pukk et al., 2013). Perch is a diurnal forager, and shows activity peaks at dawn and dusk (Eriksson, 1978; Jamet and Lair, 1991). During night time, perch tends to lower its activity level, go from a shoaling behaviour to become more solitary and rest on the bottom (Hasler and Villemonte, 1953). In traps, perch are known for being cautious on its way into the gear. It often swims near the bottom and can easily escape through openings between the bottom rope and the Sea bed.

There is no reliable information on the status of the perch populations along the coasts of Sweden (Swedish Board of Fisheries, 2011). Trends of both increases and decreases of perch abundance can be seen at the local level (Ljunggren et al., 2010). However, at the international level, commercial catches have decreased to half the size compared to those in mid 90's, and questionnaire studies indicate that there is also a decrease in catch per unit effort (Olsson et al., 2012). This decrease may be explained by a combination of factors such as changes in the ecosystem (Casini et al., 2008; Ljunggren et al., 2010), increased populations of cormorants (Östman et al., 2012; Östman et al., 2013) and an increase in recreational fishing (Olsson et al., 2012). The annual landing of perch in the Swedish commercial fisheries is currently approximately 85 tonnes (Swedish Agency for Marine and Water Management (SwAM), 2013), but catches from recreational fishing are many times higher (Persson, 2010).

3.2 Study areas

The studies in paper I, II and III were located in the Bothnian Sea, in inshore waters at 61°57´N, 17°22´E (Fig. 6). The area is good fishing spot for spring spawning herring. Paper IV and V were carried out on a location 45 km further north, near the mouth of the river Indal (62°23´N, 17°31´E). During June and July, large amounts of salmon migrate in this area, and the presence of whitefish is relatively good. The study in paper V was carried out together with a fisherman in Gudinge, near Forsmark, Sweden (60°28´N, 18°04´E).

Figure 6. Locations of the experiments (Paper I to V).

3.3 Traps

The herring trap used in study I, II, III consisted of a leading net, wings and adapter (Fig. 2). Stretched mesh length was 24 mm. A single-walled pontoon fish chamber was attached to the trap. For the trials reported in paper I, the netting in the fish chamber was of nylon, 32 mm stretched mesh length. In the trials reported in paper II and III it was of Dyneema®, 24 mm stretched mesh length. The pontoon fish chamber consisted of two parts, the middle chamber and the fish chamber (Fig. 7). In study I, seals could swim into the middle chamber, but were prevented from swimming into the fish chamber by a steel rod fixed across the middle of the entrance. During study II and III, seals were prevented from swimming into the middle chamber by a netting of 500 mm stretched mesh length mounted inside the main entrance.

The two salmon/whitefish traps used in study IV consisted of leading nets of 400 mm stretched mesh length. The wings were of 200 mm mesh length and bottom-set at a depth of 9 meters. The fish chambers consisted of a double netting of Dyneema® with an inner netting of 70 mm and an outer netting of 160 mm stretched mesh length respectively. The two perch traps used in study V consisted of leading nets of 120 mm stretched mesh length. The wings and adapters were made of 80 mm stretched mesh length. The design of the traps differed in such way that the wings on one trap had a roof netting and lacked the entrance between the wings and adapter.

3.4 Selection panels and camera system

For paper I, two sets of selection grids were used in different trials. The first was a square grid, with each side measuring 25 cm and 16 mm spacing between bars. The square grid was placed on one side of the fish-chamber, between the foremost rings (Fig. 7). The second grid was circular, with a diameter of 53 cm and 14 mm bar spacing; this was placed in the cone-shaped end of the fish chamber. Both grids were manufactured using smooth steel bars. A 15 m long collection bag was attached to the circular grid to collect escapees. The purpose of this configuration was to obtain a controlled measure of selection efficiency and size composition. The circular grid was only filmed during one 48 hour period, to investigate whether herring would return to the trap through the grid.

In paper II, the fish chamber was modified with the addition at each end of a 300 mm wide selection ring, of the same hoop-shaped tubular aluminium construction as the framework of the fish chamber itself. Within these rings, 2 mm diameter stainless steel rods were fitted vertically (and reinforced with horizontal cross-ties every 200 mm) to form the selection grids (Fig. 7). The grids, 7 m in length, reached around the entire chamber, apart from 2 m at the bottom which was covered with a solid stainless steel plate, to prevent herring from getting caught in the bottom net when emptying the trap. The fish chamber netting behind the grids could not be completely removed without compromising the strength of the whole construction. Instead the original 24 mm stretched mesh was replaced with a square meshed net with 100 mm mesh sides, in order to make as little impact on the selection process as possible. The grids were made in two sets, one with 14 mm bar spacing and one with 15 mm bar spacing. Grids with a bar spacing of 14 mm were used during trials one to four and grids with a bar spacing of 15 mm were used during trials five to nine.

For paper IV, the selection panel replaced a section of inner netting between the first two aluminum rings in the fish chamber structure. It encircled the pontoon fish chamber (Fig. 7). The total length of the selection panel was 1.25 m, with a total width of 7.5 m. This represented 26% of the total inner netting area. The material of the selection panel was square mesh Dyneema® netting with 50 mm bar length. In study V, the selection grids were placed on one side of the rear part of the fish chambers. The grids were made of vertical 2 mm stainless steel bars covering an area of 300 x 400 mm, with 30 mm wide gaps between the steel bars.

For paper I, II, IV, the camera system consisted of four underwater video cameras manufactured by Watec®. The model was the WAT-902H monochrome camera. The video footage was saved on a CamDisc Recorder with exchangeable hard disks of 80-120 GB, powered by a 72Ah battery. The software used to adjust the recording settings was Camtel® for Windows v.3.26. The recorder was set to film at a speed of 3-4 frames per second and with a time and date stamp included. For viewing the recorded material, CamControl player v.3.29 was used. For paper V, a single camera (Sony CCD, 3.8 mm lens) was used for each trap.

For paper I, the cameras were aimed at the fish-chamber, the entrances, the square grid, and for one period at the circular grid (Fig. 7). Footage from various angles allowed studying herring behaviour in response to different stimuli. In paper II, one camera was set up facing the west side of the rear grid, a second camera faced the west side of the front grid and the third camera monitored the east side of the rear grid (Fig. 7). In study IV, two cameras faced each side of the selection panel. In study V, the camera was aimed at the grid.

In paper I and II, a current meter, model Mini Current Meter Sensordata SD-6000, was used for measuring temperature, velocity and direction of current. These parameters were measured at 30 minute intervals throughout the whole study period.

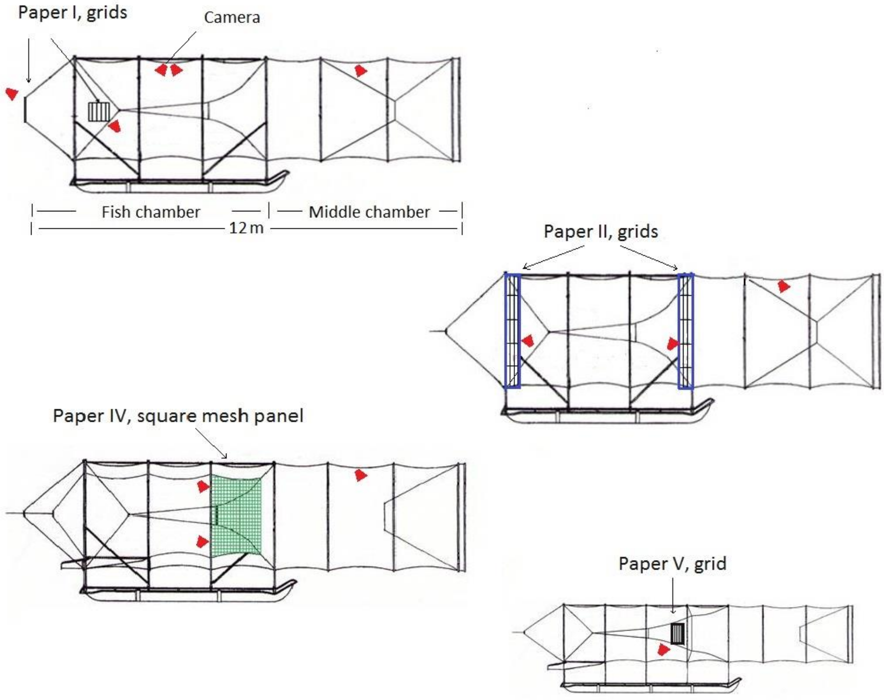

Figure 7. The different pontoon chambers, including selection panels and cameras, used in the studies I, II, IV, V.

