Introductory Research Essay

# Herring (*Clupea harengus membras*) in the Baltic and Bothnian Sea: Biology, behavior and a sustainable, viable fishery

**Mikael Lundin**

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Department of Wildlife, Fish, and Environmental Studies
Swedish University of Agricultural Sciences
901 83 Umeå, Sweden

# Herring (*Clupea harengus membras*) in the Baltic and Bothnian Sea: Biology, behavior and a sustainable, viable fishery

**Mikael Lundin**
**Institutionen för vilt, fisk och miljö**
**SLU**

## Introduction

The most important species for the fishery in the Baltic Sea and Gulf of Bothnia is herring *(Clupea harengus membras),* which is a subspecies of the larger North Atlantic herring *(Clupea harengus).* Herring is probably one of the most studied fish species in the world (Blaxter et al. 1963, Aneer 1983). Most of these studies have been conducted in large tanks and only a few in their natural environment. Herring has a large impact on ecosystem function, similar to a key species, in the sense that it represents a large biomass of pelagic marine life and thus can have a major impact on the marine ecosystem (Mills et al. 1993, Power et al. 1996, Davic 2003).

Since time immemorial, coastlines along the Baltic Sea and the Gulf of Bothnia have been dominated by small fishing villages with processing facilities and commerce. The inshore fishery in Sweden has had a great economic and cultural importance to society. In recent decades, this ancient tradition has come to disappear. Fishermen retire and no young are taking over.

One of the reasons is the increased grey seal population, causing damages to gear and catch. In order to find a solution to these problems and to maintain the tradition of an inshore fishery, it requires the development of seal safe and sustainable fishing gears with optimized trapping efficiency. Achieving this goal demands research and knowledge of target fish species´ behavior.

This paper describes the biology and behavior of the Swedish commercial fishing's most valuable species, the herring. It also provides an overview of possible methods for conducting a sustainable and long-termed inshore fishery for herring in the Baltic and Bothnian Seas.

## Herring biology

Herring migrate over large areas near the coast and offshore. It follows the plankton movements during the day, which usually means closer to the surface at night and closer to the bottom during the day. The main diet consists of small crustaceans and fish larvae. Herring can reach 25 years of age and a maximum length of 26 cm. They mature at between 2 to 4 years of age (Swedish Board of Fisheries, 2010).

### Spawning

In the Baltic Sea, sometime in early May, herring comes close to the coast to spawn. The spawning season goes on uninterrupted for about three months in the same area. When spawning, herring release all the gametes freely within hours, and fertilization takes place in the sea water. Herring is a communal spawner with no pairing or parental care of the offspring. Reproductive success is depending on several factors: the number and fecundity of the females and the fertilization capacity of the males; i.e. the number and viability of the sperm cells (Rajasilta, 1997). Herring appear to prefer spawning beds situated near the deepest regions of the sea area containing broad and rich vegetation zones on hard ground (Kääriä, 1997).

After spawning, herring migrates back to deeper waters further out from the coast where they are staying for the rest of the year (Rajasilta et al. 1993). Herring can spawn up to 10-15 times per 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).

### Predation

Herring is an important species for many predators. In the Baltic and Bothnian Sea, the most important are grey seal *(Halichoerus grypus),* cormorant *(Phalacrocorax carbo sinensis)* and cod *(Gadus morhua).* Dietary studies of grey seals have shown that 81% of the diet consists of herring (Lundström et al., 2007). Grey seals prefer larger sized herring which can affect the size-distribution in a herring stock (Östman, unpublished, 2010, cited in Lundmark, 2010 ). Studies have shown that cormorant diet locally can consist of 32% herring and thus can have a big impact on a herring stock (Boström et al., 2009).

The impact by cod is considered of importance only in the southern Baltic, where the cod population is still viable. To what extent the cod influence the herring populations is unknown. Other species which prey upon herring are salmon *(Salmo salar)*, trout *(Salmo trutta)*, pike (*Esox lucius)* and perch *(Perca fluviatilis).* The former appears to prefer European sprat (*Sprattus sprattus*) (Karlsson et al., 1999) and the predation by the latter three have decreased with declining stocks.

