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Composition and fate of the catch and bycatch in the Farne Deep (North Sea) *Nephrops* fishery

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Landings of *Nephrops* in the North Sea Farne Deep *Nephrops* fishery represented only 12% of the original catch by weight. The bycatch included 34 species of fish and 23 invertebrate taxa, as well as undersized and unmarketable *Nephrops*. There were small landings of lemon sole, plaice, whiting, cod, haddock, and starry ray, but the large majority of the bycatch was of juvenile fish or species of no commercial value and they were discarded. Survival of discarded *Nephrops* and fish was probably minimal. The discards were usually on deck for several hours before they were thrown overboard, by which time the large majority of fish and a high proportion of *Nephrops* were dead. *Nephrops* and some fish sank when they were returned to seawater, but other species of fish floated on the surface. In all cases, seabirds took the majority of discards (>70%) when they were thrown overboard. Those *Nephrops* landing on the seafloor alive are likely to have suffered further mortality because: (1) the bycatch was often discarded distant from the fishing grounds (i.e. the natural habitat), at places where conditions were probably unsuitable for their survival; (2) a high proportion of *Nephrops* was injured in the trawl and it is evident from laboratory tests that such injuries may cause death several days later; and (3) laboratory studies suggest that injured *Nephrops* may have difficulty re-establishing themselves on the seafloor because they compete unsuccessfully with conspecifics for food or shelter. There is concern that, in addition to the impact of the *Nephrops* fishery on stocks of *Nephrops* and the commercially important fish (especially whiting) which are caught in large numbers in the bycatch, it may have profound effects on the ecology of the seabed. The fishery effectively transfers organic matter from the seafloor to the surface of the sea, where most of it is removed for human food or by seabirds. Little of the fish or *Nephrops* catch returns to the seabed, dead or alive.

Key words: North Sea, *Nephrops*, discards, seabirds, seabed ecology.

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Introduction

The process of discarding unwanted parts of the bycatch back into the sea is an important feature of the world fisheries, involving as much as 10% of the total world catch (Saila, 1983). Attention has focused in particular on shrimp fisheries in which the bycatch may be 5 to 10 times greater by weight than the catch of target species (Allsop, 1982; Slavin, 1982), and may amount for 8 to 16 million tonnes per year for world shrimp fisheries as a whole (Andrew and Pepperell, 1992). The extent to which the bycatch is utilized varies in different parts of the world. Most of it is landed in some Asian shrimp fisheries (e.g. Silas *et al.*, 1984; Unar and Naamin, 1984), but little, if any, is used in shrimp fisheries in most of Europe, North America, and Oceania (Saila, 1983; Gulland and Rothschild, 1984).

The bycatch may include: undersized individuals of target species; that part of the catch which is above quota; and non-target species. There are major concerns that discarding: (1) wastes potentially good food; (2) reduces stocks of target and commercially valuable non-target species; and (3) disrupts ecological processes on the seabed (e.g. Saila, 1983).

The present study is based on the *Nephrops norvegicus* fishery off the north-east of England, which is the largest fishery of its kind in the North Sea. The fishing area is adjacent to the Farne Deep. The main port is North Shields, where 1260 tonnes of *Nephrops* (valued at £1.8 million) were landed in 1989 (MAFF, 1991), but the fishery includes several other small ports between Seahouses (to the north) and Hartlepool (to the south). Regulations, which are aimed at protecting the fishery and/or reducing the bycatch, are as follows: (1) the

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minimum permitted mesh size of nets used by vessels trawling for *Nephrops* is 70 mm; (2) the minimum permitted percentage catch of legal-sized *Nephrops* on board is 30%; (3) the maximum permitted percentage bycatch of protected fish species (also of legal size weight) is 60%; and (4) the minimum size (carapace length) of *Nephrops* is 25 mm [Council Regulations (EEC) No 3094/86, dated 7 October 1986]. An additional requirement under the UK Sea Fish (Specified Sea Areas Regulation of Nets and Other Fishing Gear) Order 1991 is that, since 1 July 1991, fishermen have been required to fix square-mesh panels to their nets. Trials using these panels have demonstrated their effectiveness in reducing bycatches of cod, haddock, and whiting (Main and Sangster, 1982; Arkley, 1991; Briggs, 1992).

The primary objectives of the present study were to obtain information on the size and composition of the bycatch in the North Sea *Nephrops* fishery and the survival and fate of discards which are returned to the sea. The study was divided into five parts. First, estimates were made of the size and species composition of the catch and bycatch in the North Sea fishery. Second, an investigation was made of fishing practices and, in particular, the extent to which unwanted bycatch is discarded over fishing grounds, on the way back to port, or in port itself, by asking fishermen to respond to a short questionnaire. This part also included an investigation of the distribution of *Nephrops* along transects from Blyth into the fishing grounds because some fishermen suggested informally that populations of *Nephrops* had become established closer inshore in recent years because of discarding practices. Third, estimates were made of the injuries received by *Nephrops* in the trawl, their mortality, and their fate after being discarded. Fourth, a laboratory study was made of the effect of injury on the ability of *Nephrops* to compete with conspecifics for food and shelter. Fifth, a study was made of the mortality of fish which had been captured by the trawl and their fate after being discarded.

Methods

Studies were carried out between December 1990 and November 1992. The Dove Marine Laboratory's (University of Newcastle) RV "Bernicia" was used for all boatwork, except where samples of the commercial catch were purchased directly from fishermen (see below). The trawl used by RV "Bernicia" had a net with a mesh of 12.5 mm, reduced to 10 mm at the cod-end. *Nephrops*, which were brought back to the laboratory for longer-term studies of survival or behavioural experiments (see below), were placed in buckets of seawater soon after capture and transported back to the laboratory. Throughout the paper, means are presented ± their standard errors.

Catch, bycatch, and discards in the *Nephrops* fishery

Surveys of *Nephrops* catches were carried out between January and August 1991. Samples of unsorted catch and sorted discards were purchased from fishing vessels when they returned to the ports of Amble, North Shields, or Hartlepool throughout this period. Samples were taken from 50 vessels as follows: January (1), February (5), March (14), April (5), May (4), June (2), July (8), and August (11). They were obtained either by contacting skippers by radio and arranging for them to bring samples back to port or, in cases in which sorting of discards from landings was carried out in port, they were purchased at the quayside without prior arrangement. Samples were taken only from vessels which spent less than 24 hours at sea. One basket of unsorted catch (approximately 20 kg) and half a basket of sorted discards (approximately 10 kg) was taken from each vessel. Samples were shovelled into baskets. In addition, samples of approximately 50 individuals of the sorted landings were purchased from each vessel in each of the three landing categories: "large", "medium", and "small". Total landings were weighed before they were brought ashore from each of the vessels that was sampled.

