

**SURVIVAL OF MACKEREL AND SAITHE
ESCAPING THROUGH SORTING GRIDS IN PURSE SEINES**

by

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Abstract

Technology for 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 escaping fish. We have conducted a series of mesoscale experiments where penned fish were forced through rigid grids and into new storing net pens to quantify the survival of mackerel and saithe. These experiments showed insignificant mortality of both mackerel and saithe. Full scale experiments during mackerel purse seining off western Norway and saithe purse seining in fjords in western and northern Norway have also been conducted. During these experiments control groups were established by transferring parts of the catch gently from the purse seine to attached net pens. Experiment groups were established by collecting fish escaping through the selection grids in attached net pens. The net pens were then towed up to 30 nautical miles for anchoring inshore. In the mackerel experiments, up to 95% of the fish in the control groups and up to 60% in the experiment groups were alive one month after the experiments. This indicates that the size selection process in mackerel purse seining induce too high mortality to be recommended in 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.

Introduction

The introduction of rigid sorting grids has greatly improved the selection properties of trawls, both with regard to species and size selection (Valdemarsen and Isaksen, 1994). In shrimp trawling, mounting of the rigid Nordmøre grid in the extension piece of the trawl successfully sort out bycatch of fish that is too large to pass between the bars of the grid (Isaksen et al., 1992; Bradhurst, et al., 1996). In bottom trawling for gadoids, mounting of a rigid sorting grid improves the size selection properties of the trawl (Larsen and Isaksen, 1993). Compared to size selection through meshes, the selection curves of rigid grids are steeper, and the selection range (L_{75} - L_{25}) narrower. Field experiments have shown that gadoids like cod, haddock and saithe survive being sorted out through trawls via rigid sorting grids (Soldal et al., 1993; Jakopsen et al., 1992), and rigid grids can therefore be applied to optimize the size composition in trawl catches of these species.

Purse seining in Norway is usually conducted on schools or dense shoals, and the catches consist normally of a single species with a rather narrow length distribution. The uniform catches during purse seining on schools arise because of the natural selection mechanisms with regard to species and size distribution in formation of fish schools (Pitcher and Parrish, 1993). Still, there is an interest for methods for size selection during mackerel (*Scomber scombrus*) and saithe (*Pollachius virens*) purse seining by Norwegian vessels. In the mackerel fishery this interest arise because fish above 600 grams are paid about twice that of fish less than 600 grams when delivered for the Japanese market. The Norwegian mackerel fishery which take place off the coast of western Norway and in the North Sea in August - November, is regulated by a total quota that is split into definite vessel quotas. For the fishermen there is therefore an economic incitement for methods to increase the proportion of fish above 600 grams in the catches.

In the saithe purse seining which is located in fjords and coastal waters in western and northern Norway, the incitement for size selection is twofold. The fishery is regulated by a total quota and a minimum landing size that at present is 32 cm in western Norway and increasing gradually for definite regions northwards to 40 cm in northern Norway. Occasionally, there may be a substantial fraction of fish under the legal landing size in the catches, and if the fraction of fish under the legal landing size is more than 10% the catch has to be released. With a continued high

fraction of undersized fish in the catches, the Director of Fisheries normally close the actual area for fishing until the situation improve. A method to sort 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-dependant prise differentiation so that fish larger than 700 grams are paid about twice that of fish less than 700 grams.

By use of an adjustable selection grid developed for size sorting of farmed salmon, Misund and Skeide (1992) conducted successful experiments on sorting purse-seine-captured saithe according to size. The saithe were stored in net pens and sorted according to size from one net pen to another by forcing the fish towards the grid that was mounted between the pens. The grid gave a sharp sorting with a selection range of just 5 cm, and there was no mortality of the fish sorted through the grid. Recent experiments, in 1996, gave as narrow selection range as 2.5 cm and a sorting capacity of 2.5 tonnes per hour. 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 give rather sharp size selection of both mackerel and saithe, and the fraction of mackerel over 600 gram was increased by about 10% in catches up to 60 tonnes.

However, an important aspect of size selection in fishing gears is the survival of the escapees. Recent survival experiments showed that herring are very fragile to physical contact with the net in trawls, and nearly total mortality has been observed for herring escaping through trawls or through sorting grids in trawls (Suuronen et al., 1996). Experiments with mackerel have also shown that this species may suffer high mortality when crowded in net cages (Lockwood et al., 1983). We have therefore conducted a series of mesoscale and field experiments to quantify the survival of mackerel and saithe escaping through selection grids in purse seines. The field experiments were conducted by hired purse seiners and carried out on regular fishing grounds during the fishing season for mackerel and saithe in coastal waters off Norway.

Mackerel - Mesoscale experiments

Mesoscale experiments on the survival of mackerel escaping through a rigid sorting grid in a purse seine were conducted on fish that had been attracted to artificial light and captured by a small purse seine in a fjord south of Bergen, Norway, 17 and 21 August 1993. The mackerel were kept in two net pens until one day before the experiment. On 2 September, the penned mackerel were split in six groups that were transferred to six different net pens. Three control groups of about 1000 fish each were kept in small net pens, while three test groups of about 16 000, 24 000 and 40 000 fish, respectively, were kept in larger pens. The mackerel in the pens averaged 31.8 cm (SD = 1.9 cm, N = 92) in length and 262 g (SD = 55.5 g, N = 92) in weight.

The survival experiments were conducted 3 September 1993 from the hired purse seiner M/V "Ligrunn" (769 GRT), which were anchored in the bay where the mackerel pens were positioned. A 10 m² sorting grid of aluminium frame and bars of stainless steel with an inter-bar distance of 42 mm was mounted to one end of a net pen, taken in the deck crane of the vessel and hoisted overboard. The net pen was stretched out along the side of the vessel, and a net pen with a test group towed up along the side of the vessel and mounted to the other side of the grid. The grid was then lowered about 2 m in the sea, and the net pen with the test group taken in the power block of a small purse seiner and dried up slowly (Fig. 1). When being confined in a smaller and smaller volume of the net pen, the mackerel seem to panic, leapt out of the sea, or swam fast in occasional directions. Large amounts of fish then escaped quickly through the grid. The 42 mm inter-bar distance was so wide that nearly all fish escaped through. When the selection process was over, the net pens were released from the grid, and the net pens with the fish towed gently ashore and anchored. The same procedure for the selection experiments was applied to all three test groups.