4 Data collection and analysis

4.1 Selection efficiencies

Samples from the catches of all traps in all studies were taken continuously over the seasons. The herring trap was emptied once or twice a week, depending on weather conditions and the amount of fish in the trap. The salmon/whitefish traps and the perch traps were emptied more frequently (2-4 times a week). The total length of fish in samples was measured to the nearest lower 0.5 cm length class. All selection panels in all studies were monitored with underwater cameras. When larger encircling grids were used (paper II and IV), the cameras were set to film a smaller demarcated area of the entire panel, to get a sufficient overview of the escaping fish.

Different approaches of measuring the selection efficiency were used in the studies. For the circular grid in paper I, the efficiencies were measured by comparing the number of escapees collected in the collection bag with the number of potential escapees retained in the trap. The size of a potential escapee was judged by measuring the widths and lengths of the fish in a sample taken from the trap. For the square grid, the efficiencies were estimated by counting escapees filmed during a 5 minute sequence every 30 minutes of the entire catch period. The mean number of escapees per 5 minutes was then extrapolated to the entire study period and then related to the amount of potential escapees remaining in the trap. The same method was used in paper II. However, an extra step of extrapolation was needed. This extrapolation was from the grid area filmed up to the total effective grid area of the fish chamber. Confidence intervals (CI) of 95% around the mean number of escapees per demarcated area and 5 minute period were calculated by using the normal bootstrapping method (Efron and Tibshirani, 1986) with 1000 repetitions. In the two cases where more than one camera was used, a combined mean and CI were weighted by the number of cameras on each grid.

For paper IV, the experimental trap with the selection panel was fishing simultaneously as a control trap without panel. The selection efficiencies were calculated by comparing the amount of potential escapees retained in each trap. The experimental set-up, using one experimental trap and one control trap simultaneously in the same area permitted the usage of the SELECT-method (Millar and Fryer, 1999) for analyzing the data. Thereby, a selection curve was fitted to the data and the selection parameters L25, L50, L75, SR were attained (see 1.4).

For paper V, the two perch traps were fishing simultaneously but at different locations with unknown background populations of fish. Since the battery time of the camera systems allowed only up to 24 hours filming on the grid, the entire fishing periods could not be filmed. Therefore, the selection efficiencies were estimated by using two methods; (1) Extrapolation of the number of escapees seen on the recordings to the total time of the fishing periods and comparisons with the amount of potential escapees retained in the trap. (2) Covering of the grid by fine meshed netting during certain fishing periods. The amount of young fish of perch, roach and whitefish was then compared between the periods when the grid was in function and when it was covered.

4.2 Behaviour of fish in relation to the size-selection process

For paper I, the influence on the selection efficiency of ambient factors (currents, temperature, amounts of herring in the trap and seal presence) was measured by using a total of 463 sets of data from the current meter, which were related to the number of escapees during the 5 minute time period following each current reading. To estimate the amount of fish in the trap during each 5 minute period, a linear rate of increase was assumed, using data from the size of the catch and the length of the catch period. To determine which factors were significant for the selection, a generalized estimating equation (GEE) (Liang and Zeger, 1986) was used to analyse the data. To put selection in relation to seal presence, film recorded from the middle chamber was analysed and seal observations were noted. Seal presence was defined as from when the seal had its head inside the entrance of the middle chamber until it had completely exited.

For paper IV, the date, time and the position of where the fish passed through the study area were noted. The position of where the fish passed through the selection panel was analyzed and visualized in Mathematica (Wolfram Research, Inc., Version 9.0, Champaign, IL (2010)) by adapting a Smooth Kernel Distribution to the data. The positions from the southern study area were mirrored and combined with the positions from the northern study area into a single visualization of the northern study area. Aggregations in the positions of escapees were highlighted by dividing the study area into 20 squares of cell size 5x5 meshes. A chi-square test was used to test if the distribution for the chosen cell size was different from randomness.

For paper V, the difference in escape rate at different time periods (Morning 03:00-09:00h; Day 09:00-15.00h; Evening 15:00-21:00h, Night

21:00-03:00h) was tested separately by species. A χ^2 - test compared observed escapes with the expected number if all time periods had the same escape rate, adjusting for number of hours recorded during the different periods.

4.3 Assessing mortality rate after escape

For paper III, mortality rates after escape through a grid were measured by using the fish chamber of the trap as a fish holding cage. The entrance to the fish chamber was equipped with two hatches, both hung from the top edge of the frame like a 'cat-flap': hatch A: square frame with a grid consisting of vertically mounted 2 mm stainless steel rods with 14 mm gaps between. Hatch B: square frame equipped with a closing net (24 mm stretched mesh size). By closing the entrance with hatch A, grid-selected herring could enter. By closing with hatch B, the caught herring were trapped inside the fish chamber. As a control, with all hatches open, all herring could enter the fish chamber. All hatches were controlled by ropes attached to the top of the trap, thereby minimizing the stress on trapped herring when opening or closing hatches. The trapping of a sufficient amount of herring took between 24 h and 48 h. There was no forcing of fish involved in the trapping procedure. Trials with control and grid-selected herring were run every other week. After seven days the number of dead and live herring was counted. The effects by the grid-passage and of temperatures on the mortality rates were analyzed with a generalized linear model (GLM) (Liang and Zeger, 1986).

4.4 Effects by size-selective fishing on the Bothnian Sea herring population

For paper VI, data on the length distributions of the herring stock in the Bothnian Sea was obtained from BIAS (Baltic International Acoustic Surveys), while the total stock size was obtained from a state-space assessment model (SAM, ICES, 2013). Data on length distributions from a size-selective herring trap was obtained from the samples taken during the study in Paper II. Data from Finnish trawl landings in 2010 was obtained from the Finnish Game and Fisheries Research Institute *(*FGFRI) and data on the mean grey seal consumption between 2001 and 2005 was obtained from estimates in Gårdmark et al. (2012) where the size-distributions of herring consumed by grey seals were derived from Lundström et al. (2010). The total consumption by grey seal on herring was multiplied up to the current population size. Calculations on average length of mature individuals were made after four different harvesting scenarios: (1) Fishing the entire quota (100k tonnes) with traps (2) Fishing the entire quota with trawls (3) The quota divided equally (50k tonnes) for both gears (4) Adding grey seal consumption to traps (12k tonnes).

The proportion of herring for each length class sampled in the trap, trawls and in the digestive tracts of grey seals was first multiplied by the length-specific weight. The catch effort by gear or the consumption by grey seal was then divided by the total sample weight for each gear and grey seal, respectively, which provided ratios between the total harvest and the samples for each gear and grey seals. The number of individuals per length class to deduce from the mature population after harvesting was obtained by multiplying the number of individuals per length class in each sample by the ratios obtained in the previous step. After the deduction of the harvested herring from the population, the total number of herring per length class (>14 cm) were multiplied by its own length. Adding all these lengths together and divided by the total number of mature individuals provided the new mean length of the mature population after harvesting.

5 Results and discussion

5.1 Paper I

The main results of paper I were that the selection efficiency (SE) of the 16 mm grid for the two periods in May and June was 27% and 14% respectively, and for the 14 mm grid in July it varied between 4% and 28%. This demonstrates that effective selection of small herring through a selection grid installed in a herring pontoon trap is achievable. The conclusion is that a significantly better efficiency could be attained with a larger grid and more advanced designs. The 14 mm bar spacing gave a size selection equivalent to a manual sorting for the local commercial market.