The samples of catch and discards were brought back to the laboratory and sorted into constituent species. Sub-samples of 100–120 *Nephrops* were taken from each sample; individuals in them were weighed, sexed, and measured (carapace lengths). All fish in the samples were weighed and their lengths measured from head to tail. Invertebrates (other than *Nephrops*) were identified but the total weight only of the invertebrate catch was measured. Individuals in the samples of landed *Nephrops* were weighed and measured. Landings had been "tailed" at sea in some cases, and, when this had occurred, a raising factor of 2.96 was used to convert tail weights to equivalent whole-animal weights.

The data collected was used to estimate the total weights and numbers of *Nephrops* in the catch and discards for each fishing vessel. The total weight of discards was calculated using the method described by Pope *et al.* (1991), which requires the mean weights of: (1) individuals in the discards; (2) those in the catch; and (3) those in the landings. The formula is as follows:

$$W_D = W_L[w_D(w_L - w_C)]/[w_L(w_C - w_D)],$$

where W_D and W_L are the total weights of the discards and landings, and w_D, w_L, and w_C are the mean weights of *Nephrops* in the discards, landings, and catch, respectively. The total weight of the *Nephrops* catch was calculated by summing the weight of the discards and that of the landings (which had been measured directly on board; see above). Numbers of *Nephrops* in the catch, discards, and landings were then calculated by

dividing the total weight of each by the mean weight of individuals in the respective samples.

Total weights of fish species and invertebrates (other than *Nephrops*) in the original catch or discards were estimated by raising the weights of each sample of catch or discards by a factor determined by dividing the total weight of the *Nephrops* catch or discards (as estimated above) by the weight of *Nephrops* in the sample of catch or discards. This was done separately for each fishing vessel sampled.

Discarding practices of fishermen and the distribution of *Nephrops*

Nine fishermen from vessels which fished from North Shields and 10 from vessels from Amble answered the following questionnaire relating to their fishing practices:

1. On your last fishing trip what percentage of discards was returned to the sea?
   (i) Over the fishing grounds where you trawl for *Nephrops*?
   (ii) On the way back to port, between the fishing ground and port?
   (iii) In port itself?
2. Approximately how long is it between bringing the catch on board and discarding the unwanted catch back into the sea? Since this obviously varies, please could you give a minimum and maximum time?
3. Approximately how long does each trawl last before the catch is brought on board? Again, please give a minimum and maximum time.

The distribution of *Nephrops* off the Northumberland coast was investigated along three transects, which were in approximately north-easterly, easterly, and south-easterly directions from Blyth (see Fig. 4 below). Trawling could not be undertaken in water which was less than 20 fathoms deep because of large boulders, which are scattered over the substrate close to the shore. A single trawl, of duration 10 minutes, was made at each station, and the numbers of *Nephrops* counted in it.

Injury and survival of *Nephrops* in the catch

Mortality and injury of *Nephrops* in the catch was investigated in two samples: one was a sample of the catch purchased from a fishing vessel returning to Amble; the other was a trawled sample taken by RV "Bernicia". In the former case, the catch had been on deck for an unknown period of time, but for at least several hours. The RV "Bernicia" catch was examined after it had been on deck for approximately 1 h. Individual *Nephrops* were recorded as dead or alive and, in addition, records were kept of the extent of their injuries (i.e. loss of chelipeds or walking legs, and/or damage to the carapace or abdomen).

The effect of injuries received in the trawl on mortality several days later was investigated by taking samples of injured and (as far as could be discerned) uninjured *Nephrops*, collected by RV "Bernicia", back to the laboratory. They were placed in seawater containers, $1.0 \times 1.4 \times 0.3$ m, in which there was constantly-running seawater to a depth of about 0.2 m. Survivorship of males and females was not the same in trawled samples of *Nephrops* (see below), so that the two sexes were kept separately from one another in these tests. When first set up there were 50–58 *Nephrops* in each container. Ten standard building bricks were placed in each of them in order to minimize contact between individuals. Each container was examined daily and dead *Nephrops* removed from it.

The relationship between the extent of injuries received by *Nephrops* and the duration of the trawl was investigated by examining trawl samples taken by RV "Bernicia" in which trawling lasted for 15 min (n=2), 20 min (n=6), and 30 min (n=2).

The tendency for dead *Nephrops* to float or sink when returned to seawater from the catch were investigated using individuals from two trawl samples taken by RV "Bernicia". Individuals were placed in buckets of seawater on deck and then recorded as "floating" or "having sunk" 15 min later.

The extent to which discarded *Nephrops* are taken by seabirds which follow fishing vessels was investigated by throwing groups of five *Nephrops* overboard from RV "Bernicia" when there was a catch on board. Estimates were made of the number of *Nephrops* taken by birds in each of 25 tests.

Behavioural interactions between injured and uninjured *Nephrops*

The possibility that *Nephrops* which have been injured (in this case loss of a cheliped) have difficulty in competing with uninjured conspecifics for food or shelter was investigated in two situations.

Competition for food

The animals used in these experiments were live *Nephrops* which had been kept in the laboratory for approximately 1 week beforehand. Individuals of the same size (carapace length) and sex were placed in twos in aquaria measuring $54 \times 38 \times 10$ (high) cm in which there was running seawater. In each case *Nephrops* were chosen so that one of them lacked a cheliped and the other individual was intact. Shelters were constructed with three bricks at opposite ends of each aquarium, and the two *Nephrops* invariably resided in them separately from one another. They were left overnight and then, for each of the next 4 days, subjected to eight tests in each of which a single piece of chopped mussel was introduced

Table 1. Estimated weights and numbers of individuals caught and discarded by fishing vessels per day. Fish which made up more than 0.5% of the catch only have been included. The means are those of monthly averages (January–August). They are presented ± standard errors.

