Vol. 126: 31-38, 1995 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published October 5

Survival of by-catch from a beam trawl

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ABSTRACT: The passage of a beam trawl across the seabed leads to the direct mortality, or indirect mortality through subsequent predation, of some benthic species. In addition, animals retained in, or those that pass through, the cod end may also die as a result of the fishing process. The extent of this additional mortality needs to be quantified to calculate total mortality of non-target species associated with this type of fishery. Hence, we investigated the survival of animals caught by a 4 m beam trawl, in order to identify those species most sensitive to capture. Starfishes, hermit crabs and molluscs were highly resistent to the effects of capture (>60% survived in all cases). Fishes (except dogfish), sea urchins and swimming crabs suffered higher mortality after capture. Generally, the majority of the animals that passed through the meshes of the cod end survived. Experimental investigation of the cause of damage to certain species concluded that the chain matrix fitted to the gear was largely responsible for the injuries sustained. The types of injuries and their extent were species-specific, and were related to the fragility and physical characteristics of each species. Our experiments revealed that while some species are highly sensitive to capture, others are capable of surviving the effects of capture.

KEY WORDS: Survival · By-catch · Beam trawl

INTRODUCTION

Beam trawls are used extensively in the North and Irish Seas to catch flatfish, in particular sole *Solea solea* and plaice *Pleuronectes platessa*. Declining fish stocks have necessitated gear modifications, such as longer beams, tickler chains and chain matrices, which greatly improve the catch rate of flatfish (Creutzberg et al. 1987, Rogers & Lockwood 1989). These modifications have increased the quantities of by-catch of some non-commercial species of fish and invertebrates which are subsequently discarded (Creutzberg et al. 1987, Kaiser et al. 1994). Predictions of total allowable catch are derived from surveys of potential recruits to the fishery and estimates of the total fishing mortality (e.g. Pope 1977). In calculations of total fishing mortality, it is generally assumed that the mortality of discards approximates to 100% (e.g Maclean 1972, Saila 1983, Daan 1991). Furthermore, little emphasis is placed on the mortality of the by-catch of non-commercial species (but see Wassenberg & Hill 1993). As models used to predict recruitment shift towards a multispecies approach, it is essential to be able to estimate more accurately the mortality of commercial and non-commercial species that are discarded to give a better indication of total catch mortality. A further complication is the capability of different groups or taxa to survive if they escape through the meshes of the net (Sangster 1994). The present work primarily examines the survival of those animals which are retained by the cod end and deposited on the deck. In addition, we have investigated the survival of some species that pass through the cod end, and described the types of injuries sustained by a selection of animals during the capture process.

Animals may be injured by different parts of the gear, or may find certain parts of the fishing process more stressful than others (Sangster 1994). For example, sea urchins are either damaged when tickler chains pass through the sediment or are crushed when dropped onto the deck (Bergman & Hup 1992), while animals such as fishes tend to be injured by pressure changes on hauling, crushing and the abrasive action of other species' spines or scales, e.g. starfish (for a review see Anon 1994). Exposure to air inevitably

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causes stress and has frequently been shown to cause mortality if prolonged (e.g. De Veen et al. 1975, Neilson et al. 1989). It follows that an individual's ability to survive the fishing process will be directly related to its physiology, morphology and behaviour in response to the gear.

METHODS

Survival of by-catch. ***Collection and maintenance of animals from the cod end:*** Trawling was undertaken by the RV 'Corystes' at a site 34 m deep (chart datum) off Dulas Bay, Anglesey, North Wales, UK (see Kaiser & Spencer 1994) in March and August 1992, April 1993, and April and October 1994. On each occasion we used a 4 m commercial beam trawl fitted with a chain matrix and a sole net with an 80 mm diamond mesh cod end (Fig. 1). The beam trawl was towed for ca 30 min at a mean speed of 4 knots. This fishing speed is similar to that used by commercial boats fishing with this gear; however, commercial tow duration is normally 1 to 2 h depending on the size of catch and ground type. In general, it was not possible to tow for commercial durations due to constraints on time and other experimental priorities. Consequently our estimates of survival will be higher than those experienced during commercial fishing operations.

