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Survival of mackerel and saithe that escape through sorting grids in purse seines

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Abstract

Gear technology for the efficient size selection of mackerel and saithe in purse seines has been developed. A critical constraint for application of the technology is the survival of the fish that escape. We have conducted a series of small scale experiments in which penned mackerel and saithe have been forced through rigid grids into new storage pens in order to quantify their survival rates. Both species suffered insignificant mortality. We have also conducted full scale experiments during purse seining for mackerel off western Norway, and during purse seining for saithe in fjords in western and northern Norway. Control groups were established by transferring parts of the catch gently from the purse seine to attached net pens. Experimental groups were established by collecting the fish that escaped through the selection grids in attached net pens. The net pens were subsequently towed for up to 30 nautical miles before they were anchored inshore. In the mackerel experiments, maximum 95% of the control groups and maximum 60% of the experimental groups survived 1 month after the experiments. This indicates that the size selection process in mackerel purse seining may cause too high a mortality rate to allow it to be recommended for commercial fishing. On the other hand, the mortality in the saithe experiments was insignificant, and the use of size selection grids in saithe purse seines can therefore be recommended.

Keywords: Mackerel; Saithe; Purse seine; Sorting grids; Survival

1. Introduction

The introduction of rigid sorting grids has greatly improved the selection properties of trawls with regard to both species and size selection (Valdemarsen and Isaksen, 1994). In shrimp trawling, the rigid Nordmøre grid mounted in the extension piece of the trawl successfully sorts out bycatches of fish that are too large to pass between the bars of the grid (Isaksen et al., 1992; Broadhurst et al., 1996). In bottom trawling for gadoids, mounting a rigid sorting grid improves the size selection properties of the trawl (Larsen and Isaksen, 1993). In comparison with size selection through meshes, the selection curves of rigid grids are steeper, and the selection range is narrower. Field experiments have shown that gadoids such as cod,

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haddock and saithe survive being sorted out through trawls via rigid sorting grids (Jakopsen et al., 1992; Soldal et al., 1993), and rigid grids can therefore be utilized to optimize the size composition in trawl catches of these species.

In Norwegian waters, purse seining is usually carried out on schools or dense shoals, and catches normally consist of a single species with a rather narrow length distribution. The uniform catches during purse seining on schools is due to natural selection mechanisms with regard to species and size distribution in the formation of fish schools (Pitcher and Parrish, 1993). Still, there is an interest in methods for size selection during purse seining for mackerel (*Scomber scombrus*) and saithe (*Pollachius virens*) by Norwegian vessels. In the mackerel fishery this interest has arisen because fish for human consumption above 600 g in weight are sold for about twice as much as fish less than 600 g. The Norwegian mackerel fishery, which takes place off the coast of western Norway and in the North Sea in August–November, is regulated via a total quota that is split into quotas for specific vessels. For the fishermen there is therefore an economic incentive to adopt methods capable of increasing the proportion of fish above 600 g in their catches.

In the saithe purse seining fishery, which is located in fjords in western and northern Norway, the incentive for size selection is two-fold. The fishery is regulated by a total quota and a minimum landing size that is currently 32 cm in western Norway, increasing gradually northwards for defined regions to 40 cm in northern Norway. A substantial proportion of fish under the legal landing size occasionally occurs in the catches, and if the fraction of fish under the legal landing size is more than 10% the catch must be released. If a high fraction of undersized fish continues to be found in the catches, the Directorate of Fisheries normally closes the area concerned for fishing until the situation improves. A method of sorting the fish under the legal landing size out of the catches will therefore be an advantage for the fishermen. In addition, there is a size-dependent price differentiation so that fish larger than 700 g are sold for about twice as much as fish below that weight.

Using an adjustable selection grid developed for size-sorting farmed salmon, Misund and Skeide (1992) conducted successful experiments for sorting purse seined saithe according to size. The saithe were stored in net pens, and sorted according to size from one net pen to another by making the storing pen smaller and smaller so that the fish was forced towards a grid mounted between the pens. The grid gave a sharp sorting, with a selection range of just 5 cm, and the fish sorted through the grid suffered no mortality. For size selection of purse seine catches of mackerel and saithe, a method based on rigid sorting grids mounted to the bag of the purse seine has been developed (Misund and Beltestad, 1994; Beltestad and Misund, 1995). This method produces relatively sharp size selection of mackerel and saithe, and the fraction of mackerel over 600 g has been increased by about 10% in catches of up to 60 t.

However, an important aspect of size selection by fishing gear is the survival of the escapees. Recent survival experiments have shown that pelagic schooling fish such as herring are very sensitive to physical contact with the net in trawls, and high mortality has been observed for small herring escaping through trawl meshes or through sorting grids in trawls (Suuronen et al., 1996). Experiments with mackerel have shown that this species may suffer high mortality when crowded into small net cages (Lockwood et al., 1983).