	Catch			Discards		
	Mean weight (kg)	Per cent weight	Mean numbers (thousands)	Mean weight (kg)	Per cent weight	Mean numbers (thousands)
Nephrops	627 ± 41	33.1	44.3 ± 8.7	396 ± 36	22.2	37.8 ± 9.0
Cod	27 ± 10	1.4	0.2 ± 0.1	38 ± 17	2.1	0.3 ± 0.1
Dab	105 ± 43	5.5	2.0 ± 0.8	146 ± 68	8.2	2.9 ± 1.4
Dab, long-rough	69 ± 24	3.6	3.9 ± 2.5	147 ± 88	8.2	5.3 ± 3.4
Dragonet	28 ± 16	1.5	0.8 ± 0.4	32 ± 13	1.8	0.9 ± 0.4
Haddock	13 ± 3	0.7	0.2 ± 0.1	17 ± 4	1.0	0.3 ± 0.1
Pout, Norway	31 ± 9	1.6	1.6 ± 0.5	41 ± 12	2.3	1.9 ± 0.8
Plaice	41 ± 17	2.2	0.2 ± 0.1	27 ± 15	1.5	0.2 ± 0.1
Ray, starry	124 ± 53	6.5	0.3 ± 0.1	117 ± 71	6.6	0.4 ± 0.2
Rockling, four-bearded	30 ± 12	1.6	0.9 ± 0.3	45 ± 19	2.5	1.5 ± 0.6
Sole, lemon	52 ± 21	2.7	0.4 ± 0.2	39 ± 11	2.2	0.4 ± 0.1
Whiting	440 ± 111	23.2	10.5 ± 3.2	434 ± 140	24.3	11.5 ± 3.9
Other species	59 ± 25	3.1	0.5 ± 0.2	7 ± 2	0.4	1.1 ± 0.4
Total	1019 ± 127	53.8	21.5 ± 6.7	1090 ± 120	61.1	26.7 ± 7.8
Invertebrates	248 ± 49	13.1	—	299 ± 57	16.8	—
Total	1894 ± 328	100.0	—	1785 ± 327	100.0	—

into the centre of the aquarium, approximately equidistant from the shelters. The identity of the animal which took the food was recorded. Twelve aquaria were set up in these experiments, six contained two males and six contained two females.

Competition for shelters

Shelters, each consisting of three bricks and with space for one *Nephrops* only, were set-up in each of the four corners of aquaria, measuring 1.2 × 1.6 × 0.3 (high) m. They contained running seawater to a depth of about 20 cm. Sixteen aquaria were set-up and groups of four *Nephrops* (the residents), each of which was the same sex and size (carapace length) and which showed no signs of injury, were introduced into each of them. Eight of these aquaria contained males only, and eight of them contained females only. These animals normally resided so that each of them occupied a separate shelter. The following day, a group of four *Nephrops*, each lacking a cheliped, were introduced into each of eight aquaria (experimental group) and four uninjured *Nephrops* were introduced into each of the remaining eight aquaria (control groups). The introduced animals were the same size and sex as the residents. Each *Nephrops* had been marked beforehand with a small spot of cellulose paint for individual recognition. Records were kept of changes in the occupancy of shelters at 1-h intervals over the next 10 h.

Survival and fate of discarded fish

Injuries to fish caught in the trawl were investigated in three trawl samples taken by RV "Bernicia". Fish were examined within 15 min of being brought on deck. They were recorded as dead or alive, and estimates are made of the extent of their injuries (lesions to the body or fins).

The extent to which fish discards are taken by seabirds when they are thrown overboard was investigated in the same way as that described for *Nephrops* (above). Tests were carried out for four species: dab, long-rough dab, four-bearded rockling, and whiting. The test was repeated 10 times for each of them.

Results

The commercial *Nephrops* fishery

The catch and bycatch

The total estimated catch was 1894 ± 328 kg per fishing vessel per day. It included 627 ± 41 kg of *Nephrops*, which represented approximately 44 thousand individuals (Table 1). The weight of the *Nephrops* catch varied considerably from boat to boat and between months. During the study period it tended to be low in February and August, but high between March and May (Fig. 1).

The bycatch included 34 species of fish (Table 2); 13 of them are protected under EEC Council Regulation 3094/86. Eleven species dominated it: cod, dab, long-rough dab, dragonet, haddock, Norway pout, plaice, starry ray, four-bearded rockling, lemon sole, and whiting (Table 1). Whiting in particular were often abundant in the bycatch and sometimes exceeded the catch of *Nephrops* by weight. However, the abundance of species in the bycatch varied at different times of the year.