On hauling the net, the catch was deposited on the deck and any fish of commercial importance removed. This sorting process simulated the time delay before the by-catch would be returned to the sea. The by-catch was then placed in 50 l bins filled with seawater at ambient temperature. Specimens that were obviously dead or fatally wounded, e.g. completely crushed or severed in two, were counted, but not selected for observation. We selected as many representative groups of species as possible and attempted to use as many individuals as possible for each experiment. However, seasonal changes and differences in abundance made it impossible to study the same number of animals on each occasion.

Specimens selected for observation were transferred to a specially designed survival tank system (Fig. 2) which consisted of six 4 × 0.5 × 0.3 m fibreglass tanks attached to a steel frame which was locked to the deck of the ship using twist locks. Small, 1 l buckets were used to transfer the specimens from the bins to the survival tanks, such that they remained immersed in seawater during this process. Each tank was fitted with 3 removable partitions 1 m apart, which were drilled with twenty 1 cm diameter holes to allow free circulation of water. The system was connected to a fresh seawater supply (flow rate = 1 l s^{-1}) such that water entered each tank via a spray bar which enhanced aeration. Water ran to waste through an overflow pipe. The entire system was enclosed in a tarpaulin cover to eliminate light and thereby reduce stress effects.

Collection of animals that pass through the cod end: Cod end meshes are designed to allow non-commercial species and undersized individuals to escape. However, damage can be sustained while passing through the mesh and can also be due to physical contact with other species and debris. We investigated the survival of animals escaping from the cod end of the 4 m beam trawl by attaching a cover (mesh diameter 4 mm) to the dorsal portion of the cod end. Five replicate tows, each of 15 min duration, were made in order to collect as large a sample as possible. Tows were of short duration to minimise injury to these animals while they were in the cover. On hauling, the cover was immediately emptied into a 50 l bin containing

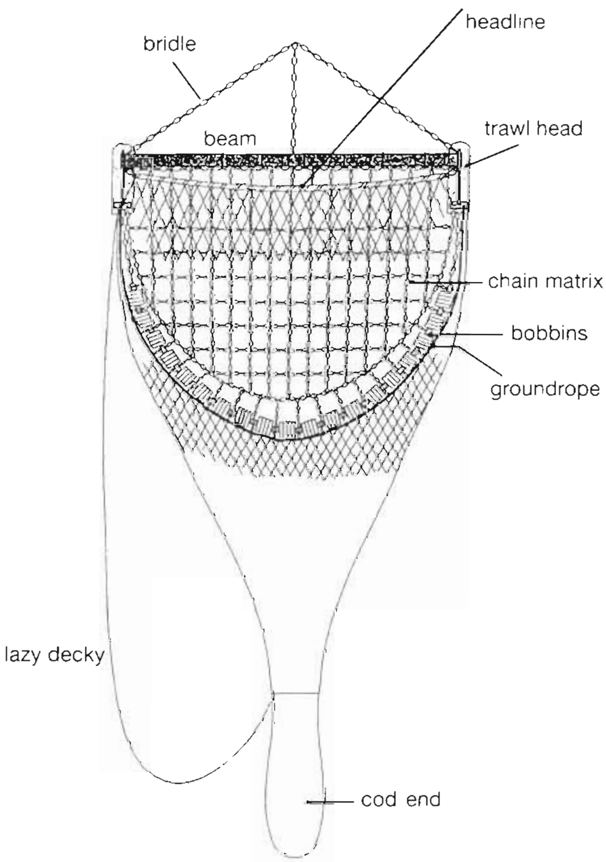

Fig. 1 Representative view of a 4 m commercial beam trawl as seen from above. Various parts of the gear are responsible for injuries to the animals. Pressure from gear weight acts through the trawl heads, which consequently crush or displace to the side any organisms in their path. Chain matrix, bobbins and ground rope crush and displace organisms found in the sediment. Catch in the cod end can inflict abrasive and crushing injuries depending on composition of catch

fresh seawater at ambient sea temperature, and the animals transferred to the survival system. In this set of observations no comparison was made to examine the survival of those animals retained in the cod end, as the objective was solely to study those passing through the meshes.

