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ON THE SURVIVAL OF PLAICE AND SOLE DISCARDS IN THE OTTER-TRAWL AND BEAM-TRAWL FISHERIES IN THE NORTH SEA

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ABSTRACT

This paper summarizes the results of survival experiments with plaice and sole discards caught by commercial beam-trawl vessels and a research vessel fishing with an otter trawl, and with soles escaped through the meshes in covered-cod-end experiments. In the commercial beam-trawl fishery the survival of both plaice and sole discards was estimated to be less than 10%. The survival of soles escaped through the meshes was estimated at 60%. The survival of discards was negatively affected by the catching process. During the catching process mortality was caused through the action of the tickler chains and the injuries imposed during the stay in the net. Under present-day commercial practice the processing of the catch on deck hardly affects the survival of discards.

1. INTRODUCTION

Trawl fisheries for flatfish are generally mixed fisheries with a variety of target species. In the North Sea the fishery for flatfish is mainly carried out with beam trawls, which are used in more than 75% of the total international landings of sole (*Solea solea* L.), plaice (*Pleuronectes platessa* L.), turbot (*Scophthalmus maximus* L.) and brill (*Scophthalmus rhombus* L). Beam-trawl fishery is characterized by a substantial bycatch of various species of fish and invertebrates and a considerable catch of dead material such as stones, fossil shells, sand, wood and garbage. A decreasing part of the total international catch is taken by otter trawls. Both kinds of gear use tickler chains in front of the ground rope to drive the flatfish from the sea bottom so that they can be caught by the net.

Sole fishery in the North Sea has to be conducted with a legal minimum mesh size of 80 or 90 mm. At these mesh sizes the 50% retention length of sole is 26 or 30 cm, respectively (RIJNSDORP *et al.*, 1981; VAN BEEK *et al.*, 1982) and a substantial part of the undersized sole (<24 cm) can escape through the meshes. In other commercial flatfish species, such as plaice, turbot and brill, which have a much lower retention length than sole, the numbers escaping through the meshes are negligible. Consequently discard rates in plaice are much higher than in sole (DE VEEN & RODENBURG, 1971; DE VEEN *et al.*, 1975). Dab (*Limanda limanda* L.), a commercially less attractive flatfish species, is also discarded in great quantities; turbot and brill, however, are discarded in low quantities as these species do not recruit to the fishing grounds before reaching the minimum landing size (DE VEEN *et al.*, 1975).

To assess the possible effects of technical management measures such as mesh size regulations, closed areas *etc.*, to improve the exploitation of plaice and sole, knowledge on the survival of plaice and sole discards is paramount. As only in sole substantial numbers escape through the meshes also the survival of these soles is important to evaluate the effect of an increase in mesh size. In the past research on the survival of discards focussed on plaice (GARSTANG, 1905; BORLEY, 1909; DE VEEN *et al.*, 1975; KELLE, 1976, 1977). Information on the survival of soles escaping through the meshes is lacking.

GARSTANG (1905) concluded that the viability of plaice discards was good directly after catching, but that high mortality occurred during their stay on deck. BORLEY (1909) showed experimentally that the survival of plaice discards was mainly affected by the haul duration, the presence of Medusae and the conditions on deck. Hot sunshine especially caused a substantial mortality. The survival of plaice discards in the otter-trawl fishery was estimated to be below 10% in most cases. In the beam-trawl fishery the condition of plaice discards was better and in short hauls under favourable conditions 50 to 75% of the catch survived (BORLEY, 1909). The survival of both plaice and sole discards in the shrimp fishery, employing a light beam trawl without tickler chains but with rollers attached to the ground rope, was estimated at about 50-60%, but was reduced to 20% in plaice and 30% in sole when shaking sieves were used to sort the catch (KELLE, 1976).

The survival of discards in modern flatfish fishery is expected to have changed with the introduction of heavy beam trawlers at the early 1960's. In comparison with the otter- and beam-trawl fishery in the be-

ginning of the century, the fishing speed had increased to about 5 knots (9 $km \cdot h^{-1}$) in the late 1970's and to about 7 knots (13 $km \cdot h^{-1}$) at present, and the weight of the gear, including a large number of tickler chains, increased to about $10 \cdot 10^3$ kg at present. Also the time that discards are exposed on deck was reduced by the introduction of conveyer belts in the early 1980's to improve the working conditions of the crew.

The present paper summarizes the results of the survival experiments with plaice and sole discards carried out between 1972 and 1982 on board of commercial beam trawl vessels and a research vessel in the North Sea. Additional experiments were carried out to estimate the survival of soles that escaped through the meshes.