The factor which had the greatest impact on the selection was the amount of herring in the trap. As more fish were enclosed in the trap, more fish escaped. Higher quantities presumably led to higher stress levels in the fish as they were observed to swim markedly faster. Additionally, with more fish in the trap, the surface area of the school increases, resulting in more herring being in the proximity of the fish chamber walls and the grid.

The second most significant factor was the season of the year, with more herring escaping from the trap in June than in May. The minor differences in the amounts and sizes of herring caught between May and June were not enough to explain this increase. Moreover, fewer seals were present in June. At the same time, by-catches of trout and salmon were higher in June than in May. Their presence could be a possible explanation for the increase in selection pressure, as salmonids are potential predators of herring. Pitcher et al. (1996) showed that herring show adaptive responses to different kinds of predatory attacks.

The third most significant factor affecting selection by size was the time of day, where selection at night was significantly higher than in the morning, day or evening. There are several possible explanations as to why there was a higher degree of selection during the hours of darkness: (1) in this study the majority of herrings swam into the trap at night. It might be that herring are more active immediately after capture and therefore more prone to escape. (2) The escape grid might appear to be brighter than the mesh wall, making it easier to see. At night, herrings searching for zooplankton orient themselves by swimming towards a lighter background (Batty et al., 1990). (3) It is also possible that herring are disorientated in darker waters, and therefore simply swim through the grid randomly.

Seal presence in the trap had a significant effect on the selection (Fig. 8). Herring escapes increased when seals were in the middle chamber. Video footage showed that the herring formed tighter schools, with an increase in swimming speed. This is supported by studies reported by Wilson and Dill (2002) in which Pacific herring responded to attacks by predators by increasing their swimming speed and depth.

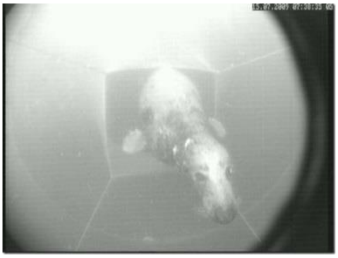

Figure 8. Seal swimming into the middle chamber during the studies in Paper I.

Even though the current velocity had no significant effect in the generalized estimating equation (GEE), there was a significant negative correlation between the current velocity and the number of escapees. One possible explanation could be that herring consume more energy to maintain their position in the water when swimming against the current, thereby reducing their chances of detecting the grid. The current velocity at the trap was measured to be between 0 and 8 cm/s, which are considered to be normal for the area. In a study by Harden Jones (1963), currents of 1–2 cm/s were sufficient to influence the herring to position themselves with their heads into the current, i.e. rheotaxis. Rheotaxis might be a behaviour which facilitates feeding.

Considering the current direction data by quadrant (0–90º, 91º–180º 181º–270º and 271º–360º), data recorded from the 91º–180º quadrant differed significantly from the others. When the current originated from a direction of between 91º and 180º, a higher proportion of escaping herring was observed. In this quadrant, the current was going straight towards the grid, thereby simplifying discovery of the grid.

In the GEE there was a significant effect of temperature on selection. There was a marked increase of selection at 10º–13º C, which according to Neuman (1982) is the optimal temperature range for herring. In this temperature window, there was most likely a higher activity level which, in turn, could lead to an increased number of escapees.

Video recordings showed that herring could squeeze through the grid. This might mean scale loss and reduced survival rates (Suuronen et al., 1996a). However, lost scales were not seen on the video footage in this study.

5.2 Paper II

The main result of paper II was that the selection efficiency (SE) of the encircling grids varied between 54 and 72% (Fig. 9). This is a considerably better SE than previously shown by the smaller square sorting grid (Paper I), and fully comparable with the estimates of SE derived for active gear (Bahamon et al., 2006). The results were similar regardless of bar spacing in the grids, soak-time and the number of demarcated areas observed. Hence, this strengthens the reliability of the results.

The selection efficiency seems to increase almost linearly over the season (Fig. 9). A similar pattern with an increased SE over the season was observed in Paper I. A possible explanation could be the reduction in size among the herring over the season or an increased bycatch of salmonids.

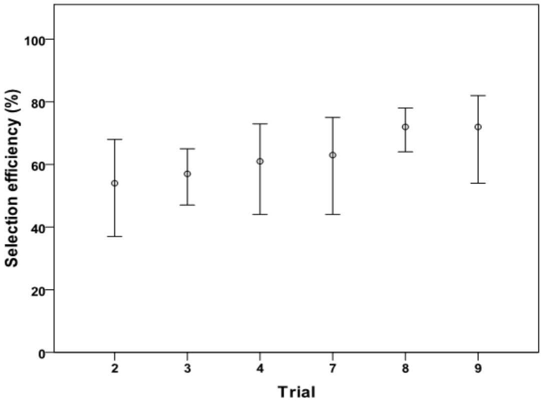

Figure 9. Selection efficiencies during the 2010 trials, over the time period 1st June (trial 2) to 7th July (trial 9) (Trial 1, 5 and 6 were not included in the calculations). Error bars represent the 95% confidence intervals of the mean values.

The increased SE during the 2010 trials compared to the 2009 trials may not only be a result of the increased grid area from 0.1% to 10% of the total fish chamber wall area. It may also depend on the placement of the grids. Our observations have shown that herring often are located at each end of the fish chamber where the grids were mounted. Moreover, the rear grid was mounted where the netting of the final entrance and the netting of the fish chamber wall meet and form a wedge. When herring become squeezed into this wedge, they may have trouble turning around and their only option is to proceed forward through the grid.

No loss of scales was observed as the herring squeezed through the bars. Nor were any scales seen floating in the water. It seems that young herring escaping through a sorting grid installed in a trap-net have substantially higher survival probabilities than herring escaping from active gear such as a trawl (Suuronen et al., 1996a,b).

5.3 Paper III

The results of paper III strongly indicates that a passage through a rigid grid does not in itself affect the short term mortality of herring. In fact, more herring died among the control herring (average 21.2%) than among the grid-selected herring (average 7.0%). An important factor for the short term mortality was shown to be the ambient water temperature. By far, the highest mortality rate (45.1%) was reached during the trial with the greatest temperature fluctuations. During this trial the temperature dropped from 15 °C to 6 °C in the course of 15 h and increased to 14 °C over a further 11 h. Four days later in the trial there was an even greater but not as sudden dip in temperature. Herring prefer temperatures in the range of 10-13 °C and 14 °C is assumed to be the upper limit (Neuman, 1982). When caught in a stationary trap, there is an obvious risk of being exposed to temperatures well above and below this range. In a real life fishing situation, the herring trap is emptied from several times per day up to a minimum of every other day which reduces the chances of finding dead herring in the catch.

Most of the dead herring had extensive scale loss with exposed muscles, presumably by being rubbed on the fish chamber bottom netting. They were thus easy to recognize. Caudal fin abrasions were common among both dead and live herring. Any size-dependent mortality as was shown after the escape through rigid grids in trawls (Suuronen et al., 1996a) was not confirmed by this study. The mean length of dead herring was in fact larger than that of live herring. This is likely connected to the fact that there is no forced swimming involved in the process, contrary to that in the trawling process. The result represents an important argument for introducing selection grids in the Baltic Sea herring trap fishery.

5.4 Paper IV

The main result from paper IV was that the selection efficiency was 72% during the experiment, meaning that this proportion of the small (< 30 cm) whitefish, otherwise captured, escaped through the panel (Fig. 10). This result is similar to the efficiency of the encircling selection grid in the herring trap (Paper II) and fully comparable to the efficiency of selection devices in trawls (Bahamon et al., 2006).