Determination of survival: When possible, the animals were inspected every 24 h, for a maximum of 6 d, to determine whether any had died. The criteria used to determine whether an individual was alive differed between each order or species; echinoderms were examined for movement of either the body, tube feet or spines; crustaceans were observed for either general movements or beating of the maxillipeds; fish were recorded as alive if respiratory movements were seen; *Eledone cirrhosa* were considered to be dead if respiratory movements had ceased; live *Aphrodite aculeata* contracted their longitudinal muscles and curled their bodies when lightly stimulated on the ventral surface; the polyps of *Alcyonium digitatum* responded to light exposure by retracting their feeding tentacles.

Damage to the by-catch. *Echinoderms:* In another experiment (at the same locality as the first experiments), we examined 3 different species of echinoderm collected from the cod end of a 4 m beam trawl that had been towed for either 1 or 2 h, i.e. tow lengths that more accurately represented commercial fishing. We quantified the damage to *Asterias rubens*, *Astropecten irregularis* and *Ophiura ophiura*, caught in these hauls, by counting the number of individuals with different numbers of broken arms. Where possible, differences among the species and the effects of tow duration on the frequency of damaged and undamaged individuals were tested using the *G*-test with William's correction for 2×2 contingency tables (Sokal & Rohlf 1981).

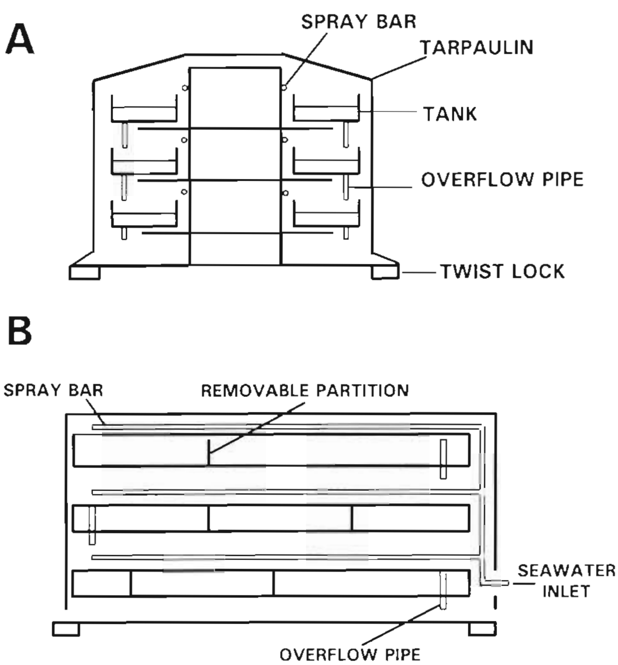

Fig. 2. (A) Side and (B) front views of the survival system (not to scale) showing the path of water flow through the tanks, the approximate position of the spray bars and overflow pipes, and the construction of the framework. The whole system was enclosed by a tarpaulin cover fitted with zipped flaps to allow access to the tanks. This helped eliminate light and reduce stress. Not shown are the plastic lids placed over each tank that prevented most specimens escaping or moving into adjacent compartments

Flatfish: Many of the flatfish caught in the 30 min tows sustained various forms of damage, which we assessed using the scale devised by Houghton et al. (1971). This was a visual assessment made by the same individual on all occasions.