## Schooling behavior

The herring is a schooling species. Schooling is a phenomenon that has evolved through natural selection for thousands of years. It can be described as displaying synchronous and coordinated movement, at some point in their life history (Shaw, 1978). Schooling can be seen in over 50% of all fish species. Herring and most other schooling fish rely on their vision and lateral line system sensing for the coordination of the school. Vision is most needed for maintaining positions and angles between fish, while the lateral line is needed for receiving information about speed and direction of neighboring fish (Partridge and Pitcher, 1980)

At a first distant view on a herring school it looks like it is only one huge individual. However, when watching closer and focusing on a few individuals, one can see that individuals do have different sizes, shapes and to some extent an individual personal behavior. This individually personal behavior could for example be a continuous shifting of positions in the school (Nøttestad et al., 2004). Herring schools can contain several million individuals (Rajasilta et al. 1993), thus there is a possibility for several different personalities in these schools.

In animal communities there is often a dominance hierarchy among the group members, with a dominant leader. However, in very large communities of fish (e.g. herring), birds and social insects, these hierarchies are not so common (Camazine et al. 2001). Such communities are instead made up of a phenomenon called self-organization (Haken 1983, Camazine et al. 2001) which is a process where interacting elements of a system produce configuration and organization among themselves in such a way that higher-level patterns arise. However, an individual-based simulation study of herring has demonstrated that individuals with a determined behavior can have a greater influence on schooling behavior than more timid individuals (Huse et al. 2002).

## Anti-predator responses

Predators and food are the keys for understanding fish schools (Pitcher and Parrish, 1993). A larger school with many searching companions will find food more easily than a lonely individual (Pitcher et al. 1981). Schooling behavior is also a defending mechanism against predator attacks. When attacked, individuals in the school can be protected behind other individuals and the risk for being stalked by a predator decreases.

Pacific herring (*Clupea pallasii)* respond to attacks by predators by increasing swimming speed and depth (Wilson and Dill, 2002). It is deemed sufficient that if 7% of the school discovers a possible predator it results in a behavioral response of the whole school (Huse et al., 2002). How long the effect of predator presence lasts for herring is debatable. In an experiment by Metcalfe et al. (1987), salmon (*Salmo salar*) were affected for two hours.

Herring's response to predators is surprisingly similar, independent of which predator species it is (Similä, 1997). However, in a study by Pitcher et al., (1996) on herring in the Norwegian Sea, it was discovered that herring show a remarkable adaptability to predator behavior and constantly re-appraised behavioral decisions on leaving or joining the school on a second to second basis, depending on which type of attack they were exposed to.

Fish schools can perform different formations and maneuvers when attacked by a predator, e.g. split, vacuole, herd and hour glass (Fig. 1). For being successful it demands that all members perform them correctly (Parrish, 1989).

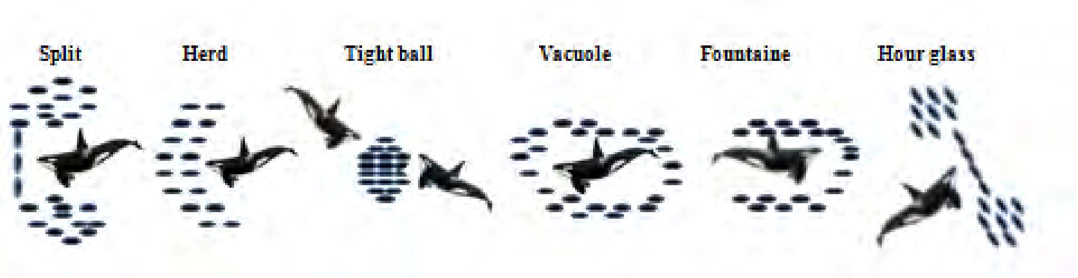


**Fig. 1.** Illustration of anti-predator responses of herring schools (Interpretation of Nøttestad et al. 2004).

Decision making in the school regarding for example swimming directions when escaping a predator attack are completely unpredictable and can be explained as a collective decision. Nearby fish strongly mimic each other and due to amplification of any tendency, one direction is rapidly chosen. Behavioral tendencies like these are called positive feedback and do also exist among humans, e.g. fashion (Nøttestad et al. 2004). Older herring can in some cases, such as in choices of overwintering area, have a significant influence on younger and less experienced herring (Nøttestad et al. 2004).