2. METHODS

Survival experiments with plaice and sole discards were carried out on board commercial beam trawl vessels operating under normal commercial conditions. Additional experiments were carried out with plaice caught with an otter trawl on R.V. 'Tridens'. Discards were sorted from the catch and their condition was classified according the scale given in Table 1. From each condition class a random sample was taken and placed in a plastic tank (size: 40x60 cm and 12 cm high) with a maximum of 15 fish per tank. Stacks of about 10 tanks almost filled with seawater were placed in a wooden frame and supplied with continuous flow of fresh seawater (Fig. 1). The tanks were placed on deck in a position where rolling and pitching of the ship were minimal. On board R.V. 'Tridens' the stacks of tanks were placed in a large closed basin of seawater, with continuous flow. If conditions permitted, the experiments were checked every 12 hours and the dead fish was recorded and removed. The experiment was terminated when all fish had died or at the end of the cruise. In a number of cases the experiment had to be stopped prematurely due to the weather conditions.

TABLE 1

Classification of the condition of flatfish according to the damage.

A:	Fish lively, no visible signs of loss of scales or mucus.
B:	Fish less lively, some scratches and some scales missing, mucus layer affected up to 20%, some small red spots on the blind side.
C:	Fish lethargic, several scratches and some areas without scales, mucus layer affected up to 50%, several red spots on the blind side.
D:	Fish lethargic, head reddish, many scratches and areas without scales, mucus layer affected for more than 50%, blind side with many red spots and haemorrhages.

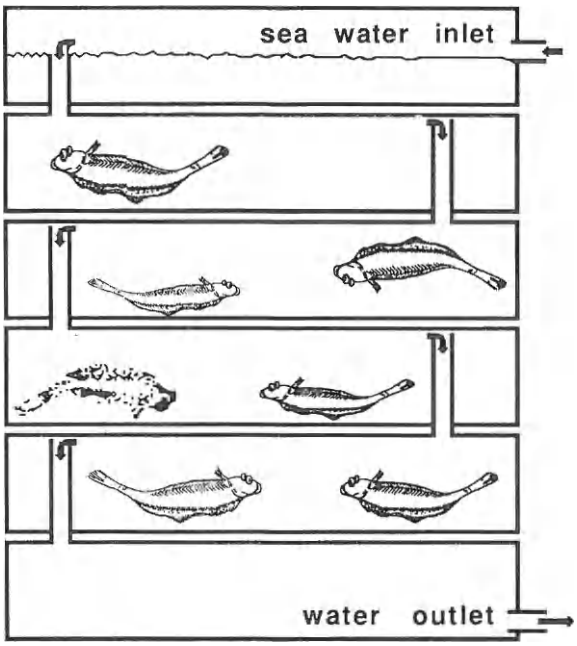

Fig. 1. Experimental set-up used to estimate the survival of flatfish discards.

Survival experiments were initiated with discards from catches that varied in the gear used (otter or beam trawl), the number of chains in front of the net, haul duration (between 15 and 120 min), fishing speed, total volume of the catch and the engine power of the vessel. Also sea conditions (wind force) and water temperature were considered. The technical information of the experiments is summarized in Table 2. The length range of the discards used in the survival experiments was 20 to 30 cm in plaice and 20 to 28 cm in sole.

In addition, the effect of the increasing processing speed on the survival of plaice discards was examined by comparing discard mortality of plaice processed by the tradition al method and of plaice discards processed with a sorting device. By this method the catch is dumped in a water filled container which supplies a conveyer belt along which the catch is sorted and processed. Discards and other unwanted material stay on the conveyer belt and are transported back to sea immediately. In the sorting device used in our experiments, the catch was kept wet with sprinklers throughout their stay on the conveyer belt.

The overall survival of the discards (S_i) at experimental time i was calculated from the proportion (P_j) and the survival ($S_{i,j}$) measured in each condition class (j = 1 .. 4) of the total discard catch according to:

$$S_i = \Sigma P_j * S_{i,j}$$

TABLE 2

Technical information on the survival experiments.

