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Mortality of North Sea herring that is crowded and subsequently slipped from a purse seine

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Abstract

Catch regulation by slipping whole or parts of the catch has traditionally been used in NE-Atlantic purse seine fisheries for pelagic species if the catches are considered too big or the quality or size of the fish is considered unsatisfactory. This is particularly the case when the prize differs between sizes or quality groups of fish (high grading) as is often found with herring. No information is, however, available on the survival rate of herring that is slipped from the purse seine or how significant this mortality is in relation to total fishing mortality. The aim of this study is to quantify mortality of herring crowded to different degrees in the purse seine and subsequently slipped. Large-scale open-sea survival experiments were carried out in the North Sea in 2008 and in 2009. Herring caught by purse seine were allowed to swim from the seine to large circular net pens in an early phase of hauling. Commercial crowding conditions were simulated by lifting the bottom of the net pen. The mortality rate four to five days after crowding ranged from 1.8% in the least crowded to 50.7% and 52.0% in the hardest crowded groups. Control group mortality was low, between 0.9% and 2.0%. These results provide important information on what crowding densities can be tolerated in the purse seine fisheries for herring and suggest a need to revise the legislation on slipping in these fisheries.

Keywords: unaccounted mortality, slipping, purse seine, herring, crowding

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Introduction

Purse seine is a highly efficient gear mainly used to catch dense schools of pelagic fish (Ben-Yami 1994). In European waters Norwegian mackerel and herring fisheries are the major purse seine fisheries with catches of about 120 000 tonnes and 1 million tonnes respectively (data from the Norwegian Directorate of Fisheries). Purse seine is, however, a non-selective gear, and it is difficult to regulate catch size. Too large catches may exceed the hold capacity of the vessel or the quota limit, or can lead to burst of nets. Currently it is not possible to control the size and quality of individual fish in the catch. This is problematic for the fishermen as the price depends on the size and quality of the fish. Slipping is commonly used to regulate the size of the catch and to release fish of unwanted size or quality. Slipping involves the release of fish by lowering the headline of the purse seine or by releasing fish through the gavel. This usually takes place in a late phase of hauling the net when the fish are crowded in the bunt, the strengthened part of the net.

Relatively little focus has been aimed at the survival of fish being slipped from purse seines, even though there is evidence suggesting that slipping may involve a significant additional mortality in many fisheries. Previous studies on the survival of pelagic fish after crowding and slipping indicate that many pelagic species experience high mortality when slipped from the purse seine in a late phase of hauling. Mackerel appears to be the most sensitive species with mortality rates between 80-100% (control group mortalities varied between 0-47%, Huse et al. 2008; Lockwood et al. 1983). Pilchard (Mitchell et al. 2002) and sardine (Marçalo and Mateus 2006; Marçalo et al. 2007) may also experience significant mortality when slipped. To our knowledge there are no previous studies on the survival of herring after crowding and slipping in the purse seine fishery. Herring is, however, highly sensitive to contact with fishing gear (Suuronen et al. 1996) and experience high mortality during net bursts (Misund and Beltestad 1995). In addition, based on reports from the fishing grounds and anecdotal evidence, there are strong reasons to believe that slipping and net bursts occur frequently in at least some of the Norwegian herring fisheries, including the North Sea herring fishery. Bad weather conditions, big dense schools and a large proportion of small herring on the fishing grounds may lead to increased slipping and frequency of net bursts.

Survival studies on fish escaping fishing gear are challenging because there are several internal (behavior, sex, age, size, maturity stage and stomach fullness) and external (weather, temperature, ambient light, season and region) factors that may influence the survival rate (Chopin and Arimoto 1995; Suuronen 2005). In addition, stress and injuries caused unintentionally by the researchers during handling and transporting the fish may influence survival rate. Field studies are expensive and time consuming and cannot be carried out in all seasons and conditions, and the number of replicates is often low. On the other hand fish may behave differently in laboratory settings than in the field. It has been observed that mackerel that had been kept in net pens tolerated significantly higher densities than mackerel in the field (Huse et al. 2008), resulting in biased survival rates. According to Davis (2002) a combination of laboratory experiments and field studies in realistic fishing conditions are needed to fully understand discard mortality. Laboratory studies are needed to understand why fish die after being discarded, but field experiments are crucial to verify the laboratory protocols, the findings, and to quantify mortality under various fishing conditions.