We have therefore conducted a series of small scale and field experiments in order to quantify the survival of mackerel and saithe that escape through selection grids in purse seines. The field experiments were conducted by hired purse seiners on regular fishing grounds during the fishing season for mackerel and saithe in coastal waters off Norway.

2. Mackerel — small scale experiments

Small scale experiments on the survival of mackerel that escaped through a rigid sorting grid in a purse seine were conducted on fish that had been attracted to an artificial light and captured by a small purse seine in a fjord south of Bergen, Norway, on 17 August and 21 August 1993. In both sets, a small net cage was laced to the floatline of the purse seine. By hanging loads on the joined floatlines until about 3 m became submerged, the mackerel could swim from the purse seine and into the cage. The mackerel were kept in the two net cages until 1 day before the experiment.

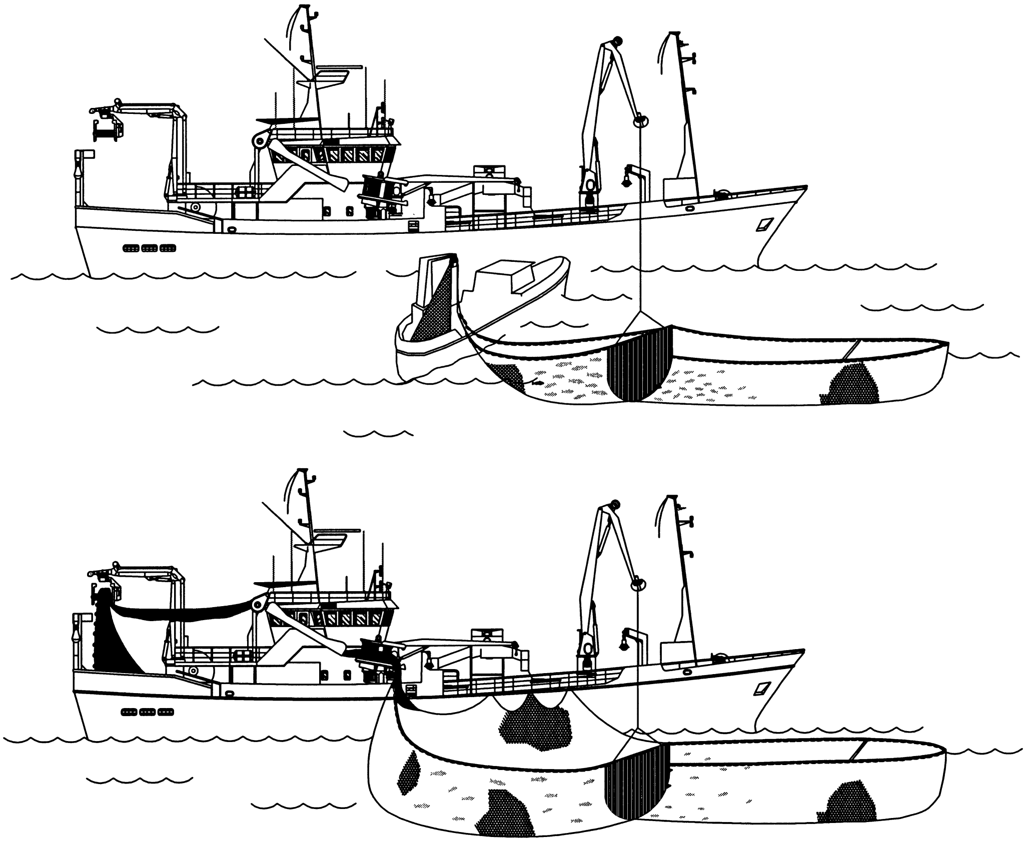

Fig. 1. Upper: small scale survival experiments with mackerel. Lower: field survival experiments with mackerel.

On 2 September, the caged mackerel were divided into six groups and transferred to six individual net cages. Three control groups of about 1000 fish each were kept in small cages (about 27 m^3), while three test groups of about 16 000, 24 000 and 40 000 fish, respectively, were kept in larger cages (500 m^3). The mackerel in the cages averaged 31.8 cm in length (S.D.=1.9 cm, N=92).

The survival experiments were conducted on 3 September 1993 from a chartered purse seiner (769 GRT) which was anchored in the bay where the mackerel cages were positioned. A 10 m^2 sorting grid of aluminium and stainless steel with a bar spacing of 42 mm was mounted at one end of a net pen, taken up by the deck crane of the vessel, and hoisted overboard. The pen was stretched out alongside the vessel, and a net pen with a test group towed up alongside the vessel and mounted on the other side of the grid. The grid was then lowered about 1 m into the sea, and the net pen with the test group was slowly drawn up by the power block of a small purse seiner (Fig. 1). As the mackerel became confined within a diminishing volume of the net pen, the mackerel seemed to panic, leapt out of the sea, or swam rapidly in random directions. Large numbers of fish then escaped quickly through the grid. The 42 mm spacing of the bars was so wide that nearly all the fish escaped between them. When the selection process was over, the net cages were released from the grid, and anchored in the bay near the control groups. The same procedure for the selection experiments was applied to all three test groups.