Exp. numb.	horse power	haul duration	total catch × 40kg cod-end	total catch × 40kg cover	number of chains	depth (m)	water temp.	air temp.	weather cond.	date
plaice: otter trawl (fishing speed: 3.5 knots)										
1	600	20	5.0	-	6	25-30	8	8	7	Nov 1972
2	600	60	5.5	-	6	25-30	8	8	5-7	
3	600	60	5.5	-	6	25-30	8	8	7	
4	600	60	5.8	-	6	25-30	8	8	8	
5	600	100	5.8	-	6	25-30	8	8	7	
6	600	100	8.8	-	6	25-30	8	8	8	
7	600	105	8.0	-	6	20-30	6	5-6	-	Feb 1975
8	600	105	8.0	-	6	20-30	6	5-6	-	
plaice: beam trawl (fishing speed: 5.0-5.5 knots)										
9	1200	60	5	-	8	20-30	9-10	-	SW 1-4	Nov-Dec 79
10	1200	60	5	-	15	30-50	9-10	-	SW 1-4	
11	1200	120	10	-	24	20-30	9-10	-	SW 1-4	
12	1200	120	17	-	24	30-50	9-10	-	SW 1-4	
13	1015	110	4	-	24	20-25	12-13	-	W 1-2	May-Jun 81
14	1015	60	1	-	8	20-25	12-13	-	S 2	
15	1235	120	22	-	24	20-30	18	-	Var 2	Sep 1982
16	1235	120	22	-	24	20-30	18	-	Var 2	
17	1235	60	11	-	15	30-40	10	-	3-8	Dec 1982
18	1235	120	23	-	24	30-40	10	-	3-8	
plaice: beam trawl, deck-processing with conveyer belt (fishing speed: 5.0-5.5 knots)										
19	1200	60	5	-	15	20-30	9-10	-	SW 1-4	Nov-Dec 79
20	1200	60	5	-	15	30-50	9-10	-	SW 1-4	
21	1200	120	10	-	15	20-30	9-10	-	SW 1-4	
22	1200	120	17	-	15	30-50	9-10	-	SW 1-4	
23	1235	60	12	-	15	20-30	16	-	7-4	Oct 1982
24	1235	120	22	-	24	20-30	16	-	7-4	
25	1235	120	22	-	15	20-30	16	-	7-4	
26	1235	60	11	-	24	30-40	10	-	3-8	Dec 1982
27	1235	120	23	-	15	30-40	10	-	3-8	
sole: beam trawl (fishing speed: 5.0-5.5 knots)										
28)[1]	1015	120	7.5	5.5	13	~30	-	-	S 1- 2	Aug 1980
29)[1]	1015	120	7.5	5.5	13	~30	-	-	S 1- 2	
30	1015	15	2.0	0.5	12	15-20	17	-	Var 2	Aug 1981
31	1015	60	4.0	1.0	12	15-20	17	-	Var 2	
32	1015	120	7.0	4.0	12	15-20	17	-	Var 2	
33	1310	30	3.0	0.5	16	20-30	16-17	-	W 2-3	Aug-Sep 1981
34	1310	60	4.0	1.5	16	20-30	16-17	-	W 2-3	
35	1310	90	6.0	2.5	16	20-30	16-17	-	W 2-3	
36	1310	60	3.5	3.5	16	20-30	16-17	-	W 2-3	
37	1310	120	7.0	7.0	16	20-30	16-17	-	W 2-3	
38	1310	15	0.5	0.5	16	20-30	16-17	-	W 2-3	

)[1] Irish Sea

The survival of soles escaped through the meshes was estimated in conjunction with mesh selection experiments on commercial beam trawlers using the covered cod-end technique (RIJNSDORP *et al.*, 1981; VAN BEEK *et al.*, 1982). The survival experiments were set up in pairs, experiment A with soles from the cod-end and experiment B with soles that escaped through the meshes of the cod-end and retained in the cod-end cover. The length range of the fish was 18 to 25 cm. The fish were not classified in condition categories. Further experimental procedures were identical to those applied in plaice.

3. RESULTS

3.1. DISCARDS

The frequency of occurrence of the different condition classes of the discards in the catch is shown in Fig. 2. The condition of plaice discards was poorer in the beam-trawl experiments than in the otter trawl. In both plaice and sole the condition decreased with increasing haul duration. Survival of the 4 condition classes (Fig. 3) corresponded to the subjective classification of condition, but the survival curves of the same condition class differed between otter and beam trawl and between different haul durations. Obviously not all injuries that may cause mortality were visible.