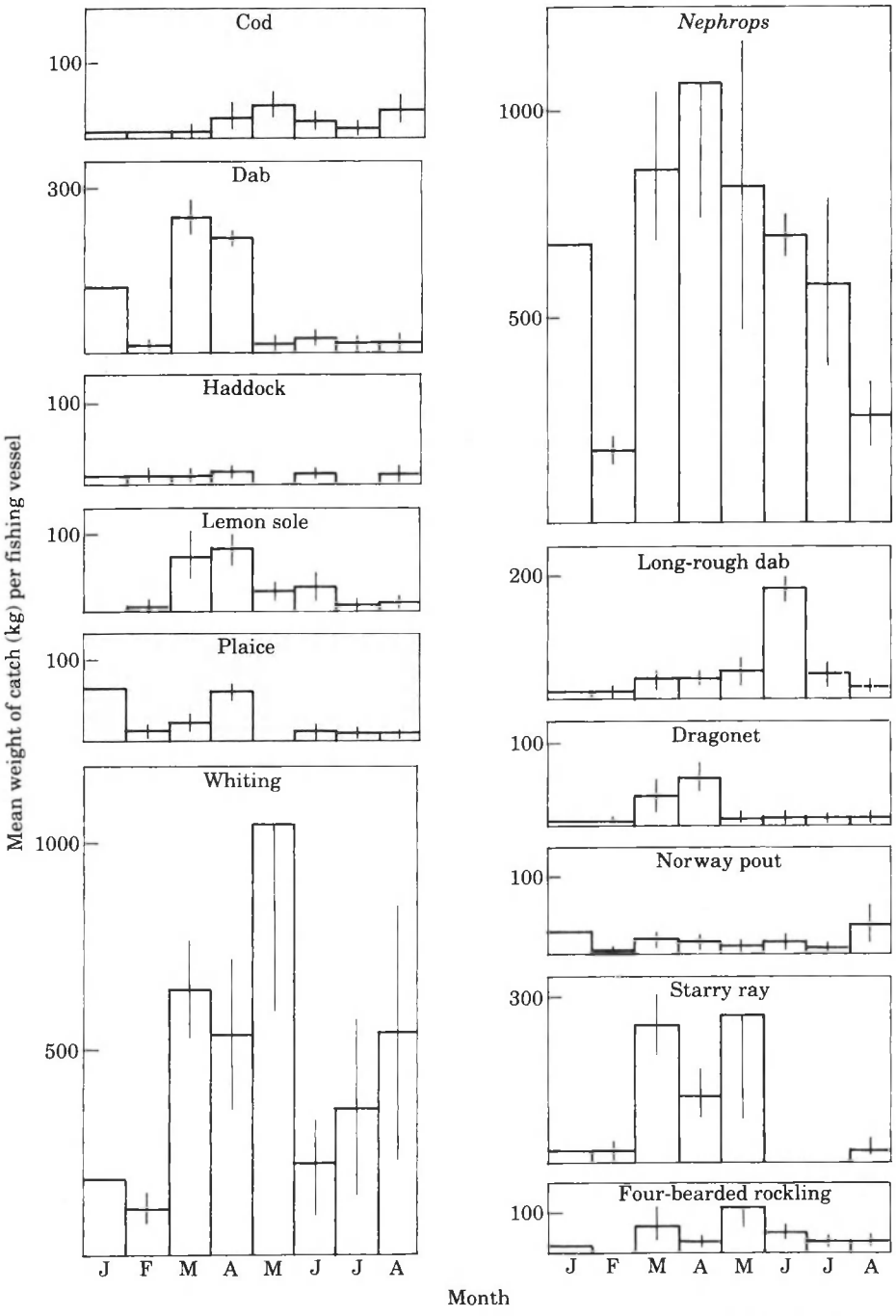

Figure 1. Mean monthly catches by weight (± their standard errors) of major fish species.

Whiting were, for example, particularly common in it between March and May, lemon sole and dab were most common in March and April, and starry ray were recorded most often between March and May (Fig. 1). There was nevertheless still some tendency for species to occur in similar relative proportions throughout the study period. Kendall coefficients of concordance for the rank orders in which fish species occurred in monthly averages were 0.41 by weight and 0.61 by numbers of individuals ($p<0.001$ in both cases).

Table 2. Fish species and invertebrates taxa recorded in the bycatch.

Fish species protected under Regulation 3094/86	Invertebrate taxa
Brill *Scophthalmus rhombus* (L).	Sea anemone *Bolocera* sp.
Cod *Gadus morhua* L.	Bivalve *Artica islandica* (L.)
Dab *Limanda limanda* (L.)	Brittle star *Ophiuroidea* spp.
Haddock *Melanogrammus aegelfins* (L.)	Bryozoan *Securiflustra securifrons* (Pallas)
Herring *Clupea harengus* L.	Common whelk *Buccinum undatum* (L.)
Lemon sole *Microstomus kitt* (Walbaum)	Dead man's fingers *Alcyonium digitatum* (L.)
Ling *Molva molva* (L.)	Gastropod *Fusus rostralus* (Olivi)
Mackerel *Scomber scombrus* L.	Great scallop *Pecten maximus* (L.)
Monkfish *Rhina squatina* (L.)	Hermit crab *Eupagurus* spp.
Plaice *Pleuronectes platessa* L.	Cuttlefish *Sepiola atlantica* (D'Orbigny)
Sole *Solea solea* (L.)	Pelican's foot shell *Aporrhais pespelecani* (L.)
Whiting *Merlangus merlangus* (L.)	Prawn *Pandalus* spp.
Witch flounder *Glyptcepholus cynoglossus* (L.)	Sea mouse *Aphrodite aculeata* (L.)
	Sea pen *Pennatula phosphorea* (L.)
	Sea squirt *Ascidiella* spp.
	Spider crab *Macropodia tenuirostris* (Leach)
	Spindle shell *Neptuna antiqua* (L.)
	Spiny crab *Lithodes maia* (L.)
	Squid *Alloteuthis subulata* (Lamarck)
	Starfish *Asteria rubens* (L.)
	Starfish *Strichastrella rosea* (L.)
	Swimming crab *Macropipus depurator* (L.)
	Tower shell *Turritella communis* (Risso)
Fish not protected	
Cuckoo ray *Raja neavus* Muller & Henle	Pipefish *Syngnathus* spp.
Dragonet *Callionymus* L.	Pogge *Agonus cataphractus* (L.)
Four-bearded rockling *Motella macrophthalma* (Cimbria)	Red gurnard *Aspitrigla cuculus* (L.)
Garfish *Belone belone* (L.)	Sandeel *Ammodytes* spp.
Gray gurnard *Eutrigula gurnhardus* (L.)	Short-spined sea scorpion *Myoxocephalus scorpius* (L.)
Hagfish *Mycine glutinosa* L.	Snake blenny *Lumpertus lumpretaeformis* (Walbaum)
Lesser-spotted dogfish *Scyliorhinus canicula* (L.)	Sprat *Sprattus sprattus* (L.)
Long-rough dab *Hippoglossoides platessoides* (Fabricius)	Starry ray *Raja radiata* (Donovan)
Norway haddock *Sebastes norvegicus* (Cuvier)	Topknot *Zeugopterus punctatus* (Bloch)
Norway pout *Trisopterus esmarkii* (Nilsson)	Wolfish *Anarhichas lupus* (L.)
Norwegian topknot *Phyrnorhombus norvegicus* (Günther)	

The bycatch of invertebrates (other than *Nephrops*) weighed 248 ± 49 kg per vessel per day, and included 23 taxa (Table 2).

Discards and landings

Nephrops of landable size and quality were sorted from the remainder of the catch on deck, and landed when vessels returned to port. The total weight of *Nephrops* landings was 231 ± 32 kg per vessel per day and, as would be expected, relatively low proportions of landed individuals (9% of males and 9% of females) were undersized (Fig. 2). The remainder of the *Nephrops* catch, estimated to be 396 ± 36 kg per vessel per day, representing about 38 000 individuals, was discarded. Surprisingly high proportions of the discards were of above minimum landing size (37% of males and 36% of females) but many of them were either "soft-shelled" or badly injured. Discard percentages were very high compared with other commercial fish species, means ranging from 47 to 73% (Table 3). Higher proportions of *Nephrops* were discarded when total catches were large than when they were small (Table 3).