Slipping is a waste of resources and may result in biased stock assessment and underestimated fishing mortalities if not included in the assessment models. It is therefore important to assess the magnitude of slipping mortality in fisheries. This is, however, highly challenging. In order to quantify the total slipping mortality caused by the fishing fleet, the mortality level at different crowding densities and fishing conditions and the total quantity slipped need to be assessed. Marcalo and Stratoudakis (2002) attempted to quantify slipping in Portuguese sardine fisheries and Borges et al. (2008) in the pelagic freezer-trawler fishery in the Netherlands. Borges et al. (2008) found that herring was the most commonly slipped species. In both studies the seasonal and regional variation and the non linear relationship between effort and catch in many pelagic fisheries made the raising of observed data to the whole fisheries difficult. In October 2008 we carried out a pilot study with the aim to use a bottom trawl survey to estimate the unaccounted mortality caused by the mackerel purse seine fleet on a fishing ground (Huse and Tenningen 2008). The trawl used in the survey was very sensitive to bottom topography (the bottom gear was replaced with a chain for close bottom contact) restricting the survey to areas with even bottom. The catchability of the trawl was also highly uncertain.

In order to reduce unaccounted mortality in purse seine fisheries both changes in the regulations and gear development are required, but before any action can be taken we need to understand what densities can be tolerated during purse seining and how these vary in different fishing conditions. In this paper we will present results from large-scale open-sea survival experiments on North Sea herring after simulated crowding and slipping in the purse seine.

Method

The survival experiments were carried out in May 2008 and in May 2009 in the North Sea (58°18’N-59°49’N and 2°54’E-3°18’E). In 2008 two replicates (each with one control and two crowded net pens) were carried out during a two week experiment period while in 2009 only one replicate was completed due to bad weather in the first week of the experiment. The method that was used was the same as has previously been used in mackerel survival experiments (Huse et al. 2008). Two commercial purse seine vessels, each 61.8 m with a 2750 kW engine power, were hired to carry out the experiments. One vessel was used to transport the net pens to the field and to carry out the crowding, while the other vessel, equipped with an 830 x 230 m purse seine, was used to catch and transfer fish into the net pens. The first vessel was also used as a video observation platform during the follow up phase.

Net pens

Three circular net pens with a diameter of 12 meters and a depth of 12 meters (eight meters straight walls and a four meter deep conical bottom, Fig. 1) were used in the experiments. A 40 meter long bag for collection of dead fish was attached to the bottom of each net pen. The net had a mesh size of 35 mm and was made from the same material as the bunt of the Norwegian North Sea herring purse seines. A transfer funnel made of the same netting, 4 m deep, 6 m wide and 6 m long was attached to each net pen, and a similar funnel was attached to the bunt of the purse seine (Fig. 1).

Transfer of herring into the net pens

The purse seine was set around an appropriate herring school registered by the sonar (about 50 tonnes). The net was hauled about halfway in, and the funnel in the purse seine was attached to the funnel in the net pen. Fish were then allowed to swim from the purse seine into the net pen through the funnel when carefully continuing hauling the net. This way the fish were not handled during transfer, they were free swimming and avoiding netting and obstacles as a part of their natural behaviour. The transfer was monitored visually and in 2009 with additional help from an underwater camera. When an estimated 5-10 tonnes (Table 1) of herring had been transferred, the channel was closed. The three net pens in each replicate were filled from the same purse seine haul and the order of transfer was randomized. One net pen was kept as control and was left to drift freely after the transfer of fish, while the two remaining net pens were used for crowding experiments.

Table 1. The amount of fish in the net pens. All three net pens within one experiment were filled from the same purse seine haul. In this table the order of the net pens indicates the order they were filled.