Both the test and control groups were kept in the net pens for about one month, and the mortality was checked twice a week. Then the bottoms of the pens were dried up so that the dead fish could be picked out with a hand brailer and counted.

Mackerel - Field experiments

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 by a hired purse seiner in September 1993 - 1995. On 15 August 1993 at about 06.00 in the morning, a school of about 20 tonnes of mackerel was captured by M/V "Ligrunn" about 10 nautical miles off Sotra, western Norway (Fig. 2). The bunt of the purse seine was not hauled in so that the mackerel was kept in a large net "bag" to the side of the vessel. M/V "Ligrunn" was then towed sideways to a sheltered position inshore at a speed of less than 0.5 m s^{-1} (1 knot) for about 13 hours by a 25 GRT fishing vessel. Rather strong northwards current forced the vessels north-east. When the towing was stopped, a control group was transferred to a large net pen (about 25 x 10 x 10 m) attached to the floatline of the purse seine. The transfer was made possible by mounting loads to a piece of the joined floatline of the purse seine and the pen so that the mackerel could swim directly from the purse seine to the net pen. When an appropriate quantity was transferred, the net pen was released from the purse seine and attached to the towing vessel by a rope of about 50 m. The breast of the purse seine was then brought on deck by the crane and a 10 m^2 metal selection grid with 42 mm inter-bar spacing attached as described by Misund and Beltestad (1994). A large net pen (about 25 x 10 x 10 m) was then stretched out from the bow of the vessel and laced to the outer side of the grid. The grid was then mounted 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 along the side 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. 3). 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 who 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 an appropriate quantity of fish had escaped into the attached net pen. The grid was then hoisted out of the sea, and the net pen with the experiment group and the purse seine released. The net pen with the experiment group was then attached to the net pen with the control group, and both pens were anchored inshore next morning at 08:00. The mackerel in the control and experiment group was kept in the pens for about one month, and as in the mesoscale experiment, the mortality in both net pens were checked twice a week. After the storage was ended, counting of the surviving fish

revealed that the control group consisted of 7590 mackerel, and the experiment group of 2980 mackerel.

Next autumn, M/V "Ligrunn" was again hired for the survival experiments, and a catch of 10 tonnes of mackerel were taken about 10 nautical miles west of Marsteinen on 28 August at 21:00. As in last year's experiment, the purse seine was not hauled back completely so that the mackerel were kept in a large bag out from 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 knot), and the next day at 17:00 the vessel had reached a sheltered position in Selbjørnsfjorden (Fig.4). An assisting vessel towed the purse seiner a few nautical miles further inshore, and a similar survival experiment by use of the metal grid in the purse seine as in 1993 was conducted. The mortality in the control and experiment groups was checked twice until a definite survival result was evident after about one week storage.

A new catch of about 5 tonnes of mackerel and horse mackerel were taken about 10 nautical miles west of Slåtterøy on August 31st at 14:00. The catch was kept in the bag out from the side of the vessel. The vessel drifted south-westwards in a rather strong current, and an assisting vessel was unable to tow the vessel towards the coast. However, the sea was calm, and we decided to conduct the survival experiment out at sea. As in the two preceding experiments, a control group was taken by letting fish swim from the purse seine bunt and directly into an attached net pen, and an experiment group was obtained by collecting fish that escaped through the grid into an another attached net pen. These net pens were dimensioned to tolerate towing offshore, and measured 20 x 10 x 10 m. When the experiment was finished on 1 September at 05:00, both pens were towed slowly (speed $< 0.5 \text{ m s}^{-1}$) by the assisting vessel towards the coast (Fig. 5). The net pens were anchored in a sheltered position inshore at 22:00 the same day. The fish were kept in the pens for about one month, and the mortality checked twice a week. When counting all the fish in the pens at the end of the storage, it was found that the control group consisted of totally 1185 mackerel and 557 horse mackerel. The experiment group consisted of totally 305 mackerel and 1119 horse mackerel.

To conduct further survival experiments, M/V "Grete Kristin" was hired in the 1995 season. On 2 September, a catch of about 50 tonnes of mackerel was taken about 15 nautical miles north west

of Stadt at about 19:00 (Fig. 6). The sea was calm, and a control and an experiment group were taken from the catch by the same procedure and the same net pens as used in the second experiment in 1994. Because of the larger catch size, a much larger number of fish was taken in both groups, and we let the selection process last 30 min before releasing the attached net pen with the experiment group from the grid. The experiment was finished on 3 September at 01:00, and the net pens were towed southward with the current for about 10.5 hours by the purse seiner at a speed of about 0.5 m s^{-1} (1 knot). An assisting vessel towed the net pens for further 11.5 hours at the same speed until the anchoring position was reached at 23:00. The mackerel in the catch averaged 35.7 cm (SD = 3.0 cm, N = 92) and 436 g (SD = 130 g, N = 92). The experiment group consisted of about 13 000 fish (5900 kg) and the control group of about 29 000 fish (12 400 kg).

Saithe - Field experiments

Two parallel survival trials with use of rigid selection grid in saithe purse seines were conducted at the island Bømlo, south of Bergen, in April 1994, and three in the Altafjord on the Finnmark coast in August 1995. The methods used are approximately the same as for the survival field experiments for mackerel, with the exception of size of the vessel and grid which are smaller and the fact that the net pens were moored in the vicinity of the catching area.

The survival trials in 1994 were carried out with the research vessel F/F "Fjordfangst" (14.7 m LOA). The grid, designed for small saithe purse seine, was made of Glassfibre Reinforced Polyester (GRP), measured 1x2 m, with an inter-bar distance of 30 mm. The saithe that escaped through the grid were collected in a net pen (3x3x3 m) and stored for one month in order to estimate the long term survival rate.

In August 1995 three new survival trials were carried out with the chartered purse seiner M/V "Nargtind" (22,77 m LOA) off the coast of Finnmark in northern Norway. The grid used during these trials was made of aluminium tubing frame and 15.5 mm GRP bars with an inter-bar distance of 40 mm. It measured 2x2 m and weighted about 60 kg. One control and one

experimental group were established for each trials. The net pens used measured 30x6x5 m and the fish were stored for about one week.