The entire bycatch of non-protected species of fish and of invertebrates was discarded. The large majority of individuals of protected fish species were juveniles of below minimum landing size, and they too were discarded. Consequently, the estimated weights of species in the discarded catch were mostly similar to their estimated weights in the original catch (Table 1), and the relative proportions in which they occurred in discard and catch samples were similar. Spearman rank coefficients of correlation for the ranks of species were 0.85 by weight and 0.98 by numbers of individuals ($p<0.001$ in both cases). There were nevertheless some landings of commercially valuable fish which were of above minimum landing size. This is evident from the length–frequency histograms of lemon sole, plaice, and whiting (Fig. 3). Catch samples included 16, 29, and 5% of individuals of landable size, respectively, but discard samples (from which they had presumably been removed) included 2, 10, and 1% of them, respectively. The proprotions of fish of above and below minimum landing size in the catch samples are significantly different from those in the discarded samples in each of these

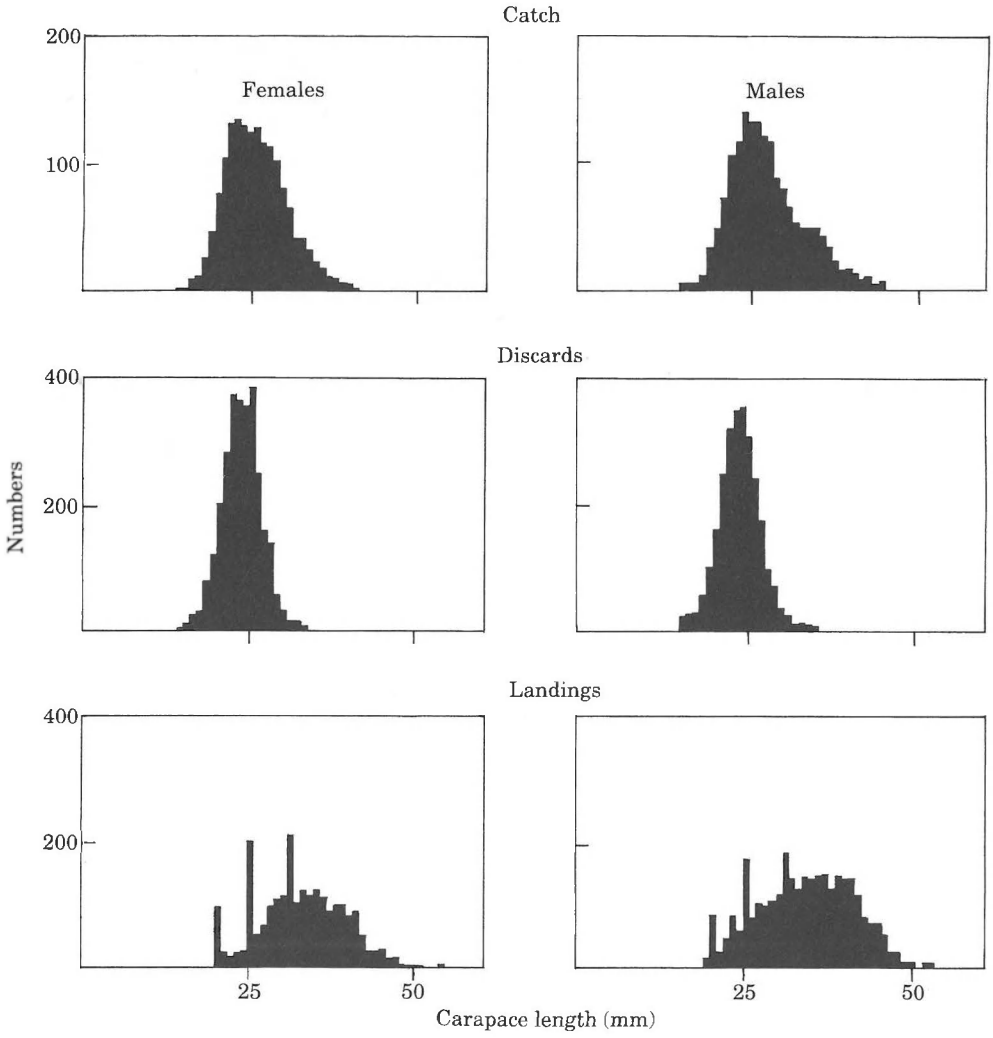

Figure 2. Size–frequency histograms of male and female *Nephrops* in samples of the catch, discards and landings.

three species ($p<0.001$; chi-square test). There are no significant differences in the proportions of fish of above and below minimum landing size in catch and discard samples of cod, haddock, dab, or starry ray ($p<0.05$ in each case), although large cod, haddock, and starry ray were landed from fishing vessels on at least some occasions (personal observations).

Table 3. The relationship between the size of the *Nephrops* catch by weight and the proportion of it that was discarded.

Weight of catch (kg)	Number of samples	Mean proportion discarded (per cent by weight)
<250	19	50.1 ± 20.8
251–500	10	46.5 ± 22.0
501–750	7	58.0 ± 10.4
751–1000	3	66.7 ± 11.9
>1000	11	73.2 ± 16.0

Fishing practices and the distribution of *Nephrops*

Responses of fishermen to the questionnaire suggest that the catch is usually on deck for several hours before it is sorted and the unwanted part of it discarded (Table 4). Only part of the discarded catch (49–62%) is returned to the sea over fishing grounds (i.e. the normal habitat of *Nephrops*). The remainder is discarded either on the way back to port or in port itself.

The distribution of *Nephrops* off Blyth was evidently similar to that described in a more extensive survey of the area by Symonds (1972). The numbers recorded in trawls taken along three transects from Blyth tended to increase with increasing depth of water offshore