Year	Net pen	N	Biomass (kg)
2008 a	Control	47822	7691
	Trial 1	28184	4580
	Trial 2	65531	9398
2008 b	Trial 1	42852	6328
	Trial 2	30047	4375
	Control	53813	7953
2009	Trial 1	33975	5705
	Control	19158	3222
	Trial 2	29062	5009

Crowding and slipping simulation

Crowding and slipping was simulated by lifting the bottom of the net pen using the crane on the fishing vessel and collecting the net by hand from the sides, thereby crowding the fish to one side of the net pen. In this way the water volume in the net pen was reduced and the fish density increased until it was considered to correspond to the density in a late phase of purse seining. The aim was to crowd the fish to two different densities; one that is equivalent to the degree of crowding needed to get a sample of the catch with a dip net and one that corresponded to the density when the catch is pumped on board the fishing vessel. The density was estimated visually and was therefore relatively uncertain. Calculations made afterwards showed that in 2008 only one net pen was crowded to a density above 200 kg/m^3 and it was therefore decided to crowd both the groups to a high density in 2009, both net pens were crowded to over 400 kg/m^3 (Table 2). To allow calculation of water volume and density after the experiment the depth, length and width of the net when fully crowded was measured using a measuring pole. The crowding density was maintained for 10 minutes after which the net was released and the net pens were left to drift freely in the sea for a period of four to five days. The net pens were equipped with Argos-transmitters and radar reflectors to allow localization.

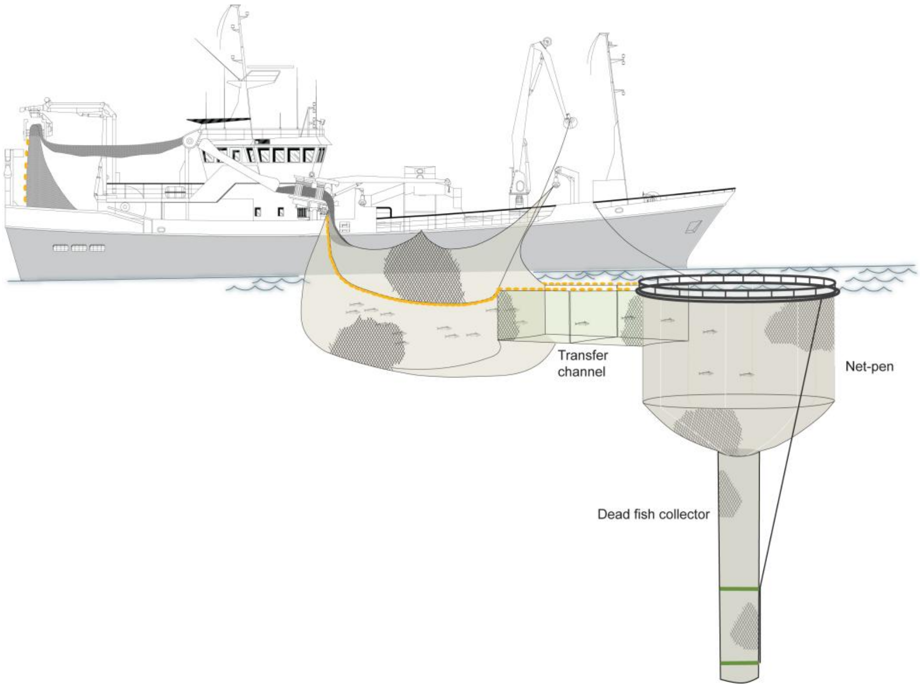

Figure 1. Herring transfer from the purse seine through the funnel into the net pen.

Monitoring period

Herring behaviour was monitored daily with a video camera fixed inside each net pen and in order not to disturb the fish a video link transferred the video signals to an assistant vessel positioned at some distance from the pens. In addition the net pens were inspected daily by visually observing the fish in the uppermost layer. This was done carefully using a small boat not to stress the fish in the net pens

Fish sampling in the end of the experiment and data analysis

Intentionally, the monitoring period should last for 5 days, but because of the weather conditions two of the replicates were terminated after a shorter time (4.2 and 4 days). The total volumes of live and dead fish were registered and weight and length samples were taken of about 100 fish from each group. It was assumed that the net pens were formed as half an ellipsoid and fish density during crowding was calculated based on the number of fish in the net pen and the water volume during crowding. Using weight samples the number of fish was converted to biomass in each net pen. Mortality percent was calculated and plotted against density and exponential regression analysis was used to test for a relationship between density and mortality. The significance of the difference in the mean lengths of the live and dead fish was statistically tested with a t-test.