Both the test and control groups were kept in the cages for about 1 month, and mortality was checked twice a week by hauling up the bottom of the cages so that dead fish could be picked out with a hand brailer.

3. Mackerel — field experiments

In order to conduct realistic survival trials with a rigid selection grid in mackerel purse seines, we searched for mackerel schools close to the coast of western Norway using a chartered purse seiner (769 GRT) in August–September 1993, 1994 and 1995. On 15 August 1993 at about 06:00 in the morning a school of about 20 t of mackerel was captured about 10 nautical miles off Sotra, western Norway (Fig. 2). The mackerel in the catch averaged 38.2 cm in length (S.D.=2.9 cm, N=111), and was kept in the bag of the purse seine alongside the vessel. A 25 GRT fishing vessel then towed the purse seiner sideways at a speed of less than 0.5 m s^{-1} (1 kn) for about 13 h to a sheltered position in a bay inshore. A rather strong northerly current forced the vessels north-east (Fig. 2, experiment A) during the tow.

When the towing operation of the purse seiner was completed, a control group was transferred from the purse seine to a large net pen (about $25\times10\times10$ m^3) attached to the floatline. The transfer was made possible by mounting loads to the joined floatlines of the purse seine and the pen until about 3 m of it became submerged so that the mackerel could swim directly from the purse seine into the net pen. When

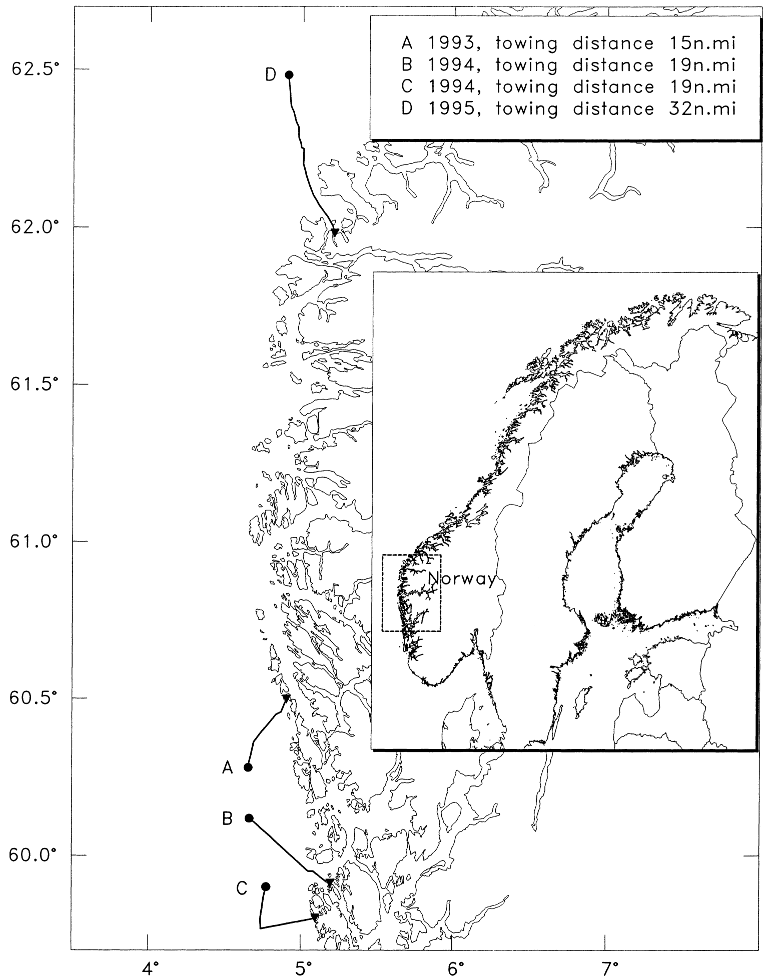

Fig. 2. (A) Catch (dot) and mooring positions (triangle) of the 1993 field experiments; (B) catch (dot) and mooring positions (triangle) of the first 1994 field experiment; (C) catch (dot) and mooring positions (triangle) of the second 1994 field experiment; (D) catch (dot) and mooring position (triangle) of the 1995 field experiment.

a suitable number of control fish had been transferred, the net pen was released from the purse seine and attached to the towing vessel by a rope of about 50 m in length.