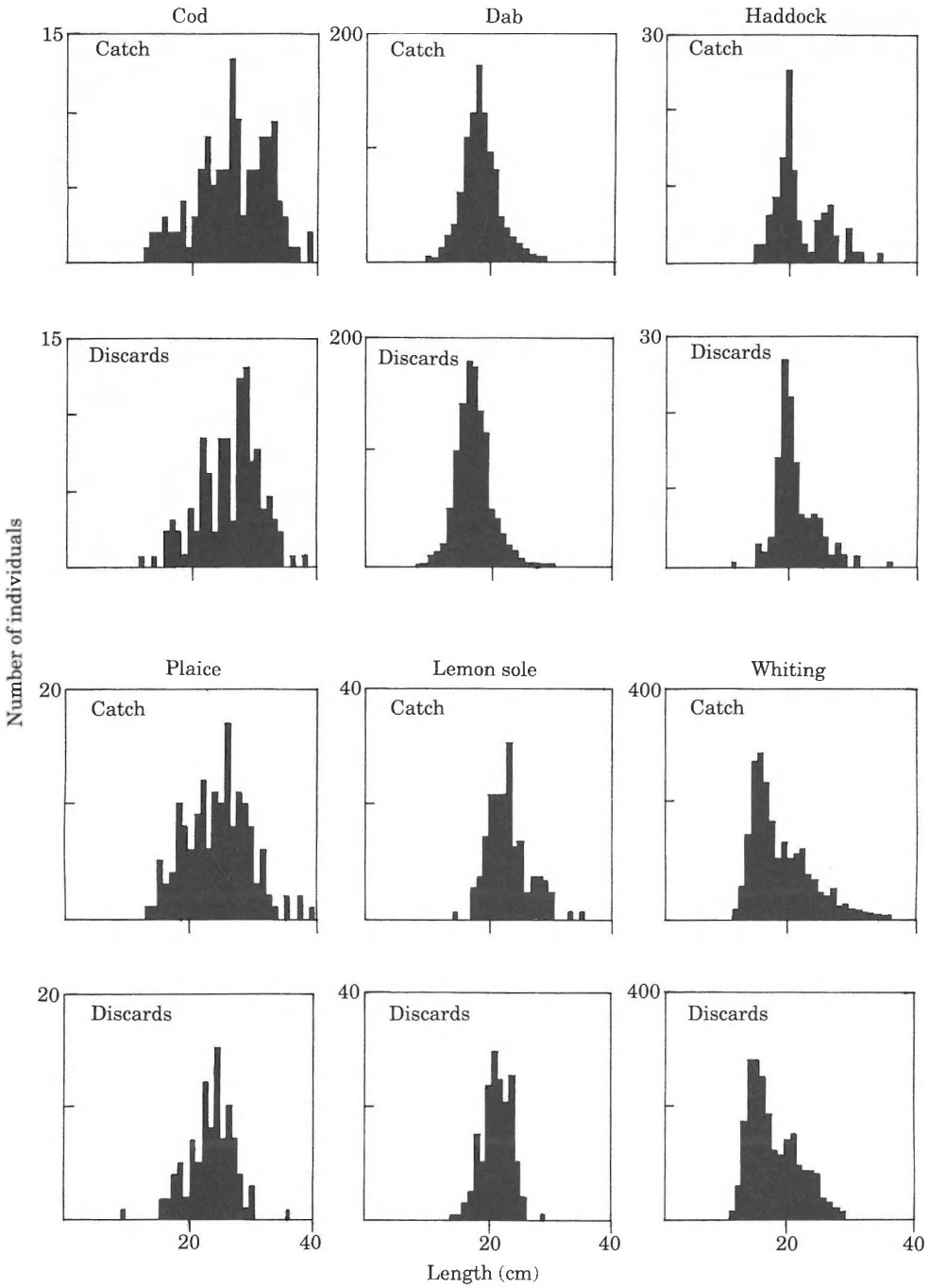

Figure 3. Size-frequency histograms of major fish species in the catch and the discards.

(Table 5; Fig. 4). Small numbers only were recorded at stations which were closer to shore than the 30-fathom contour.

Injury and survival of *Nephrops* in the catch

Most *Nephrops* are alive when the catch is brought on deck and only 15% of those trawled by RV "Bernicia" were dead when they were examined 1 h later. This is in marked contrast to numbers dead in a sample of catch purchased from a fishing vessel at Amble. The catch had been on deck for several hours, and 79% of the *Nephrops* in it were dead.

Injuries received in the trawl are probably the major cause of death. A high proportion of *Nephrops* captured

Table 4. Responses of fishermen from Amble and North Shields to the questionnaire about fishing practices.

Question		Amble (n=10)	North Shields (n=9)
Per cent of discards returned	Over fishing grounds	49 ± 3	62 ± 5
	On way back to port	45 ± 2	28 ± 5
	In port:	6 ± 3	9 ± 3
Time unwanted catch was on board (min)	Minimum	95 ± 30	113 ± 24
	Maximum	180 ± 9	227 ± 13
Duration of trawls (min)	Minimum	202 ± 7	237 ± 19
	Maximum	288 ± 7	302 ± 7

Table 5. Numbers of *Nephrops* recorded in 10-min trawls at stations along transects from Blyth (see Fig. 4).

Depth (fathoms)	Transect number I	II	III	Mean number ± standard error
20–30	0	0	0	
	15	1	0	3.5 ± 1.9
			4	
			8	
30–40	1	8	71	21.4 ± 12.6
	13	13		
>40	130	53	98.6 ± 30.8	
	50	54		
	206			

in the trawl had conspicuous injuries, including loss of one or both chelipeds, loss of walking legs and/or damage to the carapace or abdomen (Table 6). These injuries were almost certainly received in the trawl because the proportion of the catch injured was related to the duration of the trawl. Only 28% of individuals were injured in trawls of 15 min duration, but this increased to 37% for trawls lasting for 20 min, and to 59% for those lasting for 30 min (Table 7). The differences are significant ($p<0.001$: chi-square test). Higher proportions of females were injured than of males in each of the five samples shown in Tables 7 and 8. Injured *Nephrops* (both males and females) were more likely to have died than those lacking injuries. This was the case in samples collected by RV "Bernicia" and a fishing vessel returning to Amble (Table 8).

Injuries received in the trawl may also be the cause of death several days later. Some of those *Nephrops* which survived the trawl died when they were kept in running seawater under laboratory conditions (Fig. 5). Again, death was injury-related: significantly more *Nephrops* with injuries (both males and females) died than those without injuries within the 14-day period of these tests ($p<0.001$ in both cases; chi-square test).

Large numbers of seabirds, predominantly gulls, followed RV "Bernicia" when she had a catch on board. They were invariably present in large numbers when discards were thrown overboard and fed extensively on them. Discarded *Nephrops* sank when they reached the water (Table 9) but gulls were nevertheless able to take the majority (70%) of those thrown into the water before this happened (Table 10).

Behavioural interactions of *Nephrops*

Individual *Nephrops* kept in aquaria often interacted agonistically when they approached one another. They displayed aggression by facing one another and raising the chelipeds horizontally. Most encounters ended when one individual backed away from the other, but sometimes fighting occurred in which one animal seized the other by grasping it with one of its chelipeds.

Nephrops which lack chelipeds are evidently disadvantaged in competing with intact animals for food. It was found that intact animals were more successful than those lacking one cheliped in obtaining food items in each of 12 pairings ($p<0.001$; sign test). Each pair was subjected to 32 trials and, overall, the animal with both chelipeds intact took the food on 84% of them. Those with one cheliped took it in 10% of trials, and there was no outcome (i.e. neither individual took the food) in 6% of them.

When groups of intact *Nephrops* and those lacking a cheliped were kept together in aquaria, in which there were limited numbers of artificial shelters, the intact animals were relatively more successful in displacing occupants from their shelters than those with the injury. This was the case in each of the eight test aquaria ($p<0.001$; sign test) (Table 11).

Survival and fate of discarded fish

With the exception of hagfish, all fish which were examined from trawled catches were dead within 15 minutes of being hauled on deck. Some of them had lesions on their bodies or fins (Table 12).