Results

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

In the 1993 field experiment, there was substantial mortality in both the experiment and control group during the first six days of storage after the selection experiment (Fig. 7). The mortality then levelled off, and the total survival after about one month 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 drifting inshore in rather rough sea, and all fish both in the experiment and control group were dead after six days of storage. The second experiment was conducted in calm sea, and most of the mackerel (95%) in the control group survived one month storage. In the experiment group, there was 38% mortality during the first week after the selection experiment, and total survival of the mackerel was 56% after one month storage (Fig. 8). There was no mortality of the horse mackerel neither in the control group, nor in the experiment group. The result of the 1995 experiment was rather similar to that in 1993 (Fig. 9). During the first week after the experiment there was substantial mortality both in the experiment and control groups, and after 25 days storage the total survival was 18% in the experiment group and 45% in the control group.

The relative mortality between the experiment and control groups developed about similar for the 1993, second 1994, and 1995 experiments (Fig. 10). The first six days of storage, the mortality was generally higher in the experiment group, but the relative mortality then stabilized at different levels for these three experiments. The largest relative difference in mortality was found in the second 1994 experiment (36%), while the lowest was found for the 1993 experiment (18%).

The dead fish decayed quickly in the net pens, and proper length measurement of the dead fish was only possible in the 1993 experiment when the net pens were examined twice a week. These measurements revealed no length dependent mortality during the one month storage after the selection experiment neither in the experiment group nor in the control group (Fig. 11).

The results from the five survival trials for saithe showed no or insignificant mortality, either for the control group or for the fish that had escaped through the grid, even after one month storage (Table 2).

Discussion

The results from the mesoscale and field experiments on survival of mackerel escaping through a metal selection grid in a purse seine are conflicting. The mackerel in the mesoscale experiment tolerated the selection process quite well, and the total long term survival in both the experiments and control groups was more than 98%. In the field experiments the highest total long term survival for both the experiment and control groups was obtained in the second 1994 experiment in which 56% and 95% of the fish in the experiment and control groups survived, respectively. In the 1993 experiment, 36% and 56% of the experiment and control groups survived respectively. Similarly, only 18% and 45% of the experiment and control groups survived in the 1995 experiment.

Compared to the high survival in the mesoscale experiments, the substantial mortality in the experiment and most of the control groups in the field experiments indicates that the mackerel in the field experiments were exposed to more severe physical stress and injuries than the mackerel in the mesoscale experiments. The mackerel in the mesoscale experiment were a few centimeter smaller than the fish in the field experiment and escaped rather quickly through the grid when confined in a small volume of the net pen. Still, the largest experiment group in the mesoscale experiment was confined in the net pen for about 10 minutes before the selection process was over. The experiment groups in the 1993 and second 1994 field experiments were exposed to the selection process for a similar time duration but still these groups suffered substantial long term mortality.

Another major difference was that the mackerel in the mesoscale experiment were accustomed to being confined in the net pen for about two weeks before the survival experiment took place. Still, the fish were markedly stressed when being confined in a small volume of the net pen, and individuals were frequently leaping out of the water and up along the net wall. Nevertheless, the mackerel in the field experiment which probably experienced net gear for the first time showed a more dramatic panic reaction when confined in the bunt of the purse seine. Most fish then bursted around and leaped frequently out of the water and up along the net wall to such an extent that the catch seems "boiling". It is probable that this more panic-like reaction of the mackerel in the wild resulted in more severe stress and skin injuries due to physical contact with the net which again resulted in substantial long term mortality.

The mackerel in the field experiments were transported from 10 to 30 nautical miles to the anchoring position of the storing pens before or after the survival experiments. In two experiments the mackerel were transported to a sheltered position in the bunt of the purse seine before the survival experiment (1993 and first 1994 experiment), and in the other two experiments (second 1994 and 1995 experiment) the mackerel were towed in net pens to a sheltered position after the survival experiment had been conducted at sea. Undoubtedly, this long transport may have imposed severe skin injuries to the fish which may have resulted in substantial mortality in both the control and the experiment groups. This was clearly the case in the 1993 and 1995 experiments in which only 56 and 45% of the control groups survived, respectively, and especially in the first 1994 experiments where the fish in both the control and the experiment groups died after six days of storage. Then most of the fish had attained a light blue colour which is a sign of severe skin injuries (Lockwood et al., 1983) after having been kept in the bunt of the purse seine in rather rough sea while the vessel was drifting about 15 nautical miles to a sheltered position inshore.

Despite being towed for about 10 nautical miles in a net pen in the open sea, about 95% of the control group survived in the second 1994 experiment. During this experiment the sea was calm and the number of fish in the control and experiment groups rather small, so that the careful towing probably imposed only rather marginal stress and skin injury on the fish. However, the survival in the corresponding experiment group was 56% only, which indicates that the mackerel in the wild become severely stressed and skin-injured during the selection process in the purse

seine. This is also supported by the fact that in the 1993 and 1995 experiments, the mortality in the experiment groups was 20 to 27% higher than in the corresponding control groups.

Due to the high survival in the control group (95%), we argue that the most realistic experiment was the second 1994 experiment in which 56% of the experiment group survived. Mackerel escaping out of purse seines through a similar selection process as in our experiments will therefore suffer a long term mortality of at least about 40%. In real capture situations with larger catches in rough sea, the long term mortality of mackerel escaping out of the purse seine through a similar selection process may be even higher. To increase the amount of mackerel > 600 grams in the catches, about 35% of the total catch has to be sorted out through the selection grid (Beltestad and Misund, 1995). The Norwegian mackerel quota which is fished nearly exclusively by purse seiners has been about 200 000 tonnes the last years. The quota has been taken by about 2000 purse seine catches of an average size of about 100 tonnes. Assuming that the selection grid was used in the fishery, and about 35% of each catch was sorted out, and about 40% of the suffered long term mortality, then the selection grid would have caused an extra fishing mortality of about 40 000 tones. These considerations indicate that using the grid in the Norwegian purse seine fishery will increase the fishing mortality on the Eastern Atlantic mackerel stock executed by Norwegian purse seiners by about 18%. According to our results regarding the selection properties and capacity of the grid in mackerel purse seines and the survival experiments, we therefore conclude that the grid will induce a too high extra fishing mortality to be allowed in commercial purse seining for mackerel.