The breast of the purse seine was then brought on deck by the crane. A 10 m^2 metal selection grid with 42 mm bar spacing was attached to the breast of the purse seine as described by Misund and Beltestad (1994). A large net pen (about $25\times10\times10$ m^3) was then stretched out from the bow of the vessel and mounted on the outer side of the grid by an 8 mm twisted line. The grid was then attached to the crane, the net released from the rail, and the grid with the bunt and the net pen attached hoisted carefully overboard. The grid was lowered in the sea until most of it was submerged, and the net pen was stretched out towards the bow alongside of the vessel. The purse seine was then hauled in, and when the drying of the rest of the catch started, the grid formed a ''wall'' in the bunt (Fig. 1). During drying of the catch, the mackerel ''panicked'', leaped out of the water, and swam at burst speed in random directions and against the net wall. Those which encountered the grid, and escaped through the bars, swam fast into the attached net pen. This selection process was stopped after about 10 min when a sufficient number of fish had escaped into the attached net pen. The grid was then hoisted out of the sea and released from the net pen containing the experimental group and the purse seine. The net pen containing the experimental group was then attached to the net pen with the control group, and both pens were anchored in the bay. The mackerel in the control (7590 fish) and experimental groups (2980 fish) were kept in the pens for about 1 month, and the mortality in both net pens was checked once a week.

In 1994, the same purse seiner was once again chartered for survival experiments, and a catch of 10 t of mackerel was taken about 10 nautical miles offshore on 28 August at 21:00. As in the previous year experiment, the mackerel were kept in the bag of the purse seine off the side of the vessel. A northern strong breeze forced the vessel south-east at a speed of about 0.5 m s^{-1} (1 kn), and on the following day at 17:00 the vessel had reached a sheltered position (Fig. 2, experiment B). An auxiliary vessel towed the purse seiner a few nautical miles further inshore, and a similar survival experiment as in 1993, using the metal grid in the purse seine, was conducted. Mortality in the control and experimental groups was checked twice during about 1 week of storage.

A new catch of about 5 t of mackerel and horse mackerel was taken about 10 nautical miles offshore on 31 August at 14:00, and kept in the purse seine bag off the side of the vessel. The mackerel in the catch averaged 35.6 cm in length (S.D.=2.9 cm, N=170), and the horse mackerel averaged 33.1 cm (S.D.= 1.9 cm, N=79). The vessel drifted southwestwards in a rather strong current. The sea was calm, and we decided to conduct the survival experiment at sea. As in the two previous experiments, a control group was taken by allowing fish to swim from the purse seine bag and directly into an attached net pen, and an experimental group was obtained by collecting fish that escaped through the grid in another attached net pen. These net pens were sufficiently robust to tolerate towing offshore, and measured $20\times10\times10$ m^3. When the experiment was finished on 1 September at 05:00, both pens were towed slowly (speed <0.5 m s^{-1}) by an auxiliary vessel towards the coast (Fig. 2, experiment C). The net pens were anchored in a sheltered position inshore at 22:00 on the same day. The fish were kept in the pens for about 1 month, and their mortality checked once a week. When the fish in the pens were counted at the end of the storage period, it was found that the control group consisted of a total of 1185 mackerel and 557 horse mackerel. The experimental group consisted of a total of 305 mackerel and 1119 horse mackerel.

In order to conduct further survival experiments another purse seiner (702 GRT) was hired in the 1995 season. On 2 September, a catch of about 50 t of mackerel was taken about 15 nautical miles northwest of Stadt at about 19:00 (Fig. 2, experiment D). The sea was calm, and control and experimental groups were taken from the catch, using the same procedure and the same net pens as in the second experiment in 1994. The mackerel in the catch averaged 35.7 cm in length (S.D.=3.0 cm, N=92) and 436 g (S.D.=130 g, N=92). Because of the larger size of the catch, much larger numbers of fish were taken in both groups, and we allowed the selection process to last for 30 min before releasing the attached net pen with the experimental group from the grid. The experiment finished on 3 September at 01:00, and the net pens were towed southwards with the current for about 10.5 h by the purse seiner at a speed of about 0.5 m s^{-1} (1 kn). An auxiliary vessel towed the net pens for a further 11.5 h at the same speed until the anchoring position was reached at 23:00. The fish were kept in the pens for about 1 month, and their mortality checked once a week. The experimental group consisted of about 13 000 fish (5900 kg) and the control group of about 29 000 fish (12 400 kg).

4. Saithe — field experiments

Two parallel survival trials using rigid selection grids in saithe purse seines were conducted near the island of Bømlo, south of Bergen, in April 1994, and three in the Altafjord on the Finnmark coast in August 1995. The methods used were approximately the same as for the survival field experiments for mackerel. The size of the vessel and the grid were smaller and the net pens were moored in the vicinity of the area where the catch had been made.