The length at 50% probability of retention (L50) was 30.1 cm, which corresponds to the lower size target of 30 cm of whitefish that is wanted for the local market (Fig. 11). The selection range (SR) of 3.0 cm indicates that the selection is more distinct than what is normally achieved by selection devices in trawls (Sistiaga et al., 2009) and similar to what have been achieved by selection devices of other passive gears (Ovegård et al., 2011).

Most of the whitefish observed escaping through the meshes inside the study areas escaped through the front and upper part of the panel. One explanation might be that the netting of the final entrance and the rear part of the panel merges in a wedge that becomes narrow for whitefish to enter, and another explanation is that whitefish prefer swimming near the surface (Personal communication, Åke Andersson) A higher proportion of whitefish escaped on the northern side of the fish chamber facing the water current from the river. A significantly higher rate of escapements towards the water current was also seen among herring in Lundin et al. (2011a). Of the whitefish seen escaping from other parts than the study areas, an equal number fled above and below the study area. This indicates that the efficiency of the encircling selection device is similar on the top and bottom areas. With respect to these results, we recommend that fishermen who attach smaller devices to their already existing traps should place them slightly higher than the vertical centre, ahead of the entrance and on the side of the fish chamber most commonly facing the water current.

As a rule, whitefish passed through the meshes very cautiously. Even though 27% gently squeezed through the mesh within the study area, lost scales were only seen on one occasion. This happened when a whitefish escaped in panic during lifting of the fish chamber to the surface. No obvious stress behaviour or burst swimming was observed at any time. Lundin et al. (2012) found that a grid passage in a pontoon trap did not affect the short term mortality of herring. Herring is otherwise known to be vulnerable to physical contact. The survival chance for escaped whitefish in the present study can therefore be considered to be equivalent to that of herring. Only one fish was entangled and died, thus accidental losses were very minor.

No smolts were caught in the experimental trap, while 30 were caught in the control trap. A similar number of smolts probably swam into the experimental trap, but were able to escape through the selection device. The device is also thus likely to be important for the survival of young salmon in a coastal fishery with trap-nets, improving the sustainability of salmonid stocks.

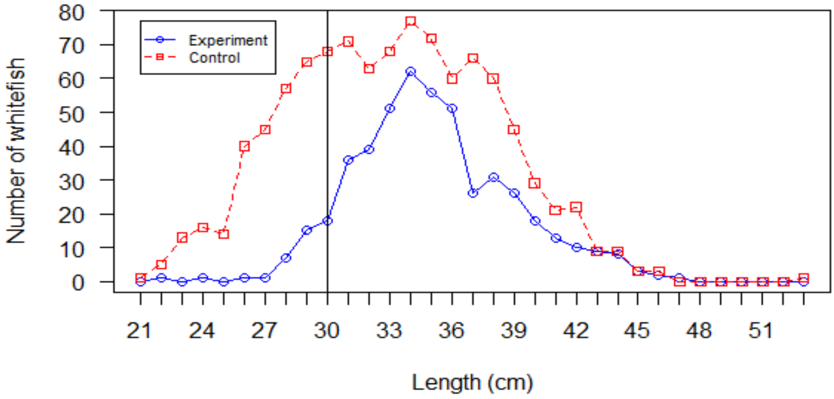

Figure 10. Length frequencies of all whitefish caught in the experimental and control trap. The vertical line indicates the undersize threshold.

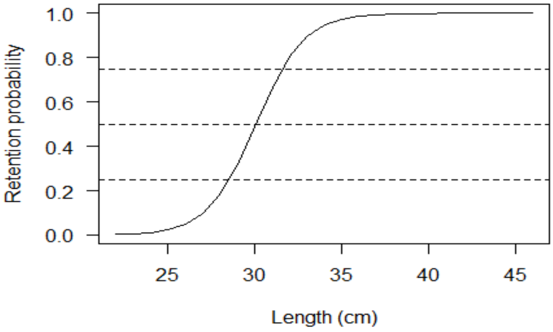

Figure 11. The fitted logistic selection curve for whitefish caught in the experimental trap. Dashed lines represents the L25, L50 and L75.

5.5 Paper V

The main results from paper V showed that the selection efficiencies based on catch comparisons were 86% and 82% for perch, 33% for whitefish and 100% for roach (*Rutilus rutilus*) (Fig. 12). The efficiency of perch and roach is then higher than what have been achieved in other traps for other species (Paper I, II, IV). The reason for this is unknown, but may depend on differences in behaviour between species or between traps. The fish chamber in a perch trap is usually placed on the bottom, while herring and salmon/whitefish traps are placed near the surface. On the bottom there is less light and lower temperature. Less light increased the selection efficiency of herring in Paper I. Also, the smaller size of the perch trap compared to the herring and whitefish traps may lead to a higher probability of detection of the grid.

In the video recordings a total of 418 fish were seen escaping from the traps of which 286 were perch and 121 roach. For perch, there were significantly more fish escaping during the evening, in connection with dusk, compared to the other time periods. For roach, most escapes occurred during night time. This may depend on differences between the species in activity pattern. Perch is a diurnal forager, and shows activity peaks at dawn and dusk (Eriksson, 1978; Jamet and Lair, 1991). Roach migration seems to occur mainly during the dark hours (Hammer et al., 1994). Few roach could be seen inside the trap during daytime, which means that they probably entered the trap in darkness and escape rather immediately. The same tendencies have been seen among herring (Paper I) – a higher escape rate immediately after capture.

When using our results to estimate number of fish managing to escape across a fishing season of two months, 3-4,000 small perch would be spared by the escape from one trap only. Hence, the implementation of grids into the perch trap fishery would be important for fish stocks and it would significantly reduce the sorting work for the fishermen.

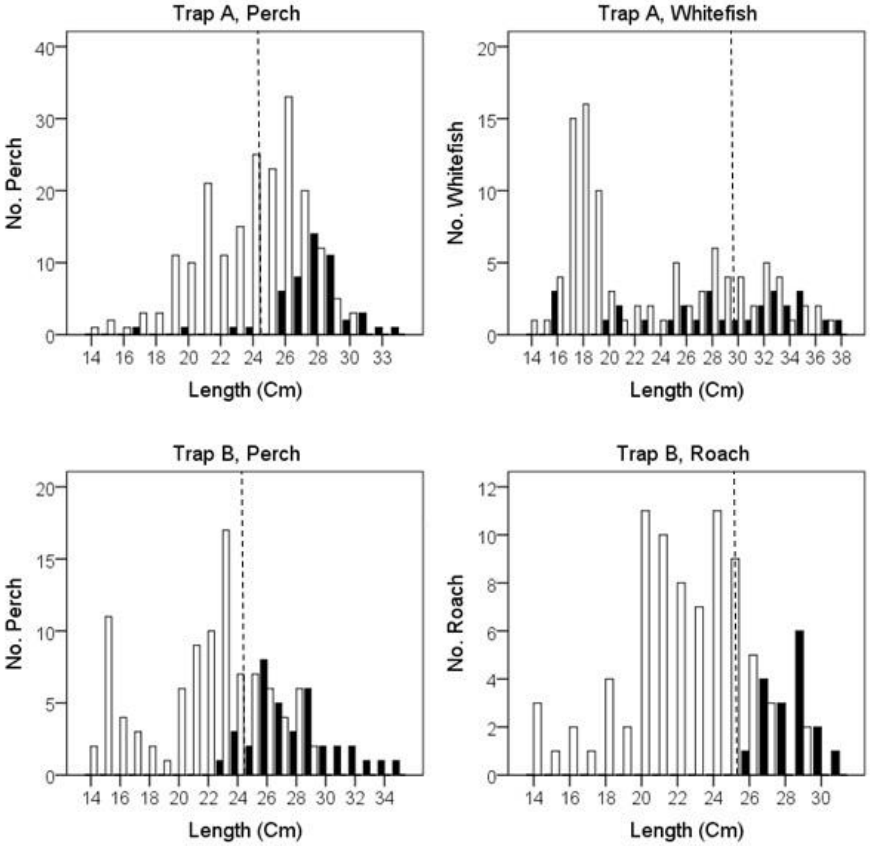

Figure 12. Size distribution of fish in the traps with (black bars) and without (white bars) selection grid. The data from all catch periods are used here. (Dashed line indicates the length at which the width of the fish is equal to the distance between the bars in the grid).