Scale damage on dorsal surface:
0. No scales lost
1. <5% lost
2. 5–40% lost
3. >40% lost

Bruising on ventral surface:
0. No bruises
1. <5% heavily bruised, or <50% superficially bruised (light pink tissues as opposed to deep red)
2. 5–40% heavily bruised or >50% superficially bruised
3. >40% heavily bruised

Wounds:
0. No cuts or lacerations
1. 1–3 small cuts
2. >3 small cuts or one severe cut or wound
3. Extensive small cuts or very severe wounds

Differences among species in susceptibility to different types of damage were ascertained using Kruskal-Wallis ANOVA (K-W)

Swimming crabs: We observed that many of the swimming crabs *Liocarcinus depurator* from the by-catch of the trawl had cracked or crushed carapaces and missing or broken appendages, which reduced their chance of survival. These injuries could have been caused by several different parts of the gear or by the abrasive action of other animals in the cod end. Due to lack of time, we were unable to investigate the cause of these effects using the RV 'Corystes', consequently a pair of 2 m beam trawls were used simultaneously (for statistical reasons) from a chartered 10 m commercial fishing boat, approximately 1 n mile off Rhos Point, North Wales (see Kaiser et al. 1994). Although this gear was not entirely comparable with the large gear, we were interested in the effects of different parts of the gear and fishing process, and have assumed that the observed effects are scaled up when using larger gears.

The 2 m beam trawls were towed for 3 different durations: 2.5, 5.0 and 7.5 min, with one of the beams fitted with linked, spiked tickler chains (hereafter referred to as chain mat) (for full details of gear and experimental design see Rogers & Lockwood 1989, Kaiser et al. 1994) or with just the weighted ground rope. The tows of different durations were set up in a Latin square design, by taking 3 tows of different duration along 1 latitudinal cruise track and repeating this at 2 other latitudes with the order of tow duration set at random along the longitude (see Kaiser et al. 1994). Thus we were able to test whether the presence or absence of chain mat, the time spent in the cod end, or a combination of these effects increased the injury rate of swimming crabs. A total of 509 crabs were examined for damage. The proportion of crabs with missing legs for each haul within each treatment was analysed using a split plot designed model (Snedecor & Cochran 1967) on arcsin-transformed data. Latitude was set as the block effect.

RESULTS

Survival of discards

Coelenterates

It was not possible to determine the initial mortality of dead man's fingers *Alcyonium digitatum* by direct observation. However, after 24 h, the colonies had taken up water, increased their volume and their polyps were extended with mobile tentacles. On exposure to light the polyps retracted.

Annelids

Between 7 and 8% of the sea mice *Aphrodite aculeata* died during the experiments and observations of those in the catch indicated that few were damaged initially.

Crustaceans

Mortality of common hermit crabs *Pagurus bernhardus* was generally low (6%) and was confined to those that had abandoned their protective gastropod shell. More than twice as many of the other species of hermit crab, *Pagurus prideaux*, had died after 120 h. Despite their fragile appearance, only 24% of the spider crab *Macropodia rostrata* died during the experiment, the dead crabs usually had cracked carapaces. Swimming crabs *Liocarcinus depurator* had the highest total mortality of any of the crustaceans (50 to 57%).

Molluscs

Of the total of 25 octopus *Eledone cirrhosa* studied, between 87 and 90% survived after 120 to 144 h. The whelks *Buccinum undatum* and *Neptunia antiqua* and the scallop *Pecten maximus* were well protected by their thick shells, hence 100% survived. Thinner shelled queen scallops *Aequipecten opercularis* were slightly more vulnerable, but the greatest proportion that died was only 10% after 144 h.

Echinoderms

With the exception of sea urchins, echinoderms were highly resilient to the effects of trawling Throughout the experiments, starfish *Asterias rubens* and *Astropecten irregularis* had a much lower mortality (0 to 1%) than any other species (Table 1). At the beginning of the experiments most (96%) of the brittlestars *Ophiura ophiura* appeared to be alive, but after 120 h total mortality increased to 19% Those specimens that died had >50% damage to the oral disc, which further disintegrated as the experiments progressed. Initially, 10% of the sea urchin *Psammechinus miliaris* died, increasing to a total of 62% by the end of the experiment. Death in these urchins was characterised by extreme loss of spines (>50%) and the inability to attach themselves to the sides of the tanks with their tube feet.