The survival trials in 1994 were carried out with the small research vessel F/F "Fjordfangst" (14.7 m LOA). The grid, designed for small saithe purse seine, was made of glass fibre reinforced polyester (GRP), and measured $1\times2\ m^2$, with an inter-bar distance of 30 mm. The saithe that escaped through the grid were collected in a net pen ($3\times3\times3\ m^3$) and stored for 1 month in order to estimate their long-term survival rates.

In August 1995, three new survival trials were carried out with a chartered coastal purse seiner (22.77 m LOA) off the coast of Finnmark in northern Norway. The grid used during these trials consists of an aluminium tubing frame and 15.5 mm GRP bars with an inter-bar distance of 40 mm. The overall dimensions of the grid were $2\times2\ m^2$, and its weight was about 60 kg. One control and one experimental group were used in each trial. The net pens used measured $30\times6\times5\ m^3$, and the fish were stored for about 1 week in order to quantify their mortality.

5. Results

The mackerel in the small scale experiment survived being confined within the small volume of a net pen and escaping through the selection grid. Total mortality in the three experimental and three control groups was less than 2% (Table 1).

In the 1993 field experiment, there was substantial mortality in both the experimental and control groups during the first 6 days of storage after the selection experiment (Fig. 3). Mortality then levelled off, and survival after about 1 month of storage was 36% in the experiment group and 56% in the control group. In the first experiment in 1994, the fish were probably seriously injured by being kept in the purse seine during the drift inshore in rather rough seas, and all the fish in both the experimental and control group were dead after 6 days of storage. The second experiment was conducted in a calm sea, and most of the mackerel (95%) in the control group had survived after 1 month of storage. In the experimental group, there was 62% survival during the first week after the selection experiment, and the final survival rate of this group was 56% after 1 month of storage (Fig. 4). There was no mortality among the horse mackerel, in either group. The results of the 1995 experiment were rather similar to those from 1993 (Fig. 5). During the first week after the experiment there was substantial mor-

Table 1
Small scale survival experiments for mackerel

	Control I	Experiment I	Control II	Experiment II	Control III	Experiment III
No. of fish at start	4000	40000	4000	16000	4000	24000
Day 3	–	–	5	3	–	4
Day 4	4	126	7	7	7	29
Day 10	9	277	22	9	3	110
Day 13	5	109	8	8	11	37
Day 20	21	118	27	29	–	65
Day 26	5	15	3	16	8	25
Total no. of fish dead	44	645	72	72	29	270
Total mortality (%)	1.1	1.6	1.8	0.5	0.7	1.1

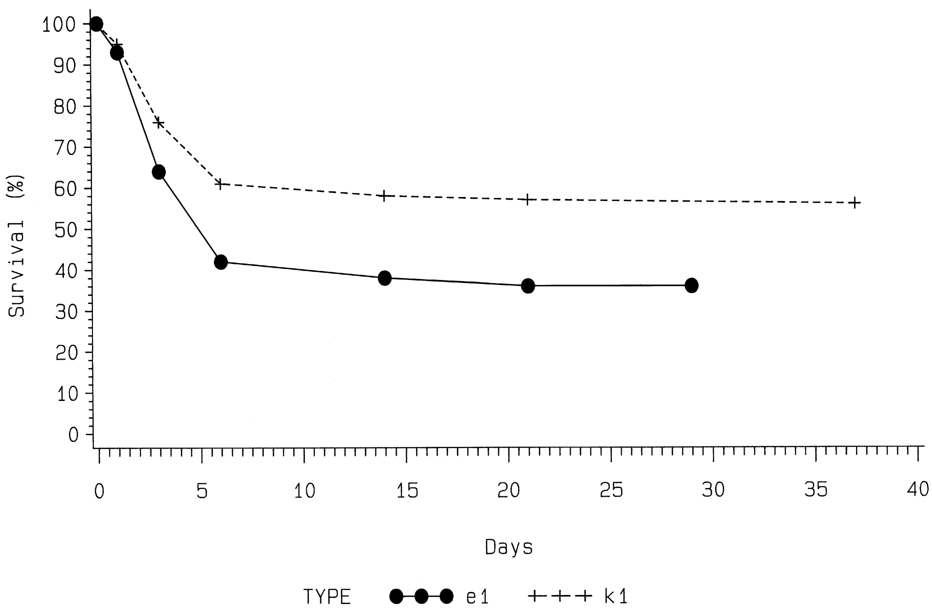

Fig. 3. Survival in the 1993 field experiment (e1: experimental group, k1: control group).