5.6 Paper VI

The main results from this study showed that if all the catches from trawls today would be taken in size selective traps, the expected average length of mature individuals of herring in the Bothnian Sea would decrease by 1.35 mm (< 1% of body length; Table 1). Thus, the risk that extensive use of traps will induce selection from phenotypic changes in mature herring and induce evolutionary changes is low.

Trawl fisheries has small size structuring effect on the herring stock in the Bothnian Sea. The average length of mature herring in the fishery-independent estimates are virtually identical (+ 0.01 mm) to the average length of mature herring after removing fish from the population with trawls. When 50% of the quota was allocated for each gear, there was a decrease in the mean length of mature individuals by 0.67 mm. When adding grey seal consumption to the trap fishery, a decrease in average length of mature individuals by 1.47 mm is predicted (Table 1).

The calculations provide a proxy on the short term phenotypic effects on the mature population after different theoretical harvesting scenarios. Even if the impact on the average length on the mature individuals, and the fishing mortality are low, the long-term effects are difficult to predict and requires further studies.

Table 1. *Mean length of mature individuals and the shift in mean length after harvest for the four different harvest scenarios. (Trap = The entire quota fished with traps, Trawl = The entire quota fished with trawls, 50-50 = The quota divided equally for both gears, Trap + Seal = The entire quota fished with trap and adding grey seal consumption)*

	Population	**Trap**	**Trawl**	**50-50**	**Trap + Seal**
Mean length (cm)	16.396	16.261	16.397	16.329	16.249
Shift in length (cm)	0	-0.135	+0.001	-0.067	-0.147

5.7 Economy and implementation in fisheries

The sorting of undersized fish from the catch is very time consuming and is often done by hand or by using a sorting machine. The sorting of undersized herring from a normal sized catch (about 1 tonne), takes about two hours for two experienced fishermen when using a sorting machine. During a normal season with normal catch sizes (about 20 tonnes), the total sorting time may reach 80 hours. This work could, for example, instead be spent on the whitefish and salmon fishery which is often conducted in combination with the herring fishery during the same time on the season. It could also be spent on the repair and maintenance of other equipment. The economic value of removing the sorting work would probably be a five figure number during a season (interviews with local fishermen).

Reduced sorting time was also seen when using selection grids in perch traps in Finland (Tschernij and Saarinen, 2012). When using grids the catch of small pike-perch (*Lucioperca lucioperca*) was reduced from 80% to 0. The total time for harvesting the trap was estimated to have decreased from 1 hour to 20 minutes.

Looking at current Swedish conditions, the price for a complete herring fish chamber is 105 000 SEK, of which the encircling selection grid stands for about 10 000 SEK. Since the Swedish Environmental Protection Agency provides up to 80% grants to licensed fishermen for purchasing seal safe fishing gears, the costs for the fishermen are reasonable. A smaller square grid or a netting panel of square mesh would be much cheaper.

When using selection panels, there is a risk that also larger, commercially valuable individuals escape, e.g. by squeezing through the selection panel. However, as shown by the distinct selection of whitefish in paper IV and by measuring the herring caught after escape in paper II, the loss of commercially valuable whitefish and herring is neglectable. The problem with loss of commercially valuable individuals at the expense of size-selection is likely more common in trawls, where the fish are more or less forced to escape through the selection panel; the selection range is wider.

A reduction in fishing efficiency of the pontoon traps due to the use of selection panels is difficult to estimate. It is possible that the fishing efficiency is affected by behavioural characteristics of the fish, such as attraction to conspecifics. In such cases, the fishing efficiency may be reduced with fewer conspecifics inside the fish chamber. Further studies are needed.

6 Concluding remarks

The studies in this thesis demonstrate that selective release of young commercial herring, whitefish and perch from pontoon traps is possible and that several factors affect the selection efficiency. The optimum conditions for size-selection of herring occurred when catches were large, at the end of June, at night, when seals were present and when current velocities were low and directed towards the grid. This knowledge may be useful in the further development of size-selective fishing gears. It might even be possible to create similar conditions by artificial means, for example, by covering up the traps during day time. Improvements in the design and location of selection panels increase the selection efficiency, and selection panels fitted around the fish chamber is indeed a successful design. The selection efficiencies achieved by encircling panels has both environmental and economic advantages; it reduces the discard rate of undersized fish and decreases the workload for the fishermen. The risk that extensive use of size-selective traps in the Bothnian Sea will induce selection from phenotypic changes in mature herring and induce evolutionary changes is low. There seems to be a good chance of survival among the fish escaping through the grids.

The techniques described in these papers can be expected to be applied permanently and to secure a good status of herring, whitefish, perch and salmonid populations in the Baltic and Bothnian Seas.

References

Alverson, D. L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment off fisheries by-catch and discard. *FAO, Fisheries Technical Paper* NO. 339, ISBN 92-5-103555-5.

Armstrong, M.J., Briggs, R.P., Rihan, D., 1998. A study of optimum positioning of square mesh escape panels in Irish Sea Nephrops trawls. *Fisheries Research* 34, 179-189.

Arrhenius, F., Hansson, S., 1993. Food consumption of larval, young and adult herring and sprat in the Baltic Sea. *Marine Ecology Progress Series* 96, 125-137.

Bahamon, N., Sardà, F., Suuronen, P., 2006. Improvement of trawl selectivity in the NW Mediterranean demersal fishery by using a 40 mm square mesh codend. *Fisheries Research* 81, 15-25.

Bahamon, N., Sarda, F., Suuronen, P., 2007. Selectivity of flexible size-sorting grid in Mediterranean multispecies trawl fishery. *Fisheries Science* 73, 1231-1240.

Batty, R.S., Blaxter, J.H.S., Richard, J.M., 1990. Light intensity and the feeding behaviour of herring, *Clupea harengus*. *Marine Biology* 107, 383-388.

Belgrano, A., Fowler, C.W., 2013. How fisheries affect evolution. *Science* 342, 1146.

Boström, M., Lunneryd, S.G., Karlsson, L., Ragnarsson, B., 2009. Cormorant impact on trout (*Salmo trutta*) and salmon (*Salmo salar*) migrating from the river Dalälven emerging in the Baltic Sea. *Fisheries Research* 98, 16-21.

Brothers, G., Hollet, J., 1991. Effect of mesh size and shape on the selectivity of cod traps. *Canadian Technical Report of Fisheries and Aquatic Sciences* 1782, 73.

Byström, P., Hudd, R. Eds., 2010. Intersik. World Wide Web electronic publication. Version (07/2010). Available on internet: www.intersik.se

Casini, M., Cardinale, M., Hjelm, J., 2006. Inter-annual variation in herring, Clupea harengus, and sprat, Sprattus sprattus, condition in the central Baltic Sea: what gives the tune? *Oikos* 112, 638-50.

Casini, M., Lövgren, J., Hjelm, J., Cardinale, M., Molinero, J.C., Kornilovs, G., 2008. Multi-level trophic cascades in a heavily exploited open marine ecosystem. *Proceedings of the Royal Society B* 275, 1793-1801.

Chopin, F.S., Arimoto, T., 1995. The condition of fish escaping from fishing gears – areview. *Fisheries Research* 21, 315-327.

Conover, D. O., Munch, *S.B.*, Arnott, S.A., 2009. Reversal of evolutionary downsizing caused by selective harvest of large fish. *Proceedings of the Royal Society B* 276, 2015-2020.

Costello, C., Ovando, D., Hilborn, R., Gaines, S.D., Deschenes, O., Lester, S.E., 2012. Status and solutions for the world´s unassessed fisheries. *Science* 338, 517-520.