Transfer of information takes place frequently between different schools. Schools split and join each other on a regular basis. Behavior and tendencies from different branches mixes and migration patterns and other traits can be changed (Nøttestad et al. 2004).

For studying school-dynamics and interactions between herring schools, predators and fishing boats, a powerful tool is the sonar (Misund 1997, Nøttestad et al. 2002). When studying individual fish influences on larger schools, one often use different kinds of simulation models, constructing artificial self-organized fish schools (Hemelrijk and Kunz, 2004).

### Experimental studies of schooling behavior

Several behavioral studies have been conducted where herring are exposed to external stimuli such as light, noise and air bubbles. These studies have shown that herring tends to increase their swimming speed with increased light intensity (Batty et al. 1990). In experiments with simulated sounds of toothed whales, a major impact on herring has been observed - they stop eating, swim downward and form schools actively (Wilson and Dill, 2002). Herring exposed for artificial sounds have shown an increase in swimming speed (Kastelein et al. 2006).

Air bubbles are often used by marine mammals in order to hold together schools and thereby simplify predation on the fish in the shoals. Experiments with artificial bubbles have shown that herring are reluctant to pass bubble curtains, even when frightened and forced (Sharpe et al. 1997). Sharpe et al. (1997) also showed that smaller schools are quicker to pass bubble curtains than larger schools and passage through a bubble curtain went faster when other herrings were on the opposite side.

## Herring fishery in the Bothnian Sea

The herring fishery in the Bothnian Sea has since the 1600s become the most important regional fishery. Today, it accounts for both the largest quantities and the largest value (Commercial fishing in the Sea in 2009). The Finnish fisheries account for about 90% of the catch.

The TAC "total allowable catch" of herring for the Bothnian Sea and the Gulf of Bothnia in 2010, was decided by the EU to 103 336 tons, of which Sweden is allowed 18 615 tons. The stock is considered used in a sustainable manner. Fishing mortality has since the 1970s been below the threshold and the recruitment has been stable (Swedish Board of Fisheries 2010).

However, there are some concerns about the herring stock in the Baltic Sea, including Gulf of Bothnia. Catch statistics indicate that herring over the last 20 years has become smaller in size (Lundmark, 2010). This is most noticeable in the southern Baltic Sea. The average weight of five-year old herrings has since 1974 decreased from 70g to 40g. There are a number of possible explanations for this size reduction, such as a hard fishing pressure, changes in plankton composition, climate change and an increased number of the competing species, such as the European sprat (Lundmark, 2010).

In the Bothnian Sea, herring are often separated into two different subpopulations depending on the time for spawning. Before the 1950s, the autumn spawning herring was the most common type, and this spawning took place between August and September (Lundmark 2010). More recently, the spring spawning (May to June) has become the dominant type. The changing in spawning periods has regarding to Lundmark (2010) occurred in every 50-100 years, and the recent change occurred in 1945. There are speculations that the reason for this is due to changes in salt concentrations and that high levels of salt favor spring spawning (Lundmark, 2010).

A known problem with traditional fishing gears used in the Bothnian Sea and the Gulf of Bothnia, e.g. trawls and traps, is that they catch herring indiscriminately. It is important to minimize the bycatch of juvenile and undersized herring and this is also one of the Swedish Board of Fisheries priority objectives (Swedish Board of Fisheries, 2004). Catching juvenile herring, before they have spawned, will reduce the productivity of the stock. The capture of undersized herring is a waste of a valuable natural resource and it also increases the sorting work for the fishermen. A minimization of bycatches can be made by using size-selective fishing gears.