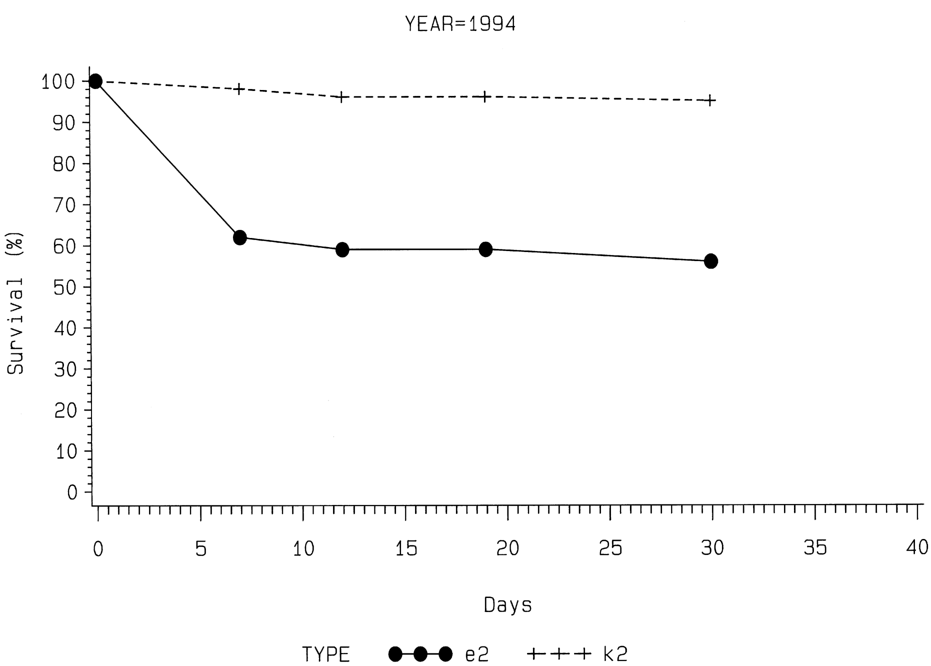

Fig. 4. Survival in the second 1994 field experiment (e2: experimental group, k2: control group).

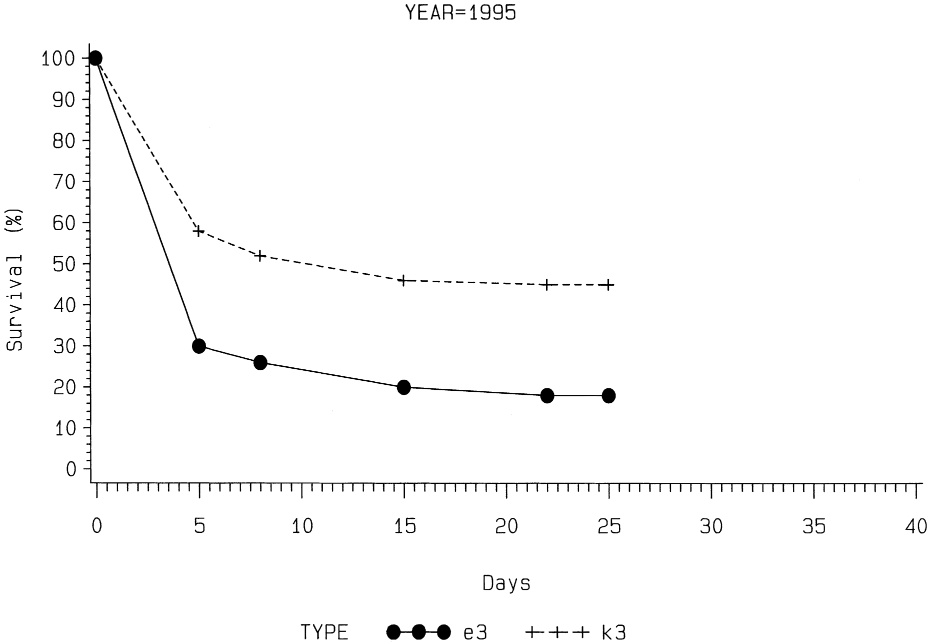

Fig. 5. Survival in the 1995 field experiment (e3: experimental group, k3: control group).

tality in both the experimental and control groups, and after 25 days of storage the final survival rate was 18% in the experimental group and 45% in the control group.

The relative mortality difference between the control and experimental groups developed similarly in the 1993, the second 1994 and the 1995 experiments (Fig. 6). During the first 6 days of storage, mortality was generally higher in the experimental group, but the relative mortality then stabilized at a different level for each of these three experiments. The largest difference in relative mortality between the control and experimental group was found in the second 1994 experiment, while the lowest was found in the 1993 experiment.

The dead fish decayed quickly in the net pens, and accurate measurements of the lengths of the dead fish were made only in the 1993 experiment. These measurements revealed no length-dependent mortality during the month of storage after the selection experiment, either in the experimental or in the control group (Fig. 7).

The results of the five survival trials with saithe showed zero or insignificant mortality, in both the control group and among the fish that escaped through the grid, even after 1 month of storage (Table 2).