Dahm, E., Wienbeck, H., West, W., Valdemarsen, J.W., O'Neill, F.G., 2002. On the influence of towing speed and gear size on the selective properties of bottom trawls. *Fisheries Research* 55, 103-119.

Davis, M.W., 2002. Key principles for understanding fish bycatch discard mortality. *Canadian Journal of Fisheries and Aquatic Sciences* 59, 1834-1843.

Efron, B., Tibshirani, R.J., 1986. Bootstrap measures for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science* 1, 54-77.

Eriksson, L.O., 1978. A laboratory study of diel and annual activity rhythms and vertical distribution in the perch, *Perca fluviatilis*, at the Arctic circle. *Environmental Biology of Fishes* 3, 301-307.

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

Folkvord, A., 2005. Comparison of size-at-age of larval Atlantic cod (*Gadus morhua*) from different populations based on size- and temperature-dependent growth models. *Canadian Journal of Fisheries and Aquatic Sciences* 62, 1037-1052.

Gale, M.K., Hinch, S.G., Donaldson, M.R., 2011. The role of temperature in the capture and release of fish. *Fish and Fisheries* 14, 1-33.

Graham, N., O'Neill, F.G., Fryer, R.J., Galbraith, R.D., Myklebust, A., 2004. Selectivity of a 120 mm diamond cod-end and the effect of inserting a rigid grid or a square mesh panel. *Fisheries Research* 67, 151-161.

Grant, G.C., Radomski, P., Anderson, C.S., 2004. Using underwater video to directly estimate gear selectivity: the retention probability for walleye (*Sander vitreus*) in gill nets. *Canadian Journal of Fisheries and Aquatic Sciences* 61, 168-174.

Gårdmark, A., Östman, Ö., Nielsen, A., Lundström, K., Karlsson, O., Pönni, J., Aho, T., 2012. Does predation by grey seals (*Halichoerus grypus*) affect Bothnian Sea herring stock estimates? *ICES Journal of Marine Science* 69, 1448-1456.

Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. Bycatch: problems and solutions. *Marine Pollution Bulletin* 41, 204-219.

Hammer C., Temming A., Schubert H.J., 1994. Diurnal variations in swimming activity of *Rutilus rutilus* (*Cyprinidae*) in a group under tank conditions. *International Rewiev of Hydrobiology* 79, 385-396.

Harden Jones, F.R., 1963. The reaction of fish to moving backgrounds. *Journal of Experimental Biology* 40, 437-446.

Hasler, A.D., Villemonte, J.R., 1953. Observations on the daily movements of fishes. *Science*, 118: 321-322.

He, P., Inoue, Y., 2010. Large-scale fish traps: gear design, fish behavior and conservation challenges. In: He, P. (Ed.), *Behavior of Marine Fishes*: Capture Process and Conservation Challenges. Blackwell Publishing Ltd., pp. 159–181.

Heibo, E., Magnhagen, C., 2005. Variation in age and size at maturity in perch (*Perca fluviatilis L.*), compared across lakes with different predation risk. *Ecology of Freshwater Fish* 14, 344-351.

Heikinheimo, O., Mikkola J. 2004. Effect of selective gill-net fishing on the length distribution of European whitefish (*Coregonus lavaretus*) in the Gulf of Finland. *Annales Zoologici Fennici* 41, 357-366

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

Herrman, B., O'Neill, F.G., 2006. Theoretical study of the influence of twine thickness on haddock selectivity in diamond mesh cod-ends. *Fisheries Research* 80, 221–229.

Hirst, A.G., Bunker, A.J., 2003. Growth in marine planktonic copepods: global rates and patterns in relation to chlorophyll a, temperature, and body weight. *Limnological Oceanography* 48, 1988-2010.

Hjerne, O., Hansson, S., 2002. The role of fish and fisheries in Baltic Sea nutrient dynamics. *Limnology and Oceanography* 47, 1023–32.

Hubert, W.A., 1996. *Passive capture techniques*. In: Murphy, B.R., Willis, D.W. (Eds.), Fisheries Techniques, 2nd ed. American Fisheries Society, Bethesda, MD, pp. 157–192.

Hutchings, J.A., Reynolds, J.D., 2004. Marine fish population collapses: consequences for recovery and extinction risk. *Bioscience* 54, 297–309.

ICES. 2013. ICES Advice 2013, Book 8. *Herring in Subdivision 30,* (Bothnian Sea). Advice summary for 2014.

ICES. 2013. *Report of the Baltic Fisheries Assessment Working Group* (WGBFAS), 10 -17 April 2013, ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:10. 747 pp.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., and Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293, 629-638.

Jamet, J.L., Lair, N., 1991. An example of diel feeding cycle of 2 percids, perch (*Perca fluviatilis*) and ruffe (*Gymnocephalus cernuus*) in eutrophic lake Aydat (France). *Annales des Sciences Naturelles – Zoologie et Biologie Animale* 12, 99-105.

Karlsson, L., Ikonen, E., Mitans, A., Hansson, S., 1999. The diet of salmon (*Salmo salar*) in the Baltic Sea and connections with the M74 syndrome. *Ambio* 28, 37–42.

Karlsson, O., Helander, B., 2005. Development of the Swedish Baltic grey seal stock 1990-2004. In *Symposium on the biology and management of seals in the Baltic Area*. Helsinki, Finland, 15-18 February 2005, 21 pp.

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

Kuparinen, A., Merila, J., 2007. Detecting and managing fisheries-induced evolution.*Trends in Ecology and Evolution* 22, 652-659.

Kuparinen, A., Kuikka, *S.*, Merila, J., 2009. Estimating fisheries-induced selection: traditional gear selectivity research meets fisheries-induced evolution. *Evolutionary Applications* **2**, 234-243.

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

Königson, S., Fjälling, A., Berglind, M., Lunneryd, S.G., 2013. Male gray seals specialize in raiding salmon traps. *Fisheries Research* 148, 117-123.

Laarman, P.W., Ryckman, J.R., 1982. Relative size selectivity of trap nets for eight species of fish. *North American Journal of Fisheries Management* 2, 33-37.

Law, R., 2000. Fishing, selection, and phenotypic evolution. *ICES Journal of Marine Science* 57, 659-668.

Lehtonen, E., Suuronen, P., 2004. Mitigation of seal-induced damage in salmon and whitefish trapnet fisheries by modification of the fish bag. *ICES Journal of Marine Science* 61, 1195-1200.

Lehtonen, E., Suuronen, P., 2010. Live-capture of grey seals in a modified salmon trap. *Fisheries Research* 102, 214-216.

Liang, K.-Y., Zeger, S.L., 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73, 13-22.

Ljunggren, L., Sandström, A., Bergström, U., Mattila, J., Lappalainen, A., Johansson, G., Sundblad, G., Casini, M., Kaljuste, O., Eriksson, B.K., 2010. Recruitment failure of coastal predatory fish in the Baltic Sea coincident with an offshore ecosystem regime shift. *ICES Journal of Marine Sciences* 67, 1587-1595.

Lundmark, B., 2010. Strömmingsbeståndets fluktuationer under de senaste århundradena I Bottenhavet. Projektrapport ”Strömmingen i Södra Bottenhavet”.

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

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

Lunneryd, S.G., Westerberg, H., 1997. By-catch of, and gear damages by, grey seal (*Halichoerus grypus*) in Swedish waters. In: ICES CM 1997/Q:11, *ICES Annual Science Conference,* Baltimore, USA, 10 pp.

Lunneryd, S.G., Westerberg, H., Wahlberg, M., 2002. Detection of leader net by whitefish *Coregonus lavaretus* during varying environmental conditions. *Fisheries Research* 54, 353-362.

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

Madsen, N., Hansen, K. E., Moth-Poulsen, T., 2001. The kite cover: a new concept for covered codend selectivity studies. *Fisheries Research* 49, 219-226.

Madsen, N., Stær, K.J., 2004. Selectivity experiments to estimate the effect of escape windows in the Skagerak roundfish fishery. *Fisheries Research* 71, 241-245.