Pisces

Despite their robust appearance and no initial mortality, dragonets *Callionymus lyra* continued to die throughout the experiments, and had a final mortality of between 68 and 97%. Generally, the cause of death was not apparent, although some individuals showed signs of bruising. Initially, none of the cuckoo rays *Raja naevus* were dead, but after 5 d 41% had died. Dead cuckoo rays were extensively bruised and had pink wings. Plaice *Pleuronectes platessa* and dab *Limanda limanda* had the highest initial mortality of the fish examined, and their total mortality increased to 61% and 76% respectively. Plaice and dab that died in the experimental tanks showed extensive scale loss (>30%) and bruising, particularly around the head. Lesser-spotted dogfish *Scyliorhinus canicula* were extremely resilient as 90% had survived after 6 d.

Table 1. Percentage survival of species retained in the cod end of 4 m beam trawl towed for 30 min. As the species and time available for experiments varied between seasons, each date is shown separately. Percentage of individuals in the total catch that were alive (initially alive) and percentage alive at the end of the survival experiments are shown (i.e. total mortality). Mean bottom (B), surface (S) and ambient (A) air temperatures are given for each sampling occasion

Species	n	Date	Temp. (°C)			% Initially alive	% Alive at the end of each experiment				
			B	S	A		48 h	60 h	72 h	120 h	144 h
Polychaetes											
Aphrodite aculeata	50	Mar 92	7.1	8.1	8.5	98	91				
	75	Aug 92	11.9	15.2	16.5	96				90	
Crustaceans											
Pagurus bernhardus	39	Mar 92				100	94				
	15	Aug 92				100				100	
	25	Apr 94				100					100
Pagurus prideaux	35	Apr 93				97				81	
	55	Apr 94				99					90
Liocarcinus depurator	50	Mar 92				90	50				
	38	Apr 93				87				55	
	18	Oct 94	10.2	12.2	12.4	95		57			
Liocarcinus holsatus	14	Oct 94				95		95			
Macropodia rostrata	23	Mar 92				98	74				
Molluscs											
Buccinum undatum	37	Apr 94				100					100
Neptunia antiqua	35	Apr 94				100					100
Aequipecten opercularis	10	Apr 94				100					90
	50	Oct 94				100		98			
Pecten maximus	65	Apr 94				100				100	
Eledone cirrhosa	15	Apr 93				100				87	
	10	Apr 94				100					90
Echinoderms											
Asterias rubens	126	Mar 92				100	99				
Astropecten irregularis	17	Mar 92				100	100				
Crossaster papposus	24	Apr 94	8.0	9.5	11.9	100					92
Ophiura ophiura	34	Mar 92				96	77				
	44	Apr 93	8.2	9.7	12.1	96				81	
Psammechinus miliaris	100	Mar 92				90	38				
Pisces											
Pleuronectes platessa	90	Apr 93				60				40	
	32	Apr 94				65					39
Limanda limanda	22	Apr 94				49					24
Callionymus lyra	65	Aug 92				100			3		
	50	Apr 93				100				32	
Scyliorhinus canicula	32	Apr 93				97				94	
	10	Apr 94				100					90
Raja naevus	32	Apr 93				100				59	

Survival of animals passing through the cod end

Compared with the animals retained in the cod end for 30 min, a greater percentage of those that passed through the cod end and into the net cover survived, e.g. hermit crabs (*Pagurus bernhardus*, 100%; *P. prideaux*, 90%), *Macropodia rostrata* (99%), dragonets (86%), and dab (84%) (Table 2). However, some species had a higher mortality, e.g. *Liocarcinus holsatus* (15% as opposed to 5%), which may be explained by smaller individuals being more vulnerable to damage. Small species, such as those of *Sepiola* and *Pomatoschistus*, were never recorded in the cod end, but none survived capture in the cod end cover (Table 2).