Table 2
Survival experiments for saithe

Trial No.	Area	Period	Vessel	Control group			Experimental group			Storage time (days)
				Length (cm)	No. of fish	Survival (%)	Length (cm)	No. of fish	Survival (%)	
1	Bømlo	April 1994	"Fjordfangst"	26–41	10000	100	26–34	400	100	30
2	Bømlo	April 1994	"Fjordfangst"	26–41	10000	100	26–34	30	97	30
3	Altafjord	August 1995	"Nargtind"	38–54	1874	100	32–46	1815	100	7
4	Altafjord	August 1995	"Nargtind"	38–54	592	100	32–46	2654	100	6
5	Altafjord	August 1995	"Nargtind"	38–54	2997	100	32–46	2949	100	6

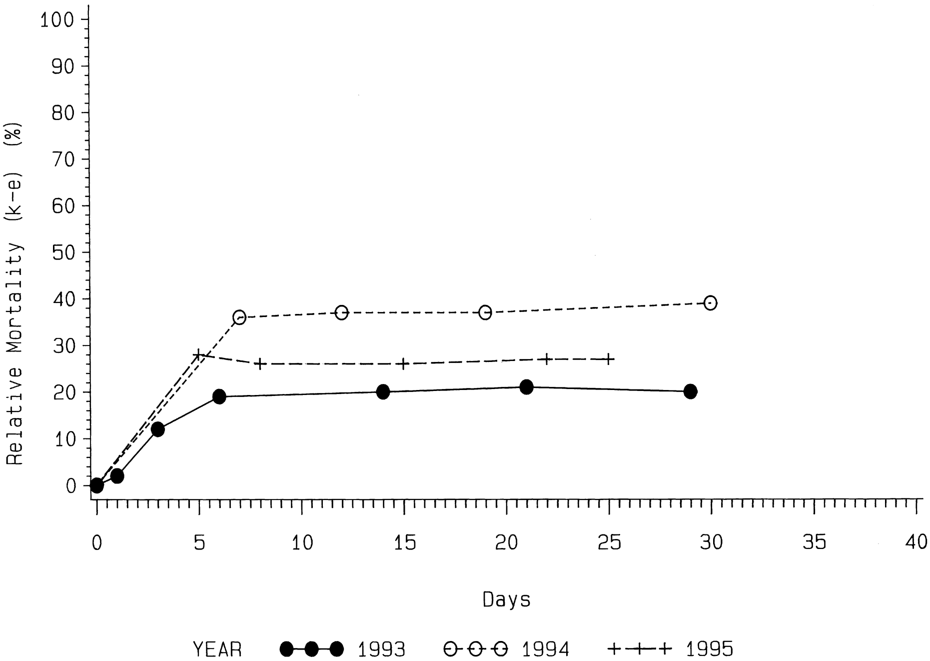

Fig. 6. Relative mortality of control (k) and experimental (e) groups in the field experiments.

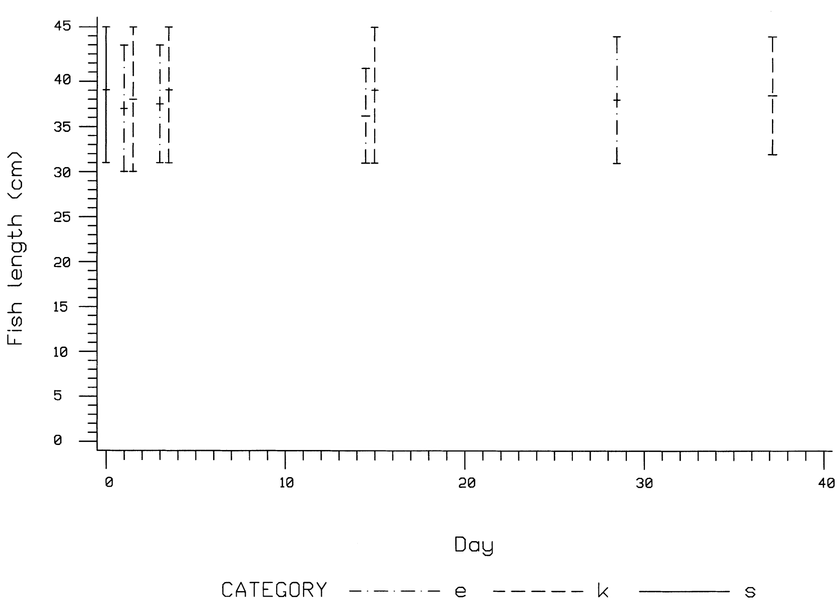

Fig. 7. Length distribution of the fish in the purse seine before the experiment (s) and of the dead fish in the experimental (d) and control (k) groups.