Madsen, N., 2007. Selectivity of fishing gears used in the Baltic Sea cod fishery. *Reviews in Fish Biology and Fisheries* 17, 517-544.

Millar, R.B., Walsh, S.J., 1992. Analysis of trawl selectivity studies with an application to trouser trawls. *Fisheries Research* 13, 205-220.

Millar, R.B., Fryer, R.J., 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. *Reviews in Fish Biology and Fisheries* 9, 89-116.

Neuman, E. 1982. Species composition and seasonal migrations of the coastal fish fauna in the southern Bothnian Sea. In: *Monographiae Biologicae*, K. Müller (ed.). Vol. 45. dr. W. Junk Publishers, The Hague. pp. 317-352.

Olsen, E.M., Heino, M., Lilly, G.R., Morgan, M.J., Brattey, J., Ernande, B., Dieckmann, U., 2004. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. *Nature* 428, 932-935.

Olsen, E.M., Lilly, G.R., Heino, M., Morgan, M.J., Brattey, J., Dieckmann, U., 2005. Assessing changes in age and size at maturation in collapsing populations of Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Sciences* 62, 811-823.

Olsson, J., Beier, U., Bergek, S., Karlsson, M., Hentati-Sundberg, J., 2012. Beståndsstatus hos abborre, gädda, sik och gös i de stora sjöarna och längs kusten. Report in Swedish, Dept of Aquatic Resources, *Swedish University of Agricultural Sciences*. 37 pp.

Ovegård, M., Königson, S., Persson, A., Lunneryd, S.G., 2011. Size selective capture of Atlantic cod (*Gadus morhua*) in floating pots. *Fisheries Reserach* 107, 239-244.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries. *Nature* 418, 689-695.

Persson, L., 2010. Sweden’s fisheries catches in the Baltic Sea (1950-2007). In: Rossing, P., Booth, S. Zeller, D. (eds). Total marine fisheries extractions by country in the Baltic Sea: *1950 – present Fisheries Centre Research Report* 18(1), Fisheries Centre, University of British Columbia, Vancouver.

Pitcher, T.J., Magurran, A.E., Edwards. J.I., 1985. Schooling mackerel and herring choose neighbours of similar size. *Marine Biology* 86, 319-322.

Pitcher, T.J., Misund, O.A., Fernö, A., Totland, B., Melle, V., 1996. Adaptive behavior of herring schools in the Norwegian Sea as revealed by high-resolution sonar. *ICES Journal of Marine Science* 53, 449-452.

Pitcher, T.J., Cheung, W.W.L., 2013. Fisheries: hope or despair? *Marine Pollution Bulletine* http://dx.doi.org/10.1016/j.marpolbul.2013.05.045

Pope, J. 2002. Chapter 4: Input and output controls: the practice of fishing effort and catch management in responsible fisheries. In: A Fishery Manager´s Guidebook. Management measures and their application (ed. K.J. Cochrane). FAO, Rome, *FAO Fisheries Technical Paper* 424, 231 pp.

Pukk, L., Kuparinen, A., Järv, L., Gross, R., Vasemägi, A., 2013. Genetic and life-history changes associated with fisheries-induced population collapse. *Evolutionary Applications* 6, 749-760.

Rajasilta, M., Eklund, J., Hänninen, M., Kurkilahti, M., Kääriä, J., Rannikko, P., Soikkeli, M., 1993. Spawning of herring (*Clupea herengus membras*) in the Archipelago Sea. *ICES Journal of Marine Sciences* 50, 233-246.

Rochet, M-J., Collie J. S., Jennings S., Hall S. J., 2011. Does selective fishing conserve community biodiversity? Predictions from a length-based multispecies model. *Canadian Journal of Fisheries and Aquatic Sciences 68*, 469-486.

Rönkkönen, S., Ojaveer, E., Raid, T., Viitasalo, M., 2004. Long-term changes in Baltic herring (Clupea harengus membras) growth in the Gulf of Finland. *Canadian Journal of Fisheries and Aquatic Sciences* 61, 219-229.

Siira, A., Suuronen, P., Ikonen, E., Erkinaro, J., 2006. Survival of Atlantic salmon captured in and released from a commercial trap-net: potential for selective harvesting of stocked salmon. *Fisheries Research* 80, 280-294.

Sistiaga, M., Herrmann, B., Larsen, R.B., 2009. Investigation of the paired-gear method in selectivity studies. *Fisheries Research* 97, 196-205.

Skaret, G. L., Nøttestad, L., Fernö, A., Johannessen, A., Axelsen, B.E., 2002. Spawning of herring: day or night, today or tomorrow. *Aquatic Living Resources* 16, 299-306.

Sneddon, L.U., 2003. The bold and the shy: individual differences in rainbow trout. *Journal of Fish Biology* 62, 971-975.

Stewart, J., Ferrell, D.J., 2003. Mesh selectivity in the New South Wales demersal trap fishery. *Fisheries Reserach* 59, 379-392.

Suikkanen, S., Pulina, S., Engström-Öst, J., Lehtiniemi, M., Lehtinen, S., Brutemark, A., 2013. Climate Change and Eutrophication Induced Shifts in Northern Summer Plankton Communities. *PLOS* 8.

Suuronen, P., 1991. The effects of a rigid grating on the selection and survival of Baltic herring - preliminary results. *ICES Fish Capture Committee*, CM 1991/B:17, 22 pp.

Suuronen, P., Lehtonen, E., Tschernij, V., 1993. Possibilities to increase the size selectivity of a herring trawl by using a rigid sorting grid. *NAFOSCR* Doc. 93/119, Serial No. N2313. 12 pp.

Suuronen, P., Erickson, D., Orrensalo, A., 1996a. Mortality of herring escaping from pelagic trawl codends. *Fisheries Research* 25, 305–321.

Suuronen, P., Perez-Comas, J.A., Lehtonen, E., Tschernij, V., 1996b. Size-related mortality of herring (Clupea harengus L.) escaping through a rigid sorting grid and trawl codend meshes. *ICES Journal of Marine Science* 53, 691-700.

Suuronen, P., 2005. Mortality of fish escaping trawl gears. *FAO Fisheries Technical Paper* No. 478, 72 pp.

Suuronen, P., Lehtonen, E., Jounela, P., 2005. Escape mortality of trawl-caught Baltic cod (*Gadus morhua*) – the effect of water temperature, fish size and codend catch. *Fisheries Research* 71, 151-163.

Suuronen, P., Siira, A., Kauppinen, T., Riikonen, R., Lehtonen, E., Harjunnpää, H., 2006. Reduction of seal-induced catch and gear damage by modification of trap-net design: design principles for a seal-safe trap-net. *Fisheries Research* 79, 129-138.

Suuronen, P., Erickson, D., 2010. Mortality of animals that escape fishing gears or are discarded after capture: approaches to reduce mortality behavior of marine fishes. In: He, P. (Ed.), *Capture Process and Conservation Challenges*. Blackwell Publishing Ltd., Oxford, pp. 265-286.

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D., Rihan, D., 2012. Low impact and fuel efficient fishing-Looking beyond the horizon. *Fisheries Research* 119-120, 135-146.

Svärdson, G., 1979. Speciation of Scandinavian Coregonus. *Report of the Institute of Freshwater Research*, Drottningholm, 57, 1-95.

Swain, D.P., Sinclair, A.F., Hanson, J.M., 2007. Evolutionary response to size-selective mortality in an exploited fish population. *Proceedings of the Royal Society B* 274, 1015-1022.

Swedish Agency for Marine and Water Management, 2013. Catch statistics. Available on internet: https://fivbi.havochvatten.se/analytics/saw.dll?PortalPages&PortalPath=%2Fshared%2FExterna+Fiskdammen%2F_portal%2FFiskdammen&NQUser=biee&NQPassword=Biee2010

Swedish Board of Fisheries, 2011. Fish stocks and the environment in marine and inland waters – a resource and environment overview. In Swedish. Available on internet: https://www.havochvatten.se/download/18.472732f513318aaf1af800075/1348912838598/ROM+2011.pdf

Säisä, M., Rönn, J., Aho, T., Björklund, M., Pasanen, P., Koljonen, M.L., 2008. Genetic differentiation among European whitefish ecotypes based on microsatellite data. *Hereditas* 145, 69-83.