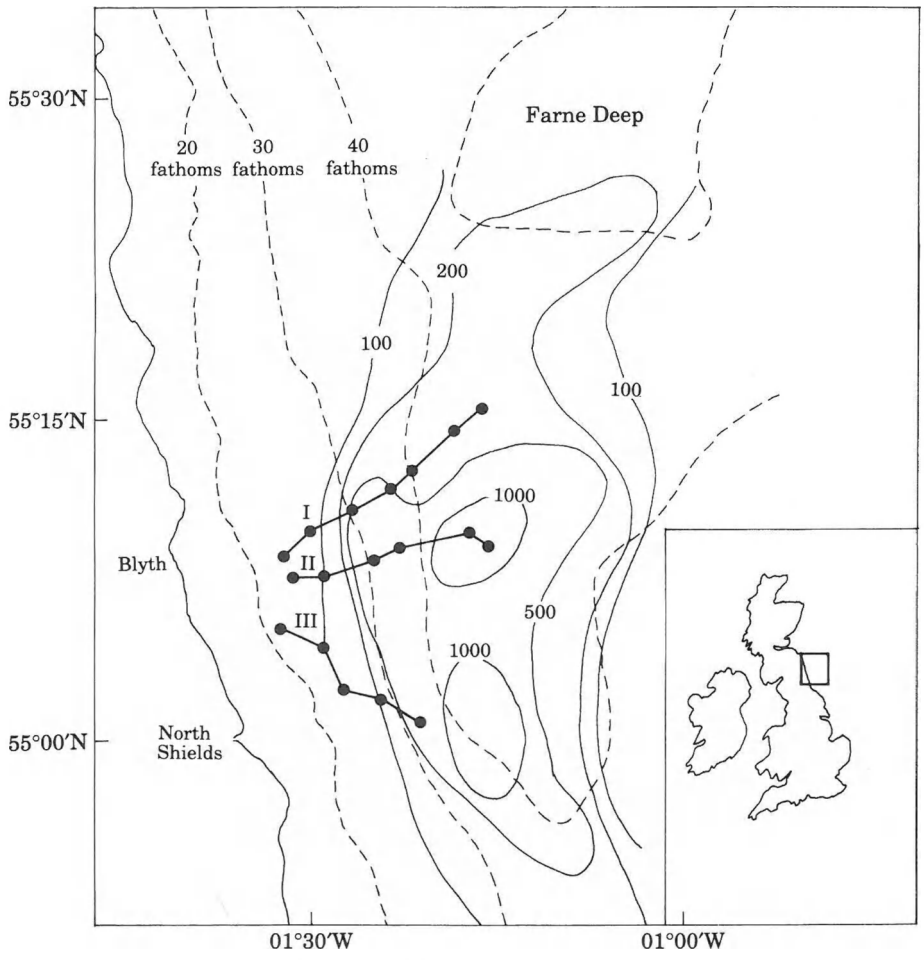

Figure 4. The positions of three transects off Blyth (I, II, III) and sampling stations at which trawls were made by RV "Bernicia". The 20-, 30-, and 40-fathom depth contours (dotted lines) are shown, together with contours showing abundance of *Nephrops* recorded by Symonds (1972). (See also Table 5.)

Table 6. The nature of injuries in samples purchased from a fishing vessel at Amble and collected by RV "Bernicia".

	Number in sample			
	Amble trawl		RV "Bernicia" trawl	
	Females 25	Males 17	Females 66	Males 73
Two cheliped missing	4	6	14	4
One cheliped missing	16	10	22	25
Walking leg(s) missing	0	1	16	18
Abdomen damage	1	0	0	0
Carapace damage	0	0	0	2
Multiple injuries	4	0	14	14

Some discarded fish floated on the surface when they were returned to seawater, others sank. Two species of dab sank in tests, while cod, dragonet, four-bearded rockling, and whiting floated (Table 9). Seabirds took the large majority of fish which were thrown overboard in tests from RV "Bernicia" (Table 10).

Table 7. Proportions of injured *Nephrops* recorded in catches in trawls by RV "Bernicia" lasting for 15, 20, or 30 minutes.

Duration of trawl (min)	Numbers of trawls		Total numbers		
			In samples	Injured	Per cent injured
15	2	Males	103	24	23
		Females	64	22	34
20	6	Males	391	133	34
		Females	298	118	40
30	2	Males	366	178	49
		Females	295	158	54

Table 8. The relative proportions of injured and uninjured *Nephrops* which were dead or alive in a commercial sample purchased from Amble and one collected by RV "Bernicia".

	Injured			Uninjured			
	Numbers	Dead	Per cent dead	Numbers	Dead	Per cent dead	Per cent injured
Amble							
Males	17	15	88	24	13	54	41
Females	25	25	100	23	17	74	52
RV "Bernicia"							
Males	138	28	20	220	31	12	37
Females	114	27	24	161	17	11	52

Discussion

The bycatch in the North Sea *Nephrops* fishery far exceeds the catch of target species, as it does in shrimp fisheries throughout the world (e.g. Gulland and Rothschild, 1984). The mean weight of *Nephrops* landings in the present study was 231 kg per fishing vessel per day, which represents 12% of the total original catch by weight. There were some landings of commercially valuable fish, but these were small by comparison with the landings of cod and whiting in the Nothern Ireland *Nephrops* fishery (Briggs, 1985). The discarded part of the catch is substantial. It included unmarketable and undersized *Nephrops*. Overall, 63.2% of the *Nephrops* caught by weight, and 85.3% by numbers of individuals, were discarded. The bycatch also included large numbers of juvenile fish of commercially valuable fish species, several species of non-protected fish which are of no commercial value, and invertebrates (other than *Nephrops*). The bycatch of small whiting alone was sometimes larger than the total *Nephrops* catch.