## Size selection

Bycatches, whether they are of undesirable sizes of the target fish or of other species is a global threat to sustainable fisheries (Abbott and Wilen, 2006, Gilman et al., 2006, Walmsley et al., 2007). The development of fishing gears should focus on developing selective methods so that for example, smaller individuals of the fish can be avoided in the catch (Alverson et al., 1994, Heales et al., 2007)

Several studies of selection have been made in active fishing gear (Suuronen et al., 1996 a, 1996 b, Armstrong et al., 1998, Madsen and Staer, 2004, Herrman and O'Neill, 2006, Bahamon et al., 2007). Active fishing gears are for example trawls and purse seine nets, which actively searches for the fish (Hayes et al., 1996). The selection device in such gears often consists of square mesh (BACOMA) or rigid grids with vertical bars. In the active gear, the fish have no choice, and is often sieved out more or less automatically through the selection device. The effectiveness of the selection device depends primarily on the fish's natural shape and size and also on the placement and design of the device.

In trawl fisheries, the survival of young herring selected from the trawl cod-end is low (Suuronen et al., 1996a, 1996b). Suuronen et al., (1996a, 1996b), argued that the high mortality of young herring in this case is largely due to the exhaustion and physical damage experienced  inside the trawl and not necessarily on the passage through the device.

Only a few studies on selective release have been done for passive fishing gears such as larger size traps and pound-nets (Laarman and Ryckman, 1982, Brothers§ and Hollett, 1991, Tschernij et al., 1993, He and Inoue, 2010).  In a passive gear, fish are not forced and any capture or possible escape requires their active behavior (Hubert, 1996). Therefore, it is highly unlikely that these fish obtain 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). Small details in the design of the gear and the selection device can be expected to affect the selection efficiency. Hence there is a need for detailed knowledge of the behavior of the fish during the selection process to be able to optimize the conditions.

**Fig. 2.** Size-selection of herring by rigid grids.

Several factors can be assumed to affect the degree of selection: (1) environmental conditions, such as currents, light intensity and temperature; (2) behavioral 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.

The flight disposition of various fish species differs. Even within a species, different individuals might have different flight disposition. Sneddon (2003) have shown that rainbow trout (*Oncorhynchus mykiss*) differ in how they act and she categorizes individuals as either shy or bold. Schooling species as herring are expected to be more difficult to select from the catch than more solitary species.

Fish movements in a passive gear are affected by environmental factors such as currents, winds and temperatures. 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, i.e. rheotaxis (Harden Jones, 1963).

A selection device should be placed where the fish spend most time and thus are easiest for the fish to detect. In the passive gears 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 (Fig. 2). Whether this is optimal or not is unknown.

Experiments with pontoon traps for salmonids have demonstrated that it is possible to selectively release unwanted fish from the catch. Lundin (2006) demonstrated that 78% of undersized whitefish (*Coregonus lavaretus*) succeeded in escaping through a selection device fitted to a pontoon trap. Achieving the same result with herring is expected to be more difficult, as herring have strong school cohesion, forming highly synchronized and polarized schools.

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).

### Seal conflict in the fishery

The increasing population of grey seals over the last 20 years has caused serious problems for the fisheries (Kauppinen et al., 2005, Westerberg et al., 2006). In 2009, ca 20 400 grey seals were counted in the Baltic Sea (Finnish Game and Fisheries Research Institute. http://www.rktl.fi ) and the total number of grey seals is estimated to be well over 25 000 individuals (Königson, 2007). The population is considered to increase by 7,5% each year (Karlsson and Helander, 2005).

The most severely affected fishery has been the inshore fishery using gill nets and traps. Seals prey upon 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). Therefore, there has been and remains a compelling need to develop seal-safe fishing gear. In 2009, 40 million SEK was used for compensating damages done by grey seals in Sweden.

According to studies by the Swedish Board of Fisheries there is a special part of the grey seal population that specializes in taking fish from fishing gears (Königson et al. 2010, unpublished manuscript). The traditional traps allow seals to swim far into the gear where they come into close contact with the fish caught (Fig. 3). There are few studies on the influences of seal presence on fish behavior and effectiveness of fishing gears.

**Fig. 3.** Seal visit in a herring trap 2009.

## Mitigation of seal-induced damages on fishing gears

<u>AHD (Acoustic harassment device)</u>
Several attempts have been made trying to scare seals away from fishing gears using sound (Fjälling et al., 2006, Graham et al., 2009). The equipment used is called AHD (acoustic harassment device) and emits a strong irritating sound in the frequency range 11-17 kHz with source levels of 187-195 dB at 1 m. When using AHD in connection to a salmon trap, the amount of caught salmon has initially increased, but a recurring fact is that the seals get used to the sound and return to the fishing gear. The equipment is also expensive, cumbersome and requires regular maintenance.