Tschernij, V., Lehtonen, E., Suuronen, P., 1993. Behaviour of Baltic herring in relation to a poundnet and the possibilities of extending the poundnet season. *ICES Marine Science Symposium* 196, 36-40.

Tschernij, V., Saarinen, M., 2012. Resultaten från KEHRA-projektets undervattensfotograferingar åren 2010 och 2011. *Report Livia/Fiskeri- och miljöinstitut*, 13 pp.

Vainikka, A., Mollet, F., Casini, M., Gårdmark, A., 2009. Spatial variation in growth, condition and maturation reaction norms of the Baltic herring (*Clupea harengus membras*). *Marine Ecology Progress Series* 383, 285-294.

Varjopuro, R., 2011. Co-existence of seals and fisheries? Adaptation of a coastal fishery for recovery of the Baltic grey seal. *Marine Policy* 35, 450-456.

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J. M., Hoegh-Guldberg, O., Bairlein, F., 2002. Ecological responses to recent climate change. *Nature* 416, 389-395.

Westerberg, H., Lunneryd, S.G., Fjälling, A., 2006. Reconciling fisheries activities with the conservation of seals throughout the development of new fishing gear: a case study from the Baltic fishery–grey seal conflict. *American Fisheries Society Symposium* 49, 587–597.

Wilson, B., Dill, L., 2002. Pacific herring respond to simulated odontocete echolocation sounds. *Canadian Journal of Fisheries and Aquatic Sciences* 59, 542-553.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., Watson, R., 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314, 787-790.

Östman, Ö., Bergenius, M., Boström, M.K., Lunneryd, S.G., 2012. Do cormorant colonies affect local fish communities in the Baltic Sea? *Canadian Journal of Fisheries and Aquatic Sciences* 69, 1047-1055.

Östman, Ö., Boström, M.K., Bergström, U., Andersson, J., Lunneryd, S.G., 2013. Estimating competition between wildlife and humans– a case of cormorants and coastal fisheries in the Baltic Sea. *PLOS*, in press.

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Appendix 1. Technical note

Whether to use rigid grids or square mesh is a question of debate. In previous trawl studies (Suuronen, 1991, Suuronen et al., 1993) it has been demonstrated that it is easier for young herring to escape through a rigid sorting grid than through a mesh. Loss of scales for haddock *(Melanogrammus aeglefinus)* selected by a mesh was significantly higher than for fish selected by a grid (Soldal et al., 1991, cited in Suuronen et al., 1996b). For herring, there seems to be better to use grids because of the physiology of the fish (more sensitive to scale loss and entangling in the netting).

For whitefish, the square mesh would instead be recommended. Pilot studies from 2006 (Lundin, unpublished data) showed that a small square mesh panel was more effective than a rigid grid of similar size. Any entangling of whitefish or scale loss of whitefish escaping through square mesh has not been indicated.

The result from paper IV motivated a replacement of the entire inner netting by square mesh. This was tested in pilot trials during 2013 (Lundin, unpublished data) and increased the efficiency even further. In the trials, only one whitefish of 117 was undersized (29.5 cm) and the only negative effects were that the cone-shaped outer end of the fish chamber became slack while the fish chamber was lifted to the surface at harvesting. While there was a slack in the netting, there were tendencies that larger whitefish than 30 cm escaped through the square mesh (Personal communication, Lennart Nyström). The final section of the fish chamber should therefore be made of the original netting or some other more fine meshed netting.

Besides from reducing the bycatch of non-commercial fish, this new model of fish chamber is also easier and cheaper to manufacture. Besides from releasing young whitefish, improving the status of whitefish stocks, it has the positive side-effect of releasing salmonid smolts which also may improve the status of salmonid stocks. I believe that a shift of netting from the original 35 mm diagonal mesh to the square mesh netting of 50 mm bar length in pontoon fish chambers would be a step towards a more sustainable trap fishery.

In the perch traps there are many different fish species being caught (i.e. perch, whitefish, roach, pike-perch and other salmonids). These species differ in the shape of their bodies (i.e. width-height ratio). Thereby, a grid is preferable since it size-select the fish only by its width. The width of a commercial perch and a commercial whitefish seems to correlate around 30 mm. It might however be a good idea to design a grid with adjustable escape openings. This would be practical if the fisherman for example decides to fish for herring for some periods. The results from the Finnish side of the Baltic Sea (Tschernij and Saarinen, 2012), where grids were more effective when painted with a more discrete color should be taken into account during production of the grids.

Appendix 2. Potential methodological weaknesses

Different approaches of measuring the selection efficiency were used in Paper I, II, IV and V. Because of practical and economical reasons, only one trap could be used in the herring studies (Paper I and II). Video cameras and a collecting bag were therefore used to measure the selection efficiency. Several thousand of fish per fishing period gave sufficient data to estimate the selection efficiency after each fishing period.

For whitefish in paper IV, two traps were used in the same area. Fewer individuals were caught and the selection efficiency was estimated by comparing the number of undersized individuals caught in each trap after the season. For perch in paper V, two traps could be used in different areas, and the selection efficiency was calculated by using video cameras and by comparing the catches after an alternating fishing with grid and with the grid covered. All of the above mentioned designs answer the same question, but they all have their own weaknesses and positive side effects.

Several steps in the calculations of the selection efficiency of herring by using video cameras are based on assumptions, sub-sampling and extrapolations. A possible source of error is the extrapolation from the 5-min periods up to the total time of the trial period. The 5-min periods were, however, randomly selected throughout the day and the total time represented a relatively large proportion of the total time of the catch period.

For paper II, a possible source of error is the extrapolation of the mean number of escapees through the study area up to the mean number of escapees through the total grid area. Although the video recordings showed a steady activity over the total grid surface, some differences might exist. For example, the lower part of the grid may be more effective at night or vice versa. In further experiments, it may therefore be an idea to try to cover up a larger study area of the grid in order to detect any differences in efficiency at different height levels on the grid.

For paper IV, the experimental fish chamber and the control fish chamber were switched between trap positions every two weeks to minimize confounding effects. The distance between the two traps was set to be as close as possible in order to minimize potential differences in various factors, such as current, wind, temperature and different subspecies of whitefish being caught. The results derived should therefore be dependable but there might still be minor differences in the properties of the trap locations at certain time periods.

For paper V, the cameras filmed only the initial parts of the fishing periods and there might have been differences in the background populations during the different periods when the grid were covered and uncovered.

For paper III, the difference in sample size is a source for potential bias. The number of herring in the different trials varied from 172 to 2170. These numbers corresponds to 5.4 fish/m^3 or 68.2 fish/m^3. In Paper I, it was demonstrated that the number of escapees augmented drastically after about 1 tonne. This corresponds to a density of 943.4 fish/m^3. Behaviour of fish in the trap is density dependent, but the densities need to be considerable before any major behavioural changes occur. In the current trials it is probable that the densities were not high enough to initiate any changes in behaviour. There might have been surrounding unknown factors affecting the mortality of the confined herring, for example grey seals or motor boats in the vicinity of the trap. There were also some bycatch of stickleback captured in the experimental trials, however, with similar ratio of the total catch for all trials. The dead herring were easy to recognize due to skin abrasions but it is possible that recently deceased herring were missed.

For paper VI, the size-structure of the herring population was based on data from BIAS (Baltic International Acoustic Survey). This survey is conducted in September-October when the herring hatched at summer is about 8 cm long and the herring hatched previous year is about 13 cm. Therefore, herring with lengths of 8-13 cm were missing in the background population. This induces abnormal peaks in the retention probability curves of trawl and grey seal, but it does not affect the results of the study.