The saithe seemed to tolerate the selection process much better than 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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Table 1. Mesoscale survival experiments for mackerel.

	Control I	Exp. I	Control II	Exp. II	Control III	Exp. III
Nos. of fish at start	4000	40000	4000	16000	4000	24000
Day 3	-	-	5	3	-	4
4	4	126	7	7	7	29
10	9	277	22	9	3	110
13	5	109	8	8	11	37
20	21	118	27	29	-	65
26	5	15	3	16	8	25
Total nos. dead	44	645	72	72	29	270
Total mortality (%)	1.1	1.6	1.8	0.5	0.7	1.1

Table 2. Survival experiments for saithe.

Trial no.	Area	Period	Vessel	Control group		Experimental group		Storing time after sorting (days)
				No. of fish	Survival (%)	No. of fish	Survival (%)	
1	Bømlo	April 94	F/F "Fjordfangst"	10000	100	400	100	30
2	Bømlo	April 94	F/F "Fjordfangst"	10000	100	30	97	30
3	Altafjord	August 95	M/V "Nargtind"	1874	100	1815	100	7
4	Altafjord	August 95	M/V "Nargtind"	592	100	2654	100	6
5	Altafjord	August 95	M/V "Nargtind"	2997	100	2949	100	6

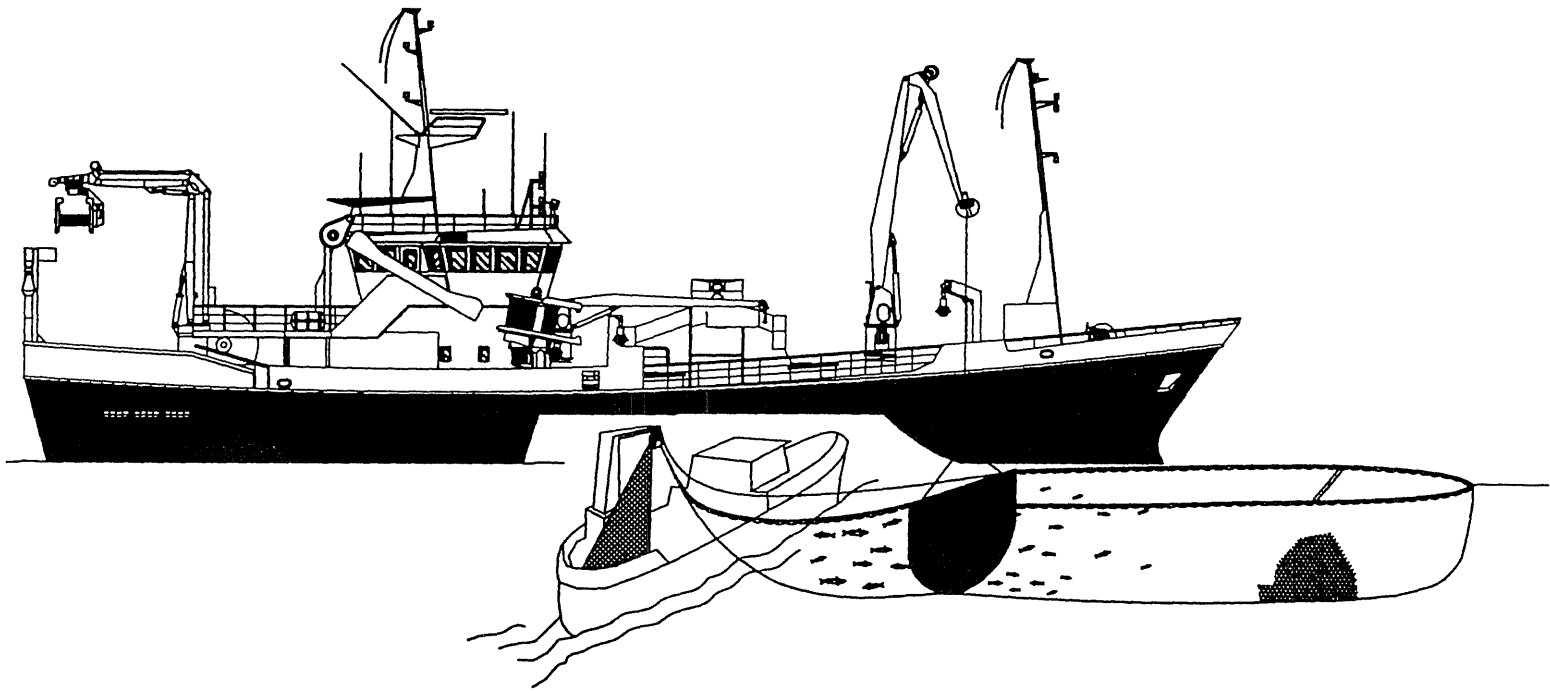


Figure 1. Mesoscale survival experiment with mackerel.

