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Factors Affecting the Physical Condition of *Nephrops norvegicus* (L.) and Bycatch Composition in the Firth of Clyde *Nephrops* Fishery

A Scientific Report by

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University of Glasgow

Factors Affecting the Physical Condition of *Nephrops norvegicus* (L.) and Bycatch Composition in the Firth of Clyde *Nephrops* Fishery

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Abstract

The fishery for *Nephrops norvegicus* (L.) is one of the most valuable in the UK. Physical damage can affect the quality of *N. norvegicus* tails and increases the mortality of discarded animals. The aim of this study was to determine whether trawl duration affected the level of damage in individual *N. norvegicus* or the total catch composition of trawls. Nine trawls were made between October 2005 and January 2006 from the Firth of Clyde. All bycatch species were recorded, as well as the wet weights of the major taxa and a subsample of *N. norvegicus* was analysed from each trawl. The level of damage in *N. norvegicus* depended on both trawl duration and carapace hardness. Damage in 'hard' *N. norvegicus* was strongly correlated with trawl duration. 'Soft' and 'jelly' animals were more likely to be severely damaged regardless of trawl duration. Long trawls recovered a higher total mass of organisms than short trawls, but there was no difference in the composition of the catches. A slight correlation between the mass of invertebrates per trawl and the mean damage score for *N. norvegicus* was found. Shorter trawls are likely to improve the quality of *N. norvegicus* catches in 'hard' animals. Trawling should be avoided during moulting periods to maintain quality and avoid capturing 'soft' and 'jelly' individuals. Reducing bycatch rates could also improve the quality of catches, although this could reduce food availability to *Nephrops* stocks and continuous monitoring of the stocks would be required to ensure populations remained stable in this region.

Introduction

Nephrops norvegicus (Linnaeus, 1758) or 'Norway lobster' is currently one of the most valuable commercially-fished species in the UK. Approximately one third of global landings are made in Scotland from stocks in the North Sea and along the west coast, and reached an estimated value of £52.5 million in 2003 (FRS, 2004).

The Firth of Clyde is one of the main inshore fishing grounds for *Nephrops norvegicus* on the west cost of Scotland, and currently supports a fleet of approximately 120 vessels (ICES, 2005a). *N. norvegicus* is a mud-burrowing decapod crustacean, and is therefore caught using demersal fishing gear. The fishing fleet is mostly comprised of smaller vessels (>30m), which use single-rig otter trawls and diamond mesh nets (ICES, 2005a).

As with many fisheries, the Scottish *Nephrops* fishery is subject to quota restrictions as set by the EU. As such, it is important that landed catches should be of high quality in order to maximise the profit to the fishermen (e.g. Ridgway, 2005). One of the most obvious quality indicators is the presence of physical damage in the individuals. Trawling gear is known to cause significant damage to benthic organisms (e.g. Kaiser and Spencer, 1996, Tuck *et al.*, 1998, Collie *et al.*, 2000) but the effects can be highly variable between species and few studies have specifically examined the effects of trawling on the physical condition of *N. norvegicus*.

Ridgway (2005) reported a positive relationship between trawl duration and the extent of physical damage in *Nephrops norvegicus* from the Clyde Sea region. Mortality was found to be higher in heavily damaged individuals compared to undamaged animals. Most other studies have focussed on the survivorship of discarded or escaped animals (e.g. Wileman *et al.*, 1999, Harris and Andrews, 2005), rather than the animals that are kept for sale, but a similar link between damage and mortality rates was found.

Physical damage and limb loss are known to affect survival in decapod crustaceans (Juanes and Smith, 1995) and may therefore affect the survival rates of animals that are being transported live, or of discarded individuals. The nature of the damage suffered is also believed to be important. For example, individuals have a higher mortality rate if limbs are forcibly removed, rather than being naturally autotomised (Bergmann and Moore 2001). In *Nephrops norvegicus,* damage to the abdomen significantly reduces survival rates in discarded individuals and may lead to necrosis of the tail muscles (Wileman *et al.,* 1999, Stentiford and Neil, 2000, Harris and Andrews, 2005). Such animals may be unsaleable and will reduce the overall value of the catch. Minimising the damage to individuals may therefore be important both in terms of increasing the value of a catch and minimising any effects to the wild population.

Another major aim for fisheries in recent years has been to reduce catches of non-target or 'bycatch' organisms. Capturing large quantities of bycatch can have significant direct economic implications for the fishermen, and can affect catches in other fisheries (e.g