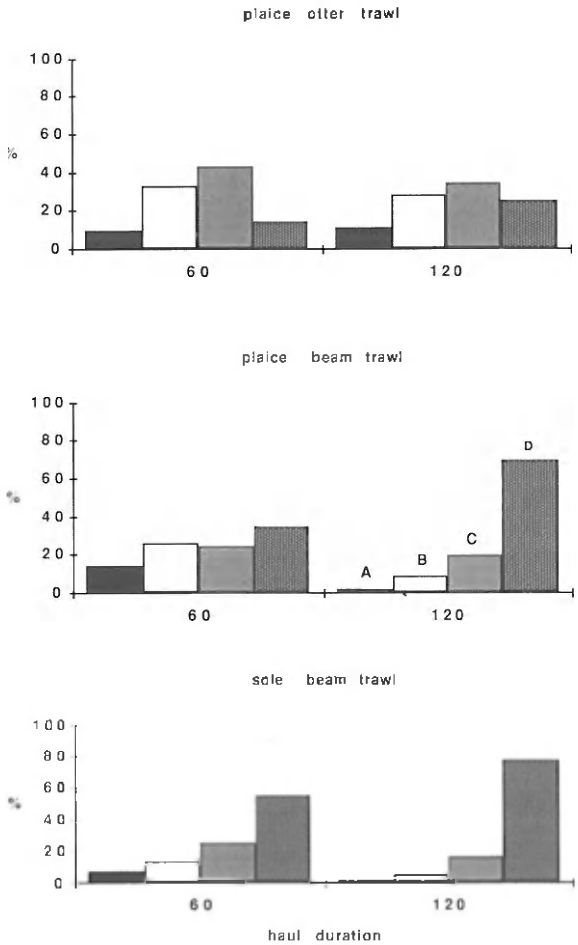

Fig. 2. Frequency distributions of the condition (A, B, C or D) of plaice discards in otter- and beam-trawl catches of 60- and 120-min haul duration and of sole discards in beam-trawl catches of 60- and 120-min haul duration. Damage increases from condition A to D (compare Table 1).

In each experiment the discard survival was estimated from the mortality rate in each condition class and the proportion of this condition class in the total catch. In general the mortality rate was highest in the first 24 or 48 h and levelled off afterwards (Tables 3 and 4). However, in some experiments substantial mortality started only after 24 h.

The overall survival was estimated as the survival after an experimental time of 84 h. After this time mortality apparently ceased or was very low (Fig. 4). In the few experiments stopped prematurely after 60 or 72 h, the percentage of surviving discards was extra polated assuming a similar mortality rate between 60-72 h and 72-84 h as in the other experiments.

Overall discard survival was estimated to be between 0 and 50% in plaice and between 4 and 40% in sole. In plaice the survival was lower in beam-trawl discards than in otter-trawl discards (Mann-Whitney, $p<0.01$). Discard survival in the beam trawl was

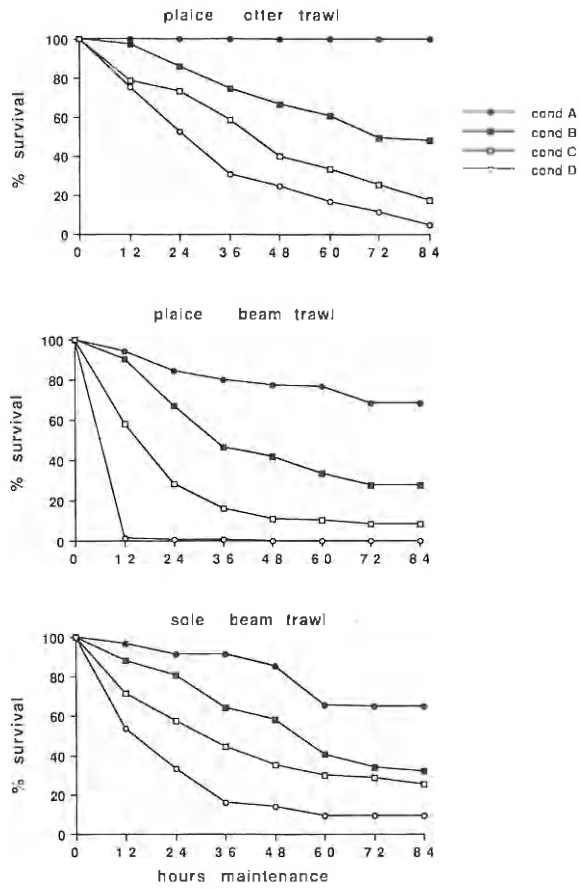

Fig. 3. Survival (%) of the different condition classes (A-D) in plaice and sole discards during maintenance in the holding tanks.

TABLE 3

Plaice: survival in percentage of discards (18-27 cm) and the number of fish at the start of each experiment (N). The **bold** figures are extrapolated values estimated under the assumption that the mortality between 60 and 72 and between 72 and 84 hours was equal to the average mortality at this time in the other experiments. The figures in *italics* are interpolations by eye between the last observation at 36 hours and the final at 96 hours. The experiment number corresponds to the information given in Table 2.