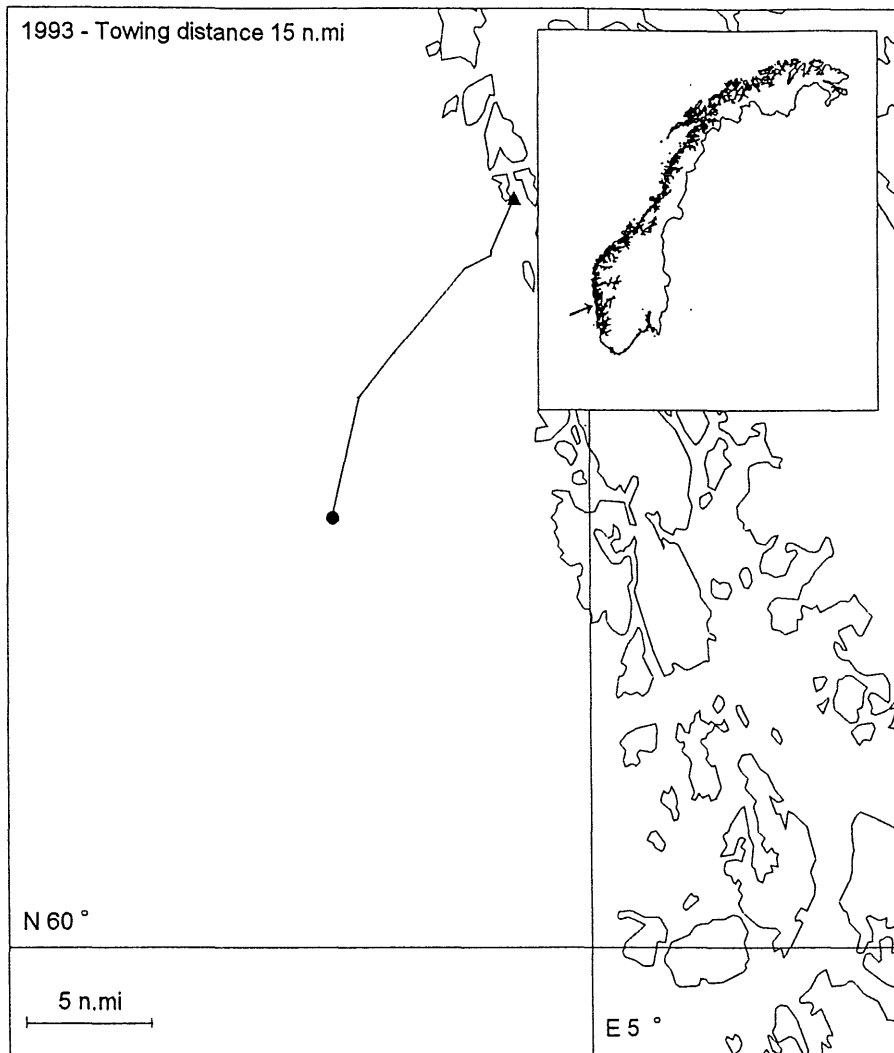


Figure 2. Catching (dot) and mooring position (triangle) of 1993 field experiments.

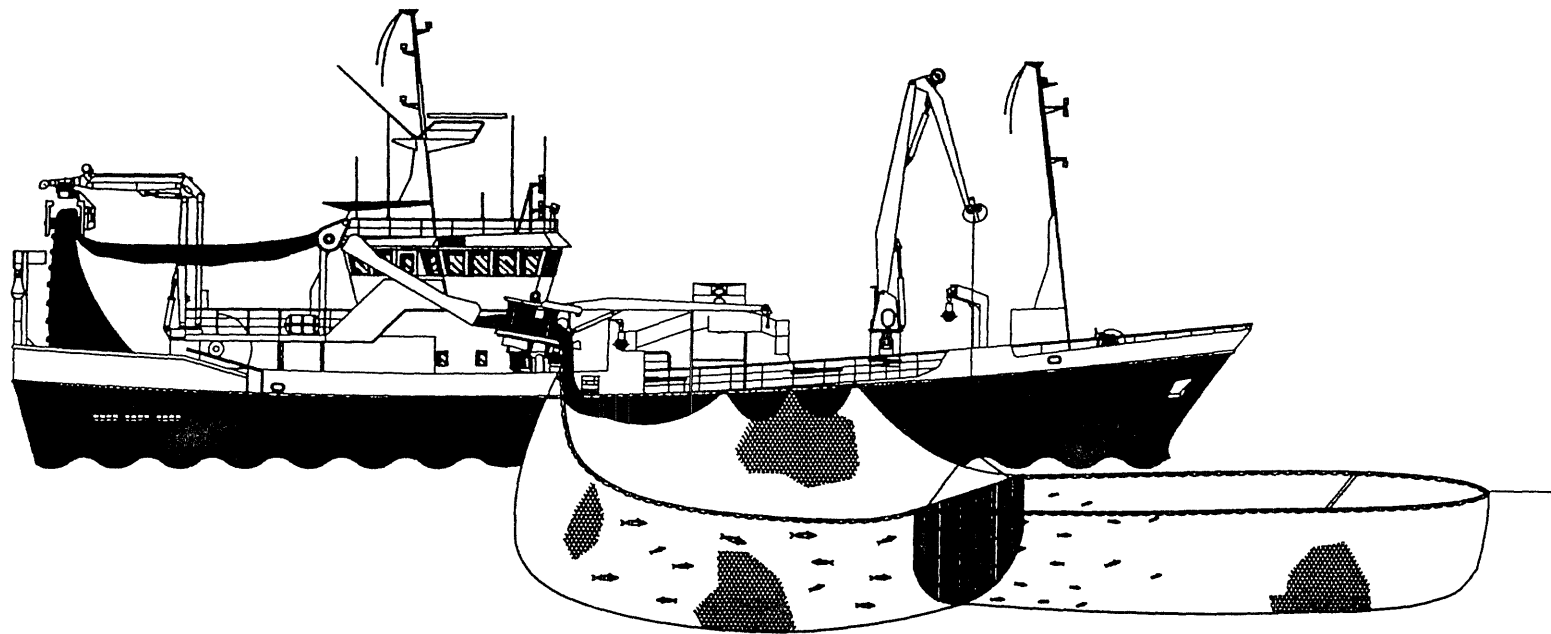


Figure 3. Field survival experiment with mackerel.