Results

Mortality in the control groups was below 2% in all experiments, while in the crowded groups mortality varied between 1.6 and 52% (Table 2). At crowding densities below 200 kg/m^3 mortality was insignificant and at the same level as in the control groups (Fig. 2). As the crowding density was increased to above 200 kg/m^3 the mortality rate increased above 28%. There was a highly significant exponential relationship between crowding density and mortality ($r=0.9487$, $p=0.00010$).

The mean length of the herring that survived was significantly higher compared to those that died in all net pens ($p<0.0001$ in all net pens except 2008 B control net pen where $p=0.002$, Fig. 3). Only living herring were weighed because many of the dead herring were partly decomposed and had lost body weight. There may therefore be a slight bias in the biomass of dead fish. The calculated mortality percentage is based on the number of individuals and is therefore not biased.

High levels of scale loss, wounds on the skin and bruised snouts and fin bases were observed on most of the dead fish, but also commonly among the live fish in the crowded groups. Control group herring appeared less injured.

Table 2. Density during crowding, mean individual weight, number of days the fish were observed and mortality (percentage).

Experiment	Net pen	Density (kg/m^3)	Density (ind./m^3)	Mean individual weight (kg)	Observation period (days)	Mortality (%)
2008 a	1	58.4	359	0.163	5	1.8
	2	220.6	1538	0.149	5	27.9
	Control	6.8	42	0.161	5	0.9
2008 b	1	141.9	961	0.148	4.2	1.6
	2	131.8	905	0.146	4.2	1.8
	Control	7.0	48	0.148	4.2	1.0
2009	1	403.4	2403	0.168	4	52.0
	2	478.4	2776	0.172	4	50.7
	Control	4.8	18	0.168	4	1.98