Experiment Number	*N*	*Time interval (hours) after start of experiment*								
		0	*12*	*24*	*36*	*48*	*60*	*72*	*84*	*96*
Otter trawl: 20 min										
1	40	100.0	100.0	87.8	62.6	35.2	32.5	22.8	22.8	-
Otter trawl: 60 min										
2	46	100.0	81.6	64.2	50.2	47.6	44.4	40.7	31.6	-
3	17	100.0	20.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	15	100.0	95.3	64.2	8.8	0.0	0.0	0.0	0.0	0.0
Otter trawl: 3 100 min										
5	30	100.0	71.6	66.9	52.3	37.4	31.8	16.9	15.7	-
6	28	100.0	82.2	64.4	53.5	45.4	41.2	**35.0**	**32.2**	-
7	63	100.0	100.0	96.6	90.3	86.9	79.0	67.7	54.1	-
8	41	100.0	82.5	74.9	57.6	47.2	35.1	33.0	30.8	-
Beam trawl: 60 min										
9	45	100.0	75.6	56.7	37.8	31.1	22.2	17.8	**14.3**	-
10	79	100.0	93.7	87.3	68.4	49.4	36.7	**29.9**	**24.0**	-
14	112	100.0	54.4	45.6	36.5	21.5	16.2	11.6	5.7	5.7
17	44	100.0	100.0	93.2	56.8	*38.0*	*28.0*	*20.0*	*15.0*	11.4
Beam trawl: 120 min										
11	48	100.0	85.4	74.0	62.5	43.8	31.3	27.1	**21.8**	-
12	73	100.0	65.8	31.5	17.8	11.0	6.8	5.5	**4.4**	-
13	111	100.0	59.1	44.0	21.5	4.8	3.4	2.9	2.1	-
15	131	100.0	21.3	13.0	7.0	5.4	4.6	4.6 -	4.6	-
16	135	100.0	25.9	20.0	16.3	14.9	12.6	9.6 -	9.6	-
18	88	100.0	87.5	65.9	52.3	*40.0*	*32.0*	*25.0*	*21.0*	19.3
Beam trawl: 60 min and deck-processing with a conveyer belt										
19	49	100.0	98.0	91.9	85.7	77.6	57.1	46.9	**37.7**	-
20	67	100.0	99.3	98.5	83.6	76.1	73.1	**59.6**	**47.9**	-
23	270	100.0	45.0	16.6	11.5	8.5	8.0	6.1	**4.9**	-
26	43	100.0	100.0	90.7	58.1	*40.0*	*25.0*	*19.0*	*14.0*	11.6
Beam trawl: 120 min and deck-processing with a conveyer belt										
21	50	100.0	78.0	61.0	44.0	38.0	30.0	26.0	**20.9**	
22	72	100.0	70.9	41.7	27.8	16.7	15.3	**12.5**	**10.0**	-
24	270	100.0	24.6	12.1	8.5	6.1	5.8	4.4	**3.5**	
25	270	100.0	24.0	11.1	7.7	5.3	5.0	3.8	**3.0**	-
27	94	100.0	89.4	55.3	35.1	*26.0*	*20.0*	*16.0*	*14.0*	12.8

TABLE 4

Sole: survival expressed in percentage of discards (20-28 cm). N indicates and the number of soles at the start of each experiment. The **bold** figures are extrapolated values estimated under the assumption that the mortality between 72 and 84 hours was equal to the average mortality at this time in the other experiments. The experiment number corresponds to the information given in Table 2.

A: soles collected from the cod-end

Experiment Number	*N*	*Time interval (hours) after start of experiment*								
		0	*12*	*24*	*36*	*48*	*60*	*72*	*84*	*96*
Beam trawl: 15-30 min										
30	43	100.0	69.9	60.0	42.1	35.9	22.2	19.4	19.4	-
33	109	100.0	89.9	69.6	54.3	48.3	40.2	39.4	36.9	-
38	45	100.0	95.6	82.2	75.6	73.3	66.7	66.7	**66.7**	-
Beam trawl: 60-90 min										
31	43	100.0	60.6	50.1	31.5	27.8	16.1	15.1	15.1	-
34	109	100.0	86.7	60.9	42.3	38.7	33.3	32.3	29.3	-
35	109	100.0	85.4	54.7	35.7	32.5	28.6	27.7	25.3	-
36	90	100.0	62.7	27.2	24.5	18.9	18.4	18.0	15.2	15.2
Beam trawl: 120 min										
28	72	100.0	8.4	6.7	5.8	5.3	5.3	5.2	4.3	3.0
29	25	100.0	34.5	28.2	18.2	8.2	5.8	5.8	**4.9**	-
32	43	100.0	53.8	43.6	24.0	22.5	12.0	11.6	11.6	-
37	90	100.0	55.7	17.3	14.6	9.4	9.2	9.2	6.5	6.5

B: soles escaped through the meshes and collected in the cod-end cover

Experiment Number	*N*	*Time interval (hours) after start of experiment*								
		0	*12*	*24*	*36*	*48*	*60*	*72*	*84*	*96*
Beam trawl: 15-30 min										
30	72	100.0	87.0	67.8	56.4	50.8	40.2	40.2	40.2	-
33	95	100.0	73.5	58.8	49.3	46.0	43.0	43.0	40.7	-
38	75	100.0	92.0	82.7	78.7	77.3	76.0	73.3	73.3	-
Beam trawl: 60-90 min										
31	72	100.0	82.6	63.0	51.0	44.6	30.6	30.6	30.6	-
34	95	100.0	67.9	50.8	41.4	38.3	35.2	35.2	33.5	-
35	95	100.0	63.4	44.5	34.9	32.7	29.3	29.3	28.5	-
36	90	100.0	66.5	33.0	30.4	25.0	24.0	23.4	20.9	20.9
Beam trawl: 120 min										
28	104	100.0	19.6	15.9	15.0	12.6	12.1	12.1	9.7	9.7
29	69	100.0	43.1	36.9	27.8	18.7	16.2	8.2	**6.7**	-
32	72	100.0	76.4	56.0	41.5	32.2	13.0	13.0	13.0	-
37	90	100.0	54.5	15.8	13.0	7.8	7.7	7.7	5.0	5.0

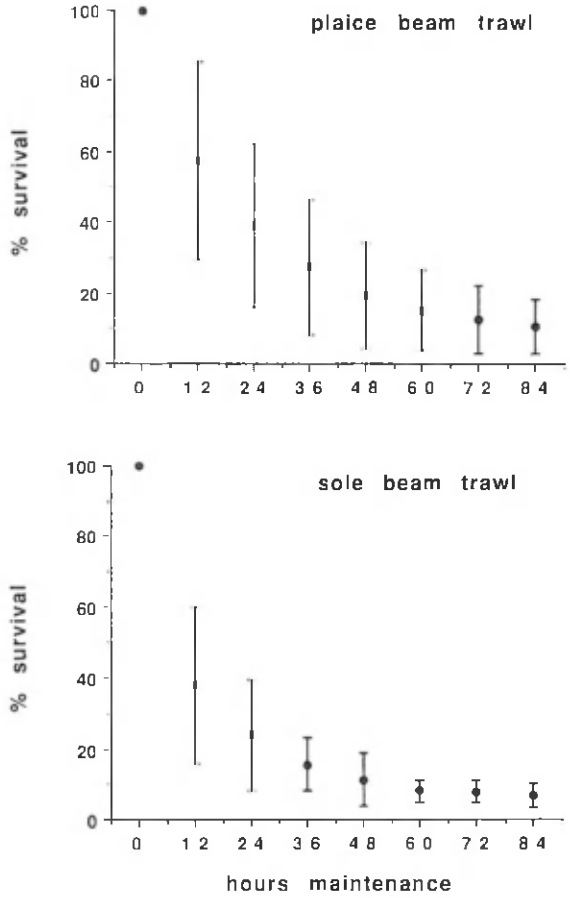

Fig. 4. Survival (%) of plaice and sole discards from 2-hour hauls in the beam trawl experiments during maintenance. The vertical bars indicate the standard deviations.

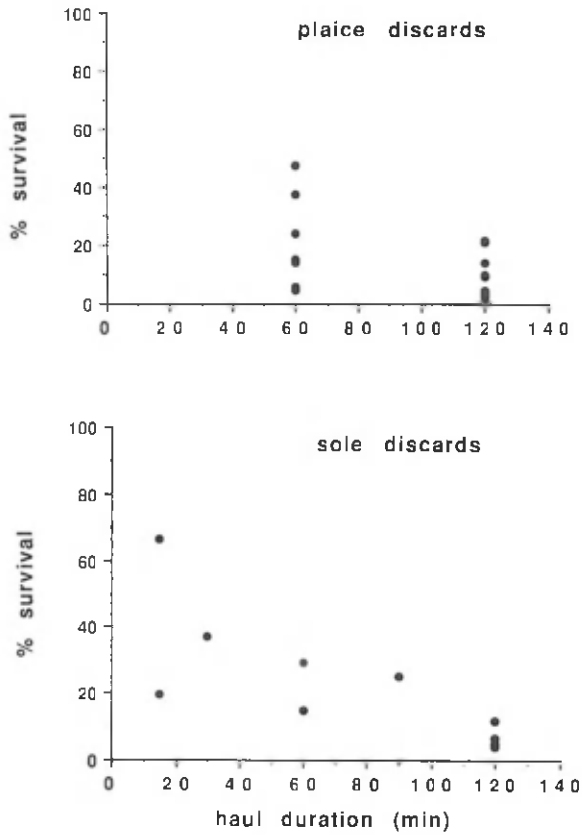

Fig. 5. Survival (%) in plaice and sole discards after 84 hours in experimental holding tanks in relation with haul duration (min.).

higher in hauls of 60 min than in hauls of 120 min (Fig. 5), the relation being significant in sole (Spearman $rs = -0.829$, $n = 11$, $p < 0.05$) and marginally significant in plaice (Spearman $rs = -0.438$, $n = 19$, $0.05 < p < 0.10$). In otter trawl discards of plaice the opposite was observed, but the number of discards of 60 min hauls was rather small. Water temperature had a slight but significant effect on the survival of plaice discards in the 60-min-beam-trawl hauls (Spearman $rs = -0.764$, $n = 8$, $p < 0.05$) and a marginally significant in the 120-min hauls (Spearman $rs = -0.593$, $n = 11$, $0.05 < p < 0.10$). Survival increased at lower water temperatures. The method of processing the catch on board did not affect the survival of plaice discards in 120-min hauls in a pairwise comparison of the 3 experiments. In the 3 pairwise experiments of 60-min haul duration, no difference occurred between conveyer belt and traditional processing in one experiment (14.0 vs 15.0) but a substantially higher survival occurred with conveyer-belt processing in the two other experiments (37.7-14.3 and 47.9-15.0). No significant effect of the maximum wind force on the survival of plaice discards could be demonstrated in 60- or 120-min hauls (Spearman $rs = -0.166$, $n = 8$, $p > 0.05$; $rs = -0.283$, $n = 11$, $p > 0.05$).

3.2. SURVIVAL OF SOLES ESCAPED THROUGH THE MESHES

A number of experiments were carried out to estimate the survival of soles escaped through the meshes and collected in the cod-end cover. The survival of soles originating from the cover was slightly but significantly higher than in those from the cod-end (Wilcoxon's signed ranks test, $P < 0.01$). The

results, given in Table 4 and Fig. 6, show that survival decreased with increasing haul duration and that substantial survival occurred at short hauls of 15 min. As the decreased survival at longer haul durations may be caused by the prolonged stay of the escaped soles in the cod-end cover, the extrapolated survival at a haul duration of 0 min is about 60% and this figure would give a credible estimate of the survival of sole that escape through the meshes.

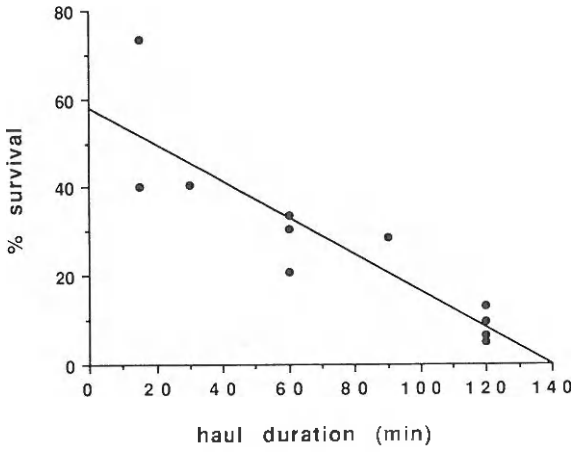

Fig. 6. Survival (%) (after 84 hours) of sole escaped through the meshes and collected in a cod-end cover of a beam trawl in relation to haul duration. The extrapolated survival at a haul duration of 0 min is estimated at 60%.

4. DISCUSSION

Several factors may contribute to the mortality of discards during catching and sorting on board. The experiments presented in this paper allow a first evaluation of the main factors influencing the discard mortality in modern beam trawl fishery.

Although the maintenance conditions of the fish in the tanks on board were carefully monitored and kept as optimal as possible, they may have caused some additional mortality. Fish can get sea sick and stressed; according to KELLE (1977) stress is a major cause of mortality. Therefore, our experiments may have overestimated the true mortality of plaice and sole discards. Although the additional mortality resulting from maintenance can be investigated in experiments initiated with fish not affected by the fishing gear, our experimental set-up did not allow this. Two observations indicate that the additional mortality is relatively low. First, no significant effect of rolling and pitching of the ship in poor weather conditions could be demonstrated for plaice. Second, in the otter-trawl experiments, plaice of condition class A (no visible damage) showed 100% survival; in the beam-trawl experiments the survival of plaice and sole of condition A was above 70% (Fig. 3). Repeated inspection of experimental fish during the experiment showed that fish which were recorded to be undamaged at the start of the experiment showed signs of damage later on in the experiments.

To evaluate the catching process itself, survival experiments were initiated with discards which differed in the number of tickler chains, total catch and haul duration. Because the number of experiments was relatively small, only a qualitative evaluation is possible. In both sole and plaice discards the survival was negatively correlated with haul duration, indicating that mortality factors working in the cod-end dominated over the effects of the tickler chains. The tickler chains will affect the survival of discards irrespective of haul duration. A maximum estimate of the contribution of the tickler chains to the discard mortality of sole is given by the extrapolated survival of the discards and of soles which escaped through the meshes at 0 min, about 50% and 60% respectively. A comparison with the survival of about 25% in 60-min hauls and 10% in 120-min hauls shows that besides the possible effect of the tickler chains also duration of the stay in the cod-end substantially contributed to the mortality. In our experiments haul duration and the total weight of the catch were correlated and therefore it is not possible to disentangle the contribution of haul duration and total catch weight.

The main injuries of discards which could be observed macroscopically were the loss of scales and mucus, and haemorrhages. The latter only appeared as dark patches on the blind side of the body several days after catching. It is assumed that these injuries were mainly caused by the scraping and pressing of the various objects in the cod-end such as starfish, stones, shells, sand and pieces of wood. The nature and degree of the injuries will depend on the composition of species and objects in the catch. This composition varied between the experiments but was not recorded. However, it is likely that the variation in composition of the catch contributed to the observed variation in survival in comparable experiments.

The survival of discards classified as either condition A or B (not or only slightly damaged fish) varied greatly. This variability is certainly influenced by the condition classification being subjective, but also by experimental conditions. In particular, temperature and direct sunlight are thought to play an important role (KELLE, 1976). Also, invisible haemorrhages in the brain can develop from oxygen deficiency. KELLE (1977) showed that exhausted plaice prevented from breathing because they were compressed in the cod-end developed bleeding in the brain which was, in most cases, lethal. Our experiments do not allow a

further analysis of these factors. Other factors that may contribute to the mortality of discards are depressurization (FEATHERS & KNABLE, 1983) and muscular fatigue (PARKER *et al.*, 1959; BEAMISH, 1966). The range of water depth of the main fishing grounds in the southern North Sea is 10-50 m, so discards will experience a fall in hydrostatic pressure of ~ 1 to 5 bar. As plaice and sole do not have a swim bladder the effect of depressurization will be relatively small in comparison with *e.g.* gadoids. As these factors will generally cause a quick death (PARKER *et al.*, 1959; BEAMISH, 1966; FEATHERS & KNABLE, 1983) their effect will be included in the mortality estimates of our experiments.

The higher survival of plaice discards in the otter-trawl experiments and the reported high vitality of plaice in the historical investigations (GARSTANG, 1905) might indicate that fishing speed is probably an important factor which amplifies the mechanical damage inflicted during the stay in the cod-end.

Once on deck the discards are subjected to mechanical damage from sorting, and to temperature differences, sun and desiccation. The influence of these factors on the survival can be substantial (BORLEY, 1909; KELLE, 1976) but is not considered in our experiments. In some of the plaice experiments the catch was not dumped on deck and sorted by hand, but was processed more quickly on a conveyer belt where the catch was kept wet. Most modern beam-trawlers are equipped with such a device. Comparison of the survival of plaice discards processed by hand and with the conveyer belt showed a higher survival in the latter at haul durations of 60 min. Other things being equal, this indicates that the processing on deck can actually affect the mortality of discards and that the quick processing under continuous supply of water gives a slightly better survival. The negative effect on the survival of discards of a long handling time on board was also observed by GARSTANG (1905), BORLEY (1909) and NEILSON *et al.* (1989). However, in modern beam-trawl fishery with haul durations of 120 min the processing of the catch on deck does not measurably affect the survival of plaice discards as the condition of plaice discards is already badly reduced during the catching process itself. This contrasts with the shrimp fishery, where the survival rate of about 50% in plaice and sole discards is substantially reduced when the catch is processed with a shaking sieve (KELLE, 1976). Rotating sieves and specially-designed shaking sieves were shown to improve the survival rate of plaice discards (BODDEKE, 1989).

In practice the haul duration of commercial beam trawlers is in the order of 120 min unless the ground is very rough and a high amount of bycatch necessitates a reduction in haul duration (DE VEEN *et al.*, 1975). Therefore, the survival of both plaice and sole discards can be estimated at 10%. This percentage is a maximum estimate, because it is likely that in the survival experiments not all fish died within the experimental period of 84 hours on which the above survival estimate is based. The survivors are possibly the fish captured in the last minutes of the haul.

The survival experiments with soles collected from the cod-end cover showed a decreasing survival rate with increasing haul duration. The extrapolated survival at a haul duration of 0 min was estimated at about 60%. The mortality of soles escaping through the net may be caused by the injures inflicted by the catching process (tickler chains, duration of stay in the net) and during escape through the meshes. Sole can escape through relatively narrow meshes by bending in the dorso-ventral axis and squeezing through the mesh. When the net is hauled in, many soles are seen to be caught halfway through the meshes ('stekers'). Visual inspection of such 'stekers' shows some loss of scales. Inspection of the experimental sole that died also show loss of scales and haemorrhages. The estimated survival of about 60% therefore seems a reasonable, but necessarily crude estimate. It implies that the gain of an increase in mesh size will be lower than generally calculated assuming that all soles that escape through the meshes survive.

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