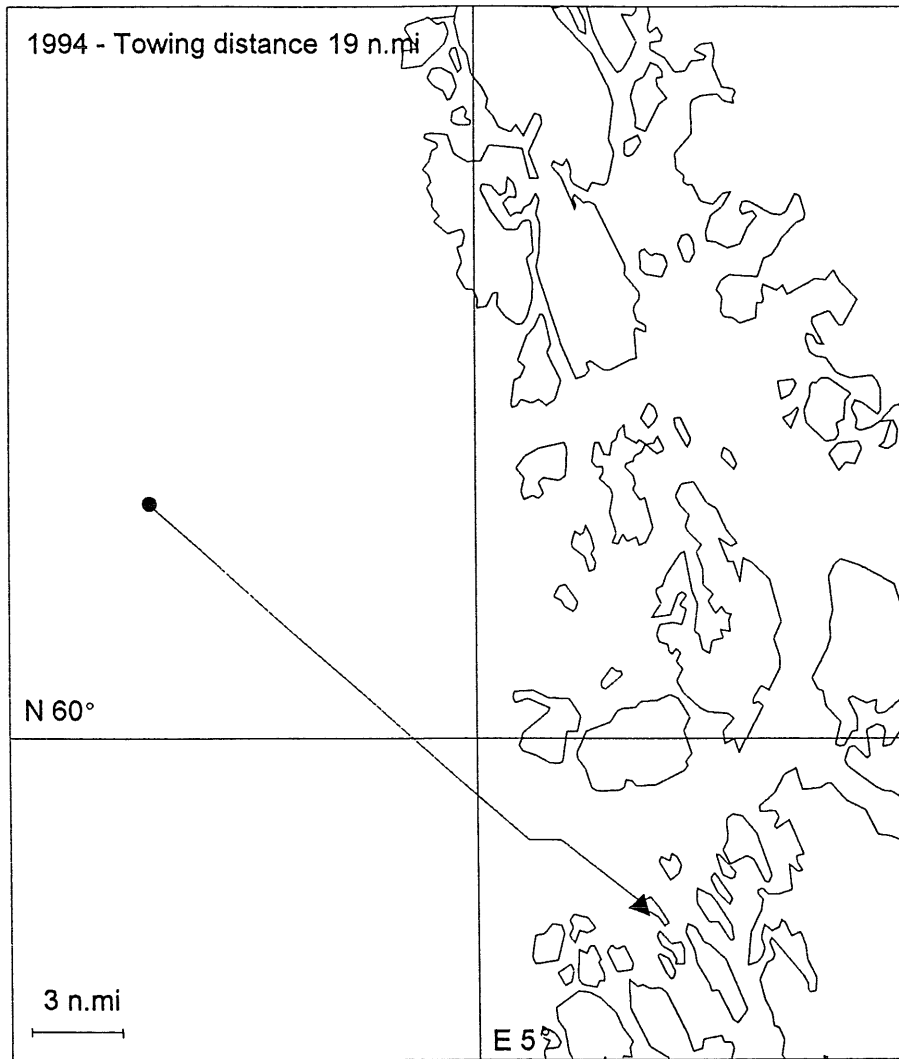


Figure 4. Catch (dot) and mooring position (triangle) of first 1994 field experiment.

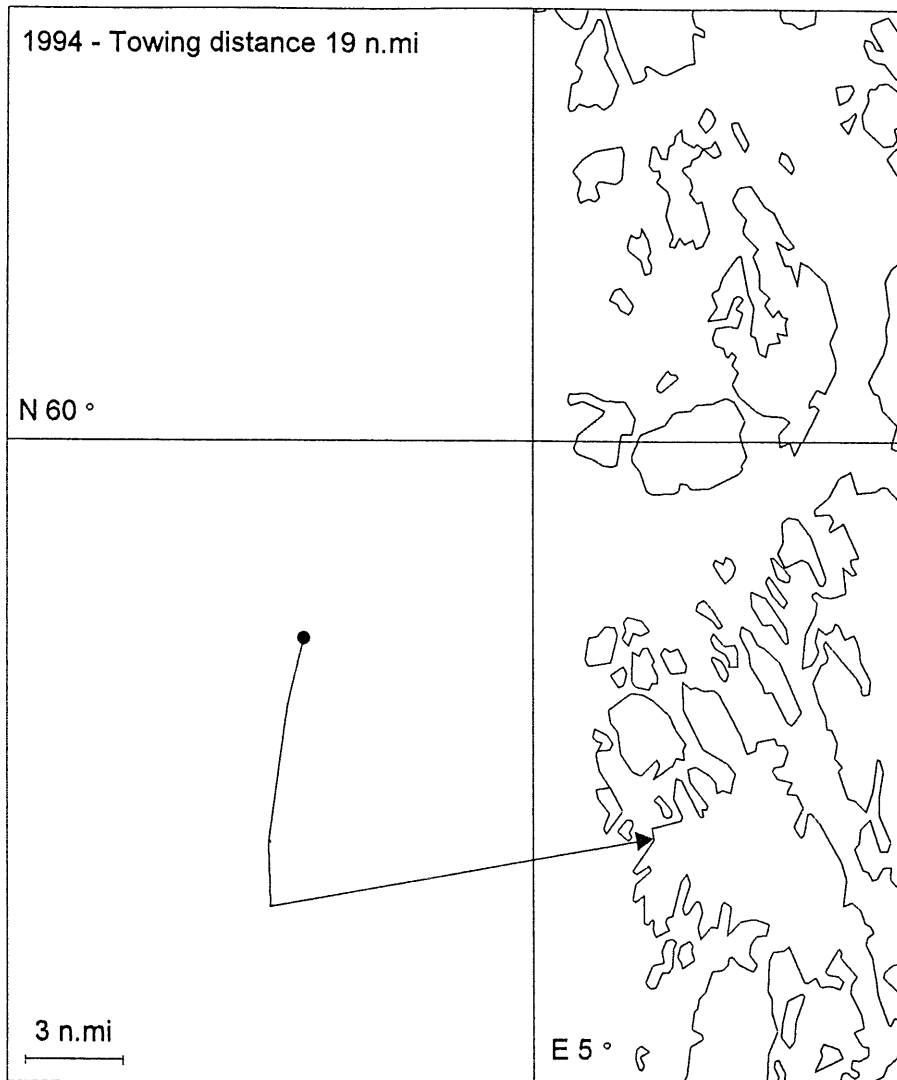


Figure 5. Catch (dot) and mooring (triangle) of second 1994 field experiment.