It has been assumed in the past that a large proportion of at least the *Nephrops* catch survives after being returned to the sea. Survival rates of between about 40 and 75% have been obtained from techniques such as keeping discarded *Nephrops* in cages on the seabed or in seawater containers (Symonds and Simpson, 1971; Edwards and Bennett, 1980), and Jones (1980) assumed 50% survival in calculations of mortality. The results of the present study suggest, however, that these are serious overestimates, and that survival is probably close to 0%. While 16% of a sample caught by RV "Bernicia" was dead when it had been on deck for 1 h, commercial vessels take between about $1\frac{1}{2}$ and 4 h to sort the catch, and mortality may be close to the 79% obtained here from a sample of commercial catch. There are at least four additional causes of death once *Nephrops* has been discarded. First, seabirds which follow trawlers take about 70% of discarded animals (see Blaber and Wassenberg, 1989; and Berghard and Rosner, 1992, for similar estimates but using different methods), and even those that escape birds may fall prey to midwater or bottom-living scavengers (Wassenberg and Hill, 1990; Hill and Wassenberg, 1990). Second, a high proportion of discards are thrown overboard distant from fishing grounds where conditions are probably unsuitable for them, and are unlikely to survive. There was no evidence that populations of them had become established between the fishing grounds and port as a result of the survival of discards (as had been suggested by some fishermen). The distribution of *Nephrops* off Blyth in 1991 was similar to that described by Symonds (1972). Third, even those *Nephrops* which do return live to their normal habitat on the seabed may die several days later

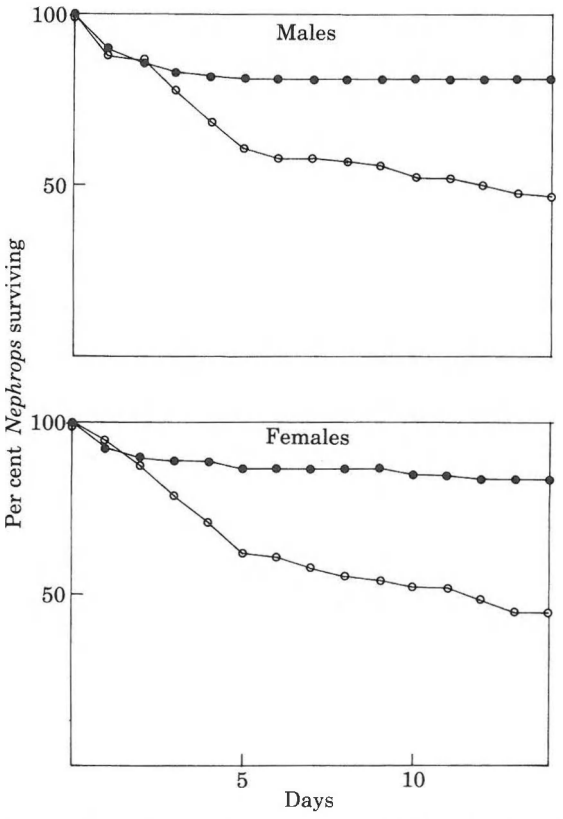

Figure 5. Percentages of injured (open symbols) and uninjured (closed symbols) male and female *Nephrops* surviving in the laboratory for 14 days after being taken in the trawl. The percentages are based on 98 injured males, 216 uninjured males, 84 injured females, and 143 uninjured females.

as a result of injuries received in the trawl. Fourth, it was shown here that injured *Nephrops* have difficulty in competing for items of food or for shelter with uninjured individuals under laboratory conditions. Farmer (1974) found that *Nephrops* were highly aggressive in burrow defence, and it is likely therefore that those discards which do return live to the seabed will have difficulty in re-establishing their territories. Survival of discarded fish species, such as plaice, sole, and Atlantic halibut, from beam or otter trawls may also be low when factors such as injury caused by fishing processes, haul duration, fish size, and handling time are taken into account (Nielson *et al.*, 1989; van Beek *et al.*, 1990).

Almost all fish in the bycatch, with the exception of hagfish, were dead by the time they were discarded. They included several commercially valuable species and particularly large numbers of small whiting. About 11 000 of them were discarded per fishing vessel per day during the study period. There are similar concerns about the impact of trawling on harvests of non-target fish species in other parts of the world. Tokai and Kutchara (1991), for example, have stressed the deleterious effects of capturing large numbers of juvenile flounder in the Seto Sea shrimp fishery on future yields of adult flounders. An additional concern is that trawling inflicts major damage to the ecology of the seabed. It causes physical damage to the substrate (e.g. de Groot, 1984; Hutchings, 1990; Daan, 1991; Bergman and Heep, 1992), but it also removes large quantities of organic matter from the seafloor to the surface where most of it is either removed as human food or, in the case of most discards, as food for surface scavengers. Relatively little of it can return to the seafloor, dead or alive. While impact of this efflux of material from the benthos is unknown, its influx to terrestrial systems via seabirds is clearly significant. Furness (1982) has pointed out that the numbers of several seabird species have increased in response to the increased availability of food from fishing operations in the North Sea, and that some populations of herring gulls, fulmars, and skuas appear to have become dependent on discards (or discarded fish offal). Similarly, populations of cormorants and terns have become dependent on discards from trawlers in the Moreton Bay (Queensland) fishery (Blaber and Wassenberg, 1989). Trawling is also likely to have an impact on predator/prey interactions on the seabed, and on species which compete with one another, by selectivity removing some

Table 9. The numbers of *Nephrops* and fish discards which floated or sank when placed in seawater.

Species	Tested	Numbers		Per cent	
		Floating	Sinking	Floating	Sinking
Cod	3	3	0	100	0
Dab	8	0	8	0	100
Dab, long-rough	27	0	27	0	100
Dragonet	10	10	0	100	0
Nephrops	20	0	20	0	100
Rockling, four-bearded	11	11	0	100	0
Whiting	35	35	0	100	0

Table 10. Numbers of discards which were thrown overboard in tests and taken by gulls.

	Numbers of tests	Numbers of individuals thrown overboard	Number taken by gulls	Per cent taken by gulls
Dab	10	50	39	78
Dab, long-rough	10	50	37	74
Nephrops	25	125	88	70
Rockling, four-bearded	10	50	47	94
Whiting	10	50	41	82

Table 11. The numbers of occasions on which *Nephrops* occupying shelters were displaced by intact individuals or injured ones lacking a cheliped in laboratory tests.

Test number	Numbers of times the occupant of a shelter was displaced by an intact *Nephrops*	Numbers of times the occupant of a shelter was displaced by a *Nephrops* lacking a cheliped
1	10	2
2	12	2
3	24	1
4	16	1
5	17	13
6	19	5
7	21	10
8	25	5

Table 12. The proportion of fish with injuries in trawls collected by RV "Bernicia", and percentage numbers dead 15 minutes after being brought on board.

Species	Total number	Injured	Per cent injured	Per cent dead
Blenny, snake	57	0	0	100
Cod	15	1	7	100
Dab	5	2	40	100
Dab, long-rough	33	16	52	100
Dragonet	1	0	0	100
Hagfish	12	0	0	0
Plaice	3	1	33	100
Rockling, four-bearded	28	2	7	100
Sole, lemon	9	0	0	100
Whiting	172	17	10	100

of them. Brander and Bennett (1989) have, for example, shown how different fishing pressures on *Nephrops* and its major predator, cod, are likely to affect their relative abundances. This relationship must, however, be only one of many which are affected by differential fishing mortality.

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