6. Discussion

The results of the small scale and field experiments on the survival of mackerel that escaped through a metal selection grid in a purse seine are conflicting. The mackerel in the small scale experiment tolerated the selection process fairly well, and the total long-term survival rates in both the experimental and control groups were better than 98%. In the field experiment the highest total long-term survival rate for both the experimental and control was obtained in the second 1994 experiment in which 56 and 95% of the experimental and control groups, respectively, survived. In the 1993 experiment, 36 and 56% of the experimental and control groups, respectively, survived. Similarly, only 18 and 45% of the experimental and control groups survived in the 1995 experiment.

The substantial mortality in the experimental group and two of the control groups in the field experiments suggest that the mackerel in the field experiments were exposed to more severe physical stress and injuries than the fish used in the small scale experiments. The mackerel in the small scale experiment were on average 3.8–6.4 cm smaller than the fish in the field experiments, and they escaped fairly quickly through the grid when confined within the small volume of the net pen. Nevertheless, the largest experimental group in the small scale experiment was confined in the net pen for about 10 min before the selection process was completed. The experimental groups in the 1993 and second 1994 field experiments were exposed to the selection process for a similar period of time but these groups still suffered substantial long-term mortality.

Another major difference was that the mackerel in the small scale experiment had become accustomed to being confined in the net pen for about 2 weeks before the survival experiment took place. Even so, the fish were obviously stressed when confined within the small volume of the net pen, and individuals frequently leapt out of the water and up along the net wall. Nevertheless, the mackerel in the field experiment, which were probably experiencing net gear for the first time, showed a more dramatic panic reaction when confined in the bunt of the purse seine. Most of these fish swam at around at burst speed and leapt frequently out of the water and up along the net wall to such an extent that the catch seem to "boil". It is probable that this more panicky reaction of the mackerel in the wild resulted in more severe stress and skin injuries due to physical contact with the net, which in turn resulted in substantial long-term mortality.

The mackerel in the field experiments were towed in the net pens for from 15 to 30 nautical miles to an anchoring position either before or after the selection experiments. In two experiments the mackerel were transported to a sheltered position in the bag of the purse seine before the selection experiment (1993 and first 1994 experiment), and in the other two experiments (second 1994 and 1995 experiment) they were towed in net pens to a sheltered position after the selection experiment had been conducted at sea. There is no doubt that this long transport could have caused severe skin injuries to the fish, which might have resulted in substantial mortality in both the control and experiment groups. This was clearly the case in the 1993 and 1995 experiments, in which only 56 and 45% of the control groups survived, and especially in the first 1994 experiment when the complete control and experiment groups died after 6 days of storage. Most fish had developed a blue colour at the time of anchoring the net pens for storage, a sign of severe skin injuries (see Lockwood et al., 1983), which they probably suffered in the bag of the purse seine in the rather rough seas while the vessel was drifting for about 15 nautical miles to a sheltered inshore position.

In spite of being towed for about 10 nautical miles in the net pen in the open sea, about 95% of the control group survived in the second 1994 experiment. On that occasion the sea was calm and the number of fish in the control and experimental groups were relatively small, so that the careful towing probably caused only rather marginal stress and mild skin injuries to the fish. However, survival in the corresponding experimental group was only 56%, suggesting that the mackerel in the wild suffered severe stress and skin injuries during the selection process in the purse seine. This interpretation is also supported by the fact that in the 1993 and 1995 experiments, mortality in the experimental groups was 20–27% higher than in the corresponding control groups.

Due to the high survival rate of the control group (95%), we suggest that the most realistic experiment was the second 1994 experiment, in which 56% of the experimental group survived. Mackerel escaping out of purse seines through a similar selection process as in our experiments will therefore suffer a long-term mortality rate of at least about 40%. In real capture situations, with larger catches in heavy seas, the long-term mortality rate of mackerel that escape from the purse seine through a similar selection process may be even higher. To increase the proportion of mackerel greater than 600 g in the catches by about 10%, about 35% of the catch needs to be sorted out through the selection grid (Beltestad and Misund, 1995). The Norwegian mackerel quota, which is fished almost exclusively by purse seiners, was about 200 000 t during the period 1992–1996. This quota was taken by about 2000 purse seine catches of an average size of about 100 t. Assuming that selection grids were used in this fishery, and about 35% of each catch was sorted out, and about 40% of the escapees suffered long-term mortality, then the selection grid would have caused an extra fishing mortality of about 43 000 t. These considerations suggest that using the grid in the Norwegian purse seine fishery would increase the fishing mortality on the Eastern Atlantic mackerel stocks that are fished by Norwegian purse seiners by about 18%. The survival results of our field selection experiments indicate that the grid may induce a too high extra fishing mortality to be recommended for use in commercial purse seining for mackerel. The saithe appeared to tolerate the selection process much better than the mackerel, and almost all the escaped saithe survived. Rigid grids may therefore be recommended as a method for size selection in the purse seine fishery for saithe.

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