Damage to the by-catch

Echinoderms

A similar proportion of both *Asterias rubens* and *Astropecten irregularis* had broken arms regardless of tow duration (*G*-test between each species and between tow duration, all non-significant at $p > 0.05$). In contrast, all the *Ophiura ophiura* had broken arms, and 45% had all their arms broken in a 2 h tow (Table 3).

Table 2. Number of dead individuals of each species that were found in the cod end cover. Remaining live individuals used for survival experiments and percentage alive after 60 h are also given

Species	No. initially dead	No. in experiment	% Alive after 60 h
Pagurus bernhardus	0	20	100
Pagurus prideaux	4	22	90
Macropodia rostrata	0	220	99
Liocarcinus holsatus	20	83	88
Liocarcinus depuratur	2	20	74
Sepiola atlantica	2	20	0
Callionymus lyra	3	23	86
Solea solea[a]	0	20	100
Agonus cataphractus	0	14	85
Limanda limanda	0	13	84
Pomatoschistus sp.	5	15	0

[a]Soles in the cover net were <24 cm total length (minimum landing size)

Flatfish

Over 68% of all the flatfish that were retained in the cod end and examined had scales removed (Table 4). Dabs had the highest mean scale damage score (1.70 ± 0.07, K-W, H = 57.3, df = 3, $p < 0.001$). Most flatfish (>69%) had some form of bruising. Although there were no significant differences among flatfish species (K-W, H = 5.6, df = 3, $p > 0.2$), sole tended to be worst affected (Table 4). Severe wounds and abrasions were less common than the other 2 forms of damage. The mean score for all flatfish species was <1 (Table 4), however flounders had a significantly higher score than the other species (K-W, H = 23.6, df = 3, $p < 0.001$).

Table 3. Damage sustained by starfish (percentage of total) in the cod end of a 4 m beam trawl towed for either 1 h (catch weight = 70 kg) or 2 h (catch weight = 328 kg). Individuals with 5 arms are undamaged; worst damaged individuals had either an oral disc with arm remnants (0) or an oral disc only, with no arm remnants

	n	No. of arms intact: 5	4	3	2	1	0	Disc only
2 h tow								
Asterias rubens	231	71	22	5	2	0	0	0
Astropecten irregularis	117	60	19	12	4	5	0	0
Ophiura ophiura	22	0	14	14	23	4	18	27
1 h tow								
Asterias rubens	67	73	19	5	3	0	0	0
Astropecten irregularis	96	67	22	9	2	0	0	0

Swimming crabs

A significantly higher proportion of crabs caught by the 2 m beam trawl fitted with chain mat had missing legs (52%), compared to the trawl fitted with just a weighted footrope (33%) (Table 5, $p < 0.007$). The percentage of crabs with missing legs did not vary with tow duration (Table 5, $p > 0.08$) for either type of gear (Table 5, ANOVA, $F_{2,15} = 0.12$, $p > 0.88$).

DISCUSSION

In general, our results indicate that survival differs greatly between taxa in the by-catch. For example, asteroid starfishes were highly resistant to the effects of entrapment in the cod end (Table 1). Mortality of echinoderms in the cod end seems to be related to the flexibility of the test, e.g the test of *Asterias rubens* is constructed of interlinked plates which allow greater flexibility than the larger plates of *Ophiura ophiura* (Table 3). At the other extreme, the fused plates of sea urchins make the test vulnerable to damage, leading to high mortalities (Table 1). Wassenberg & Hill (1993) report even higher mortality (84%) of echinoids in the by-catch of shrimp trawls, but they did not investigate the survivorship of other echinoderms. The results in Table 3 indicate ophiuroids are more susceptible to damage than asteroid starfish (1 h tow). A longer tow duration, however, did not increase the severity of damage sustained by the latter, despite a heavier catch weight (Table 3). This may indicate that a part of the gear, probably the chain mat, is responsible for the observed injuries.