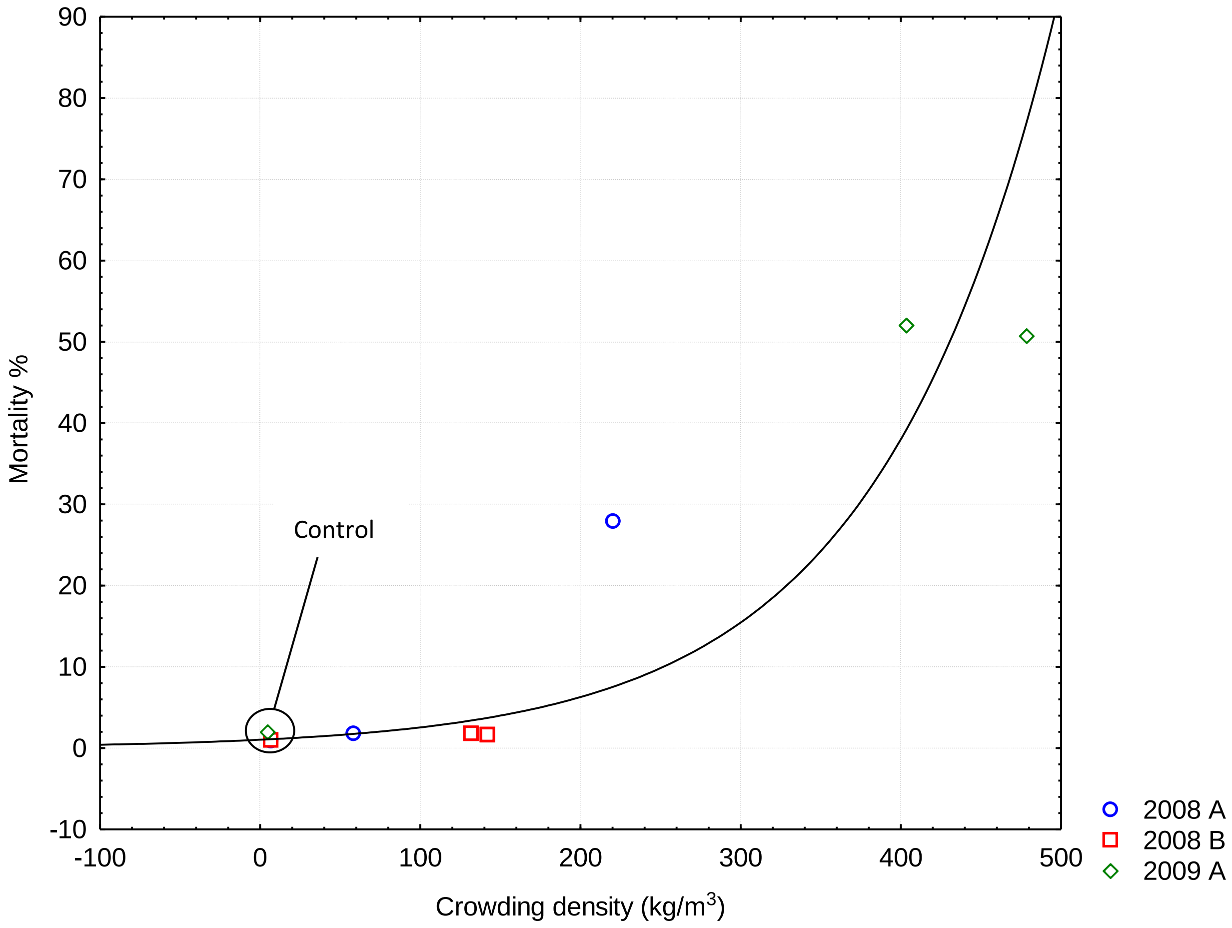

Figure 2. Mortality (percent) plotted against crowding density (kg fish/m^3). The different colours indicate the different experiments and all three control groups are indicated by the circle (the 2008 A control group mark, blue circle, is difficult to see as it is under the other control groups). An exponential regression line has been fitted to the data.