<u>Seal safe fishing gears</u>
When fishing for salmonids *(Salmo salar, Salmo trutta, Coregonus lavaretus)*, a commonly used device in the Bothnian Sea is the pontoon fish chamber (Fig. 4). It was developed in late 1990s and can be attached to traps of several kinds. The whole arrangement is usually referred to as a pontoon trap (Hemmingsson et al., 2008), or also push-up trap (Suuronen et al., 2006). It has proven to be more effective than traditional traps in the presence of seals (Lunneryd et al., 2003, Kauppinen et al., 2005, Lehtonen and Suuronen, 2010).

**Fig. 4.** Pontoon fish chamber lifted to the surface.

The pontoon fish chamber is basically a large cylinder of strong netting attached to rings of aluminium. The fixed construction with its netting protects the accumulated catch from seals. Below the chamber there are two pontoons which can be inflated with compressed air. When filled with air, the fish chamber is raised to the surface and can easily be emptied. This method lessens work significantly compared to when emptying traditional traps.

A successful combination when fishing for salmon has been to attach a pontoon fish chamber to a large-mesh salmon trap. Salmon chased by seals inside a large-mesh trap is allowed to escape through the mesh while the seal is prevented. Less stressed salmons are still guided towards the fish chamber. This deprives seals of a reward, makes the gear uninteresting to them and may have long-term mitigation effect (Lunneryd et al., 2003).

Seal catching devices and feeding stations

A further increase in the grey seal population is to expect, and the culling for seal is ineffective and complicated. Chances of an escalated seal-fishery conflict are large and may be accompanied by an increase in illegal hunting and deliberate drowning of seals in fishing gears. The needs for an effective catch method for seals are large, mainly to remove seals causing damage to fishing gears, but also for tagging seals in order to study their behavior.

Several attempts have been made with seal traps rigged adjacent to traditional fishing gears (Lunneryd and Fjälling, 2004). A few individuals have been caught but the overall results have been poor. One explanation may be that seals visiting fishing gears, in a successful manner, have a stereotyped behavior ignoring rigged baits regardless of ease of access.

More promising results have been achieved with seal catching devices mounted inside a pontoon trap (Lehtonen and Suuronen, 2010). Seals that are pushing the wire in the last entrance to the fish chamber are caught in a separate section. The trap is then alarmed and sends automatically a sms to the owner’s mobile phone, who can put down the seal. The method is gently to the animal and results in that the right individuals (the ones specialized in taking fish out of fishing gears) get caught. Seal catching devices are manufactured by Harmångers Maskin & Marin AB. They are inspected and approved by The Swedish Veterinary Association and The Swedish Environmental Protection Agency.

Experiments with feeding seals in order to keep them away from fishing gears have shown promising results. Feeding stations nearby fishing gears has attracted seals and catches in fishing gears tend to simultaneously increase. Any conclusion is, however, difficult to make and more studies are necessary.

### Herring trap fishery

The Baltic herring trap fishery started in Finland at the beginning of the nineteenth century (Parmanne 1989). It has since then become one of the most common fishing methods for spring spawning herring. Passive fishing gears like herring traps are resource-efficient and give a product of high quality. They are easy to use, ergonomic, and environmentally friendly and leave no damage on sea bottoms like trawls. Bycatches of marine mammals, birds and fish can be minimized by various methods, such as selection devices, compared with other gears. This type of fishery is held up as a model for a sustainable and responsible future fishery with gentle fishing methods. However, the gears must be able to provide an economically and viable fishery for the individual fishermen. This certainly requires resources in terms of technological equipment and further development of these devices. However, in parallel it is also needed more research on behavior and adaptations of the different species involved in the fishery.

## Conclusions

A sustainable coastal fishery can be achieved by using efficient fishing gears and selection devices. However, an optimization of this equipment requires research and knowledge of the fish's natural behavior. Moreover, for a viable fishery, the research on the effects of different measures to reduce seal damages on fishing gears must proceed.

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