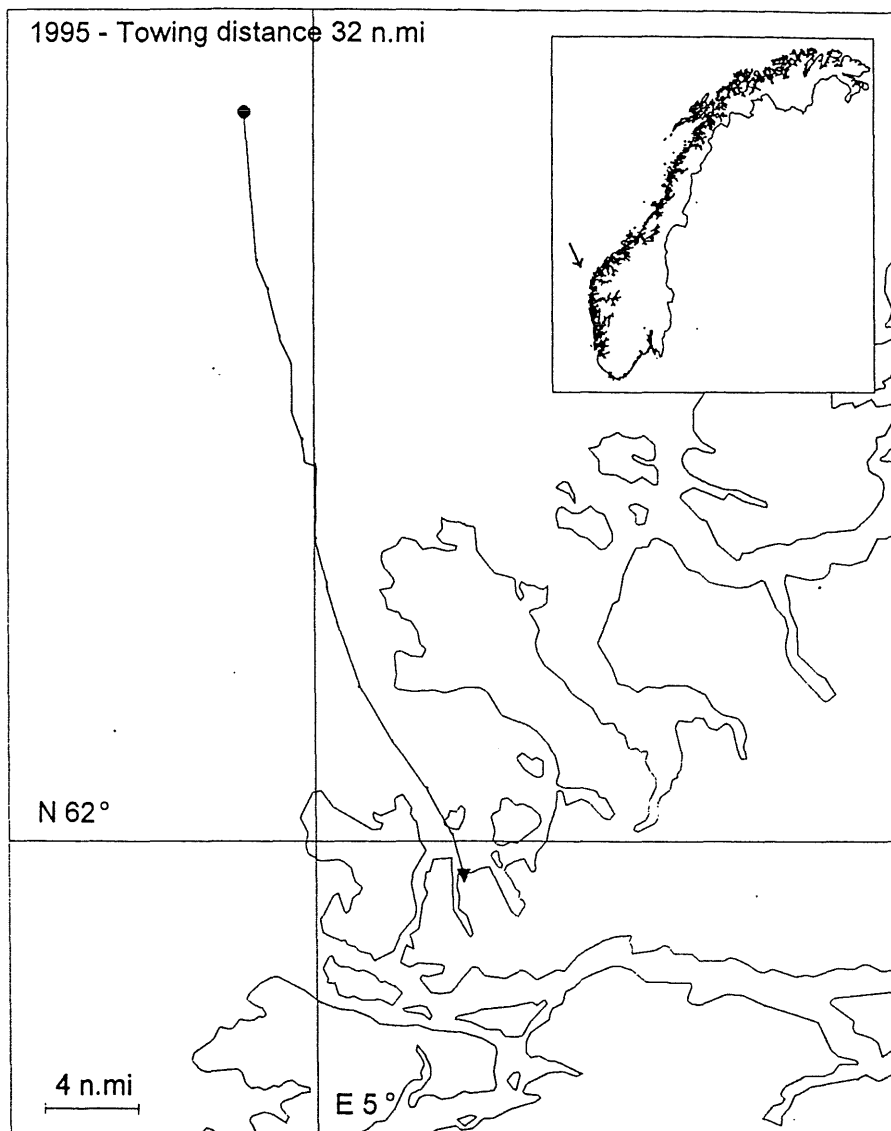


Figure 6. Catching (dot) and mooring position of 1995 field experiment.

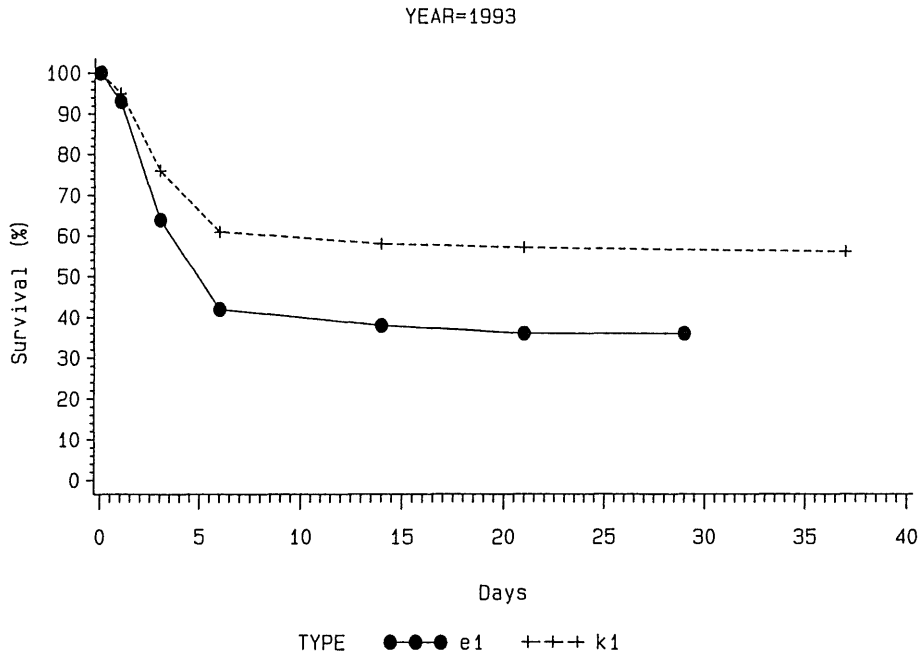


Figure 7. Survival in 1993 field experiment. (e1: experiment group, k1: control group)

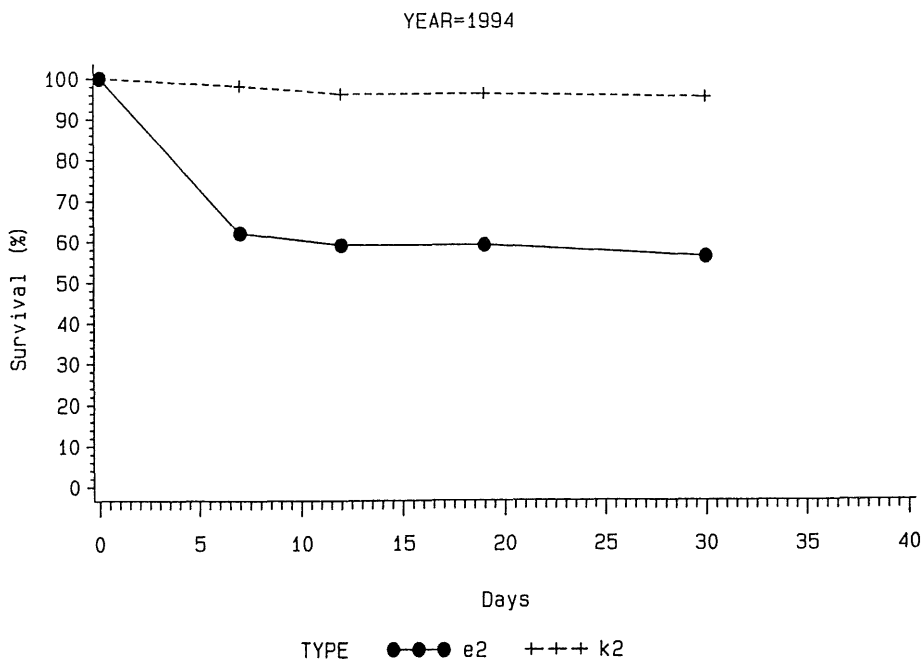


Figure 8. Survival in the second 1994 field experiment. (e2: experiment group, k2: control group)