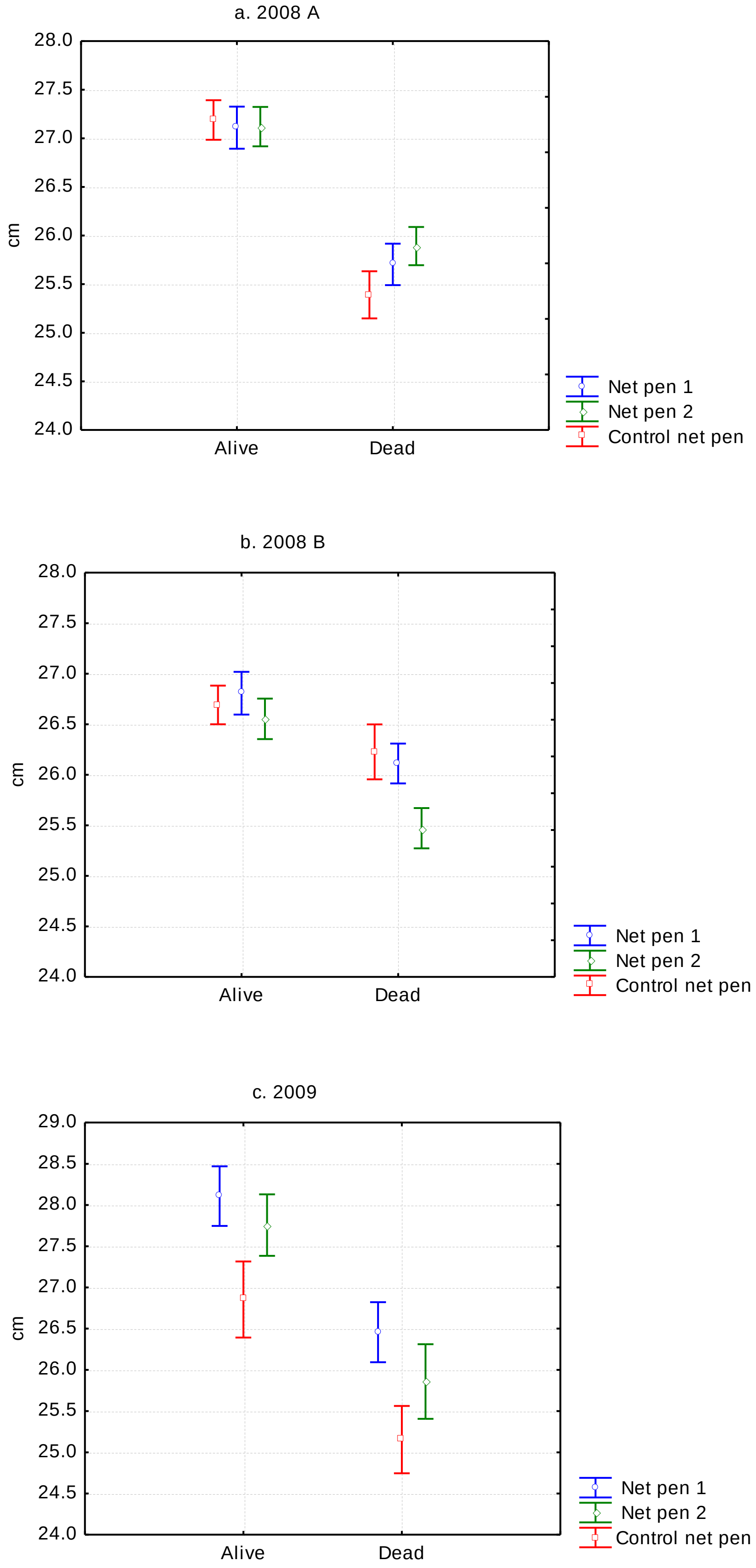

Figure 3. Mean lengths with 0.95 confidence intervals of dead and living fish in the three net pens during the 2008 A (a), 2008 B (b) and 2009 (c) experiments. In all experiments and net pens the living fish had a significantly higher mean length compared with the dead fish.

Discussion and conclusions

Herring seem to tolerate low crowding densities well but experience high mortality at densities above 200 kg/m^3. Compared with mackerel herring seem to tolerate higher crowding densities. Between 80 and 100% of mackerel that were crowded until 'boiling' (panic or flash expansion behaviour) died in similar experiments (Huse et al. 2008). Herring do not have the same behavior of 'boiling' at a certain density, and it is therefore difficult to compare the densities in our experiments with those in the mackerel experiments. Lockwood et al. (1983), however, studied the effects of different crowding densities on mackerel survival in small scale experiments. These slipping experiments showed that at densities between 1000 and 1500 fish m^{-3} between 80 and 100% died within 48 hours while at densities between 100 and 150 fish m^{-3} between 5 and 45% died within about 72 hours. Compared with our experiments densities of 1000-1500 mackerel m^{-3} may correspond to the highest densities in our experiments while 100-150 mackerel m^{-3} may correspond to the lowest densities where the herring mortality rate was about 2 %. The crowding duration of mackerel was, however, about 30 minutes compared to our crowding duration of 10 minutes. Increasing crowding duration is shown to increase the mortality rates (Lockwood et al. 1983).

Another reason why herring apparently tolerate higher crowding densities than mackerel may be that mackerel die within a shorter time period after crowding compared with herring. We believe that the mortality rate in our experiments would have further increased if the monitoring period had been extended. This is based on observations on the degree of degradation among the dead fish in the crowded groups, which varied from almost fully degraded to newly dead fish and that many of the fish in the live group in the crowded net pens were heavily injured with lacerations and bruises in the derma, indicating that they would not have survived for long. Furthermore, Suuronen et al. (1996b) registered mortality of herring that escaped through a trawl codend 14 days after capture. 76-100% of small and 44-83% of large escapees were dead after 7 days while the 14-day mortalities increased to 96-100% and 77-100% for small and large escapees, respectively. Control group mortality after 14 days was 9% in the spring and about 55% in the autumn. Misund and Beltestad (1995) also registered mortality of herring up to 9 days after the net burst experiments. In the 1000 m^3 net pens 70% survived 48 hours, but only 5% were still alive after 9 days (control group survival was 88%). Our 4 to 5 days monitoring period may therefore have been too short to capture all mortality, but due to the high cost of the sea going experiments the time could not be extended.