Between 60 and 85% of the swimming crabs *Liocarcinus depurator* and 100% of *L. holsatus* survived in our experiments, which is similar to the findings of Wassenberg & Hill (1993) for other crab species. Our own observations indicate that if crabs have crushed or cracked carapaces, and/or >50% limb loss, they invariably die within the first 48 h (Table 1). Further investigation using the small 2 m beam trawl revealed that the chain mat was the prime cause of physical damage to crabs caught in beam trawls, and that their prospects of survival are not affected by the length of time spent in the cod end (Table 5). The higher percentage survival of *L. holsatus* may be explained by differences in behaviour patterns. During daylight, which coincided with our trawling, *L. depurator* remain buried within the top few cm of the sediment (Abelló et al. 1990) where they are vulnerable to damage by chain mat. Conversely, *L. holsa-*

Table 4. Damage to sole, dab, plaice and flounder retained in the cod end of a 4 m beam trawl towed for 30 min. Definition of damage score is given in text. Percentage of each species that sustained a particular level of 3 different types of damage is given with the mean ± SE score. Significant differences were tested using Kruskal-Wallis ANOVA (* $p < 0.001$)

Species	n	Score 0	1	2	3	Mean ± SE
Scale damage						
Solea solea	13	23	47	30	0	1.08 ± 0.21
Limanda limanda	83	12	37	51	10	1.70 ± 0.07*
Pleuronectes platessa	55	29	49	18	4	0.96 ± 0.10
Platyichthys flesus	38	32	60	8	0	0.76 ± 0.10
Bruising						
Solea solea	13	15	30	40	15	1.31 ± 0.26
Limanda limanda	85	30	43	24	2	0.98 ± 0.09
Pleuronectes platessa	55	29	32	36	4	1.14 ± 0.12
Platyichthys flesus	38	29	37	34	0	1.05 ± 0.13
Cuts						
Solea solea	13	76	16	8	0	0.31 ± 0.18
Limanda limanda	85	92	2	2	4	0.20 ± 0.07
Pleuronectes platessa	55	74	18	8	0	0.32 ± 0.08
Platyichthys flesus	38	37	42	21	0	0.84 ± 0.12*

tus vary activity with tidal cycles and hence are less likely to by damaged by the chain mat. The survival of swimming crabs that passed through the meshes of the cod end was not dissimilar to that of those retained in the cod end (Table 2).

A high proportion of the hermit crabs *Pagurus bernhardus* and *P. prideaux* were alive after 48 h (94 to 100% and 81 to 90% respectively). *P. bernhardus* use empty gastropod shells to protect their soft abdomen, and are able to withdraw the entire head and thorax into the shell, affording them almost complete protection. Those that died had abandoned their shell, probably in response to severe trauma (R. Elwood pers. comm.). Conversely, *P. prideaux* is rarely protected by a complete gastropod shell; its abdomen is normally encased within the commensal anemone *Adamsia palliata* which gives little protection from physical damage and may explain why fewer *P. prideaux* survived during our experiments. A greater number of both species of hermit crab survived when they passed through the meshes of the cod end, suggesting that prolonged retention, or exposure to air when the net is emptied, increases mortality.

Although small and fragile, 74% of the spider crabs *Macropodia rostrata* were alive at the end of our experiments. While sorting the by-catch on deck, we observed that they fold their legs close to their abdomen, which reduces the risk of limb loss. Furthermore, >99% of those that passed through the cod end survived (Table 2).

In general, the soft-bodied invertebrates, such as *Alcyonium digitatum*, *Aphrodite aculeata* and *Eledone cirrhosa*, rarely died in the survival tanks. Occasionally we observed cannibalism among *A. aculeata*. All of the colonies of *A. digitatum* had emergent, feeding polyps at the end of 120 h, which retracted on exposure to light. However, although these colonies seemed to survive the initial process of capture, it is unknown whether they would survive once returned to the sea, especially if detached from their substrate. Using time-lapse cameras, we have recorded colonies of *A. digitatum* being transported by tidal currents across the seabed (Kaiser & Spencer unpubl. data), which may lead to abrasion of individual polyps and consequently to death of the colony.