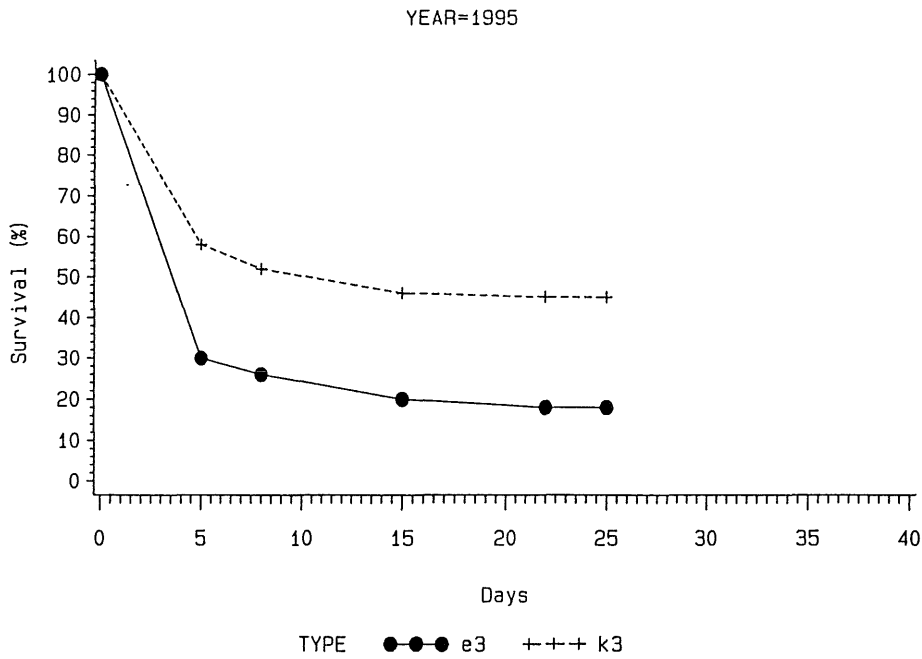


Figure 9. Survival in the 1995 field experiment. (e3: experiment group, k3: control group)

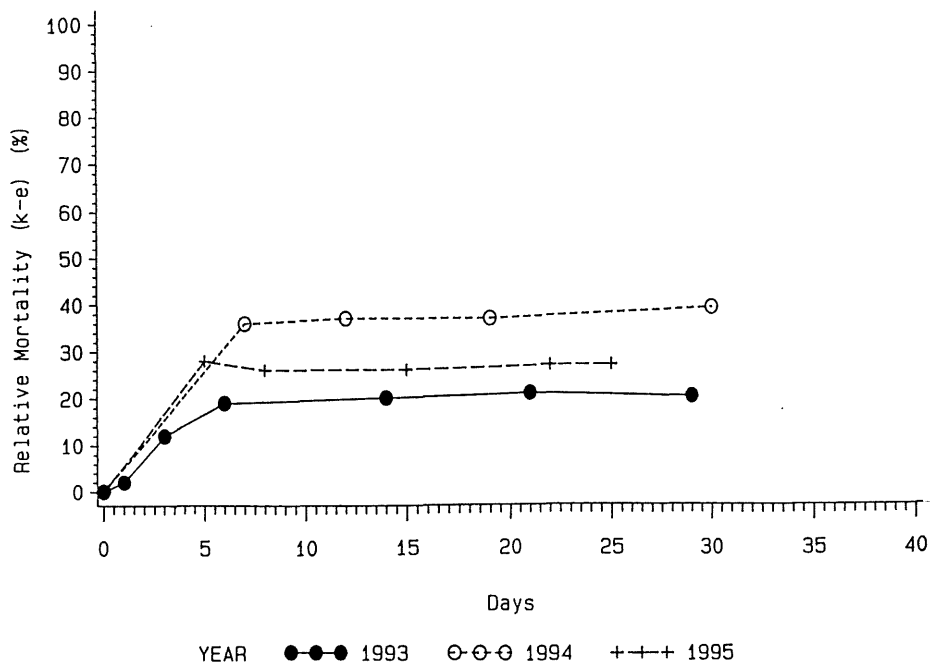


Figure 10. Relative mortality between control (k) and experiment (e) groups in the field experiments.

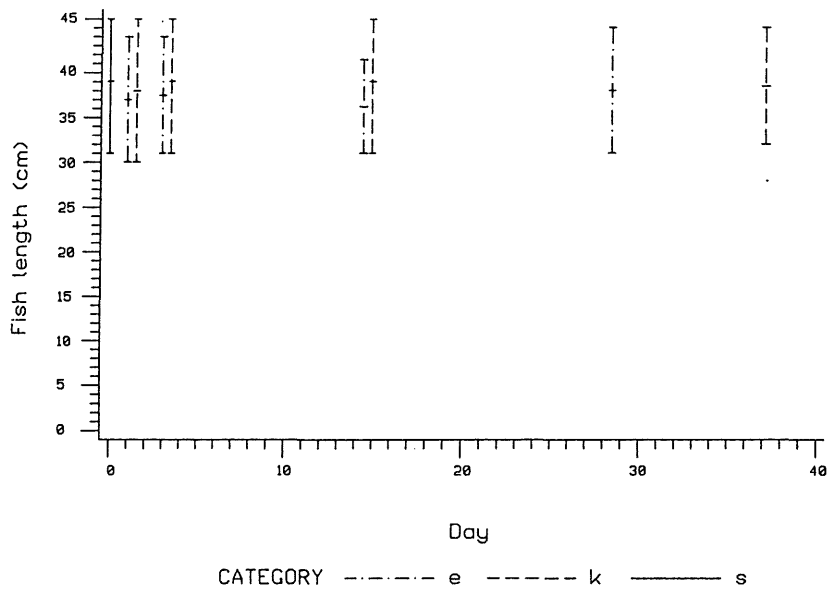


Figure 11. Length distribution of the fish in the purse seine before the experiment (s) and of the dead fish in the experiment (d) and control (k) groups.