The initial plan for 2009 was to monitor daily mortality rates by emptying the dead fish bag each day using the lifting crane on the vessel. However, during a first experiment in 2009, which was deranged by bad weather, it was observed that the fish panicked when the fishing vessel was on the side of the net pen. This was also believed to cause a high mortality in the first control group in the mackerel survival experiments (Huse et al. 2008) and in order not to influence the survival of herring we decided to stick to monitoring cumulative morality at the end of the experiment like in the previous year.

Most mackerel on the other hand seemed to die within short time (within the two first days) after the crowding trials (Huse et al. 2008). Lockwood et al. (1983) registered mackerel mortality up to 6 days after crowding, but also in their experiment most of the mackerel died within 48 hours. This may indicate that crowding induced mortality in mackerel and herring are different. There may be several reasons for mortality after crowding in the net. Direct contact with the net and other fish may result in physical injuries such as scale loss and skin injuries, which again may lead to osmoregualtory problems and infections. Stress, physical exhaustion, hypoxia and pressure may also cause mortality. Previous studies, however, indicate that both mackerel and herring died due to skin injuries. Suuronen et al. (1996a; 1996b) suggested that skin injuries and exhaustion are the main reasons for mortality of herring that escape from pelagic trawl codends. Misund and Beltestad (1995) also believed that mortality of herring after net burst was caused by severe scale loss followed by osmoregulatory problems. Pawson and Lockwood (1980) concluded that dehydration as a result of skin damage was the main reason for mortality also of mackerel in crowding and slipping experiments.

The observation of significantly higher mean lengths of herring among the living fish compared with the dead fish in all experiments indicates that large herring tolerate crowding better than smaller herring. This is supported by the results in the experiments Suuronen et al. (1996a; 1996b) carried out on mortality of herring escaping from pelagic trawl codends. They also registered significant differences in mortality between small and large herring suggesting that small herring are more sensitive to contact with the trawl.

Laboratory and small scale tank experiments may not give results that truly reflect the conditions in the fishing operations (Huse et al. 2008; Misund and Beltestad 1995) and field studies are therefore essential to get a more realistic picture of what happens in the commercial fisheries. These experiments were designed to resemble as closely as possible commercial fisheries and all unnecessary handling of fish were avoided. Still we cannot be sure that the results reflect exactly what is happening in the fishing fleet. The experiments were conducted in one particular season and fishing ground, while fisheries are carried out in different seasons and weather conditions and on fish in several conditions. The crowding experiments can only be conducted in very good weather conditions as it is a prerequisite for successful transfer of fish into the net pens, crowding and emptying of the net pens. Also during the monitoring period rough weather may damage the net pens and fish may be thrown over the sides. Fisheries are often carried out in rough weather which may increase the injury level of the fish. Whether the cause of death and the injuries suffered in the crowding experiments are the same as in commercial fisheries need to be further studied. The quantities of fish used in our experiments were significantly smaller than those normal for commercial catches and it is uncertain how this affects survival. With small quantities of fish a larger proportion may touch the net with the risk of damaging the skin, while in large catches the pressure will be higher. One major problem is that we do not know normal crowding densities in the commercial fisheries as no instrument exists to measure fish density in a seine. We therefore cannot be sure if the crowding densities tested in this experiment are in the range of densities found during normal slipping conditions. It is therefore crucial for future experiments to find a method for measuring fish densities during crowding and slipping in the purse seine fleet.

Several issues remain to be solved before any firm conclusions can be drawn as to the magnitude of unaccounted mortality caused by crowding and slipping in the herring fisheries, and how these data may best be taken into use by fisheries management. We have, however, clearly shown that herring crowded to high densities and subsequently released suffer unacceptably high mortality and slipping at a late phase of purse seine hauling should therefore not be allowed.

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