The survival of fish varied between species. Few dragonets survived retention in the cod end, but of those that passed through the meshes, 86% survived (Table 3). While it is possible that exposure to air was enough to induce brain haemorrhages, as in

Table 5. Number of crabs with missing appendages caught in a 2 m beam trawl fitted with either chain mat or a ground rope only. Data pooled for all 9 tows (3 replicates for each duration), as there was no significant difference between different tow durations. In addition to missing appendages, some crabs had crushed carapaces. Split-plot ANOVA for the effects of gear and tow duration effects also shown

	n	No. of appendages missing 0	1	2	3	4	5	6	7	8+	No. of crabs with crushed carapaces
Chain mat	271	137	62	39	14	10	3	3	0	3	61
No chain mat	238	163	36	17	10	6	2	2	1	1	17

ANOVA Source of variance	df	SS	MS	*F*	p
Latitude	2	0.0703	0.0352	3.1	0.084
Gear	1	0.1207	0.1207	10.5	0.007
Latitude × Gear	2	0.0002	0.0001	0.01	0.99
Error	12	0.1379	0.0115		
Total	17	0.3292			
Tow duration	2	0.0433	0.0216	1.16	0.24
Gear	1	0.1207	0.1207	8.96	0.01
Tow duration × Gear	2	0.0033	0.0017	0.13	0.88
Error	12	0.1616	0.0135		
Total	17	0.3292			

plaice (Kelle 1977), it is more likely that other factors such as damage from the chain matrix or by-catch are responsible. Damage sustained by flatfish differed for some species (Table 4). Dab incurred the greatest scale removal, whereas flounders had the most severe wounds. These differences in damage may be explained by the behaviour of each species in relation to a beam trawl and its body characteristics. Mortality is directly related to the extent of physical damage to these fish as observed by Van Beek et al. (1990) Fish that died had >30% scale loss and either lesions and/or bruising. Survival of dab passing through the meshes, and retained in the fine-mesh cover, was twice that of those retained in the cod end for 30 min. Although not entirely comparable, these results suggest that abrasion from other components of the catch (particularly starfish) leads to higher mortality, and that a proportionately larger number of dab passing through the cod end meshes survive.

Our estimates of total mortality, based on tows of 30 min duration, underestimate total mortality in commercial tows which are usually 1 h or 2 h long, depending on the catch rate and ground type. Van Beek et al. (1990) have demonstrated a negative exponential relationship between the survival of sole and plaice with haul duration. While this relationship is probably representative for flatfishes, it may not apply to invertebrate species.

While we have endeavoured to create the best possible conditions for holding animals during prolonged periods of observation, some experimental artefacts are inevitable. Alternative protocols such as tranferring animals to holding tanks in the laboratory adds another handling stage which could increase stress (Wassenberg & Hill 1993). None of the survival experiments conducted to date have addressed the fate of the surviving animals on return to the sea. For example, although a swimming crab may survive the loss of both chelipeds, its ability to forage and defend itself from predators will be severely limited. Thus further investigations are required to determine the fate of discards once they are returned to the sea, before any reliable estimates of total discard mortality can be formulated. We are able to conclude that by-catch mortality is highly variable between species; however, within the confines of this study, we have been unable to examine the effects of different gear, type of bottom fished and climatic conditions on deck. Our study provides a useful indication of the by-catch species which are likely to die as a result of capture, and those that have the greatest chance of survival.

Acknowledgements. The authors thank 3 anonymous referees for helpful comments and suggestions that improved the manuscript, and M. Fonds and S. Groenewold for assisting with various experiments.

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This article was submitted to the editor

Manuscript first received: January 17, 1995
Revised version accepted: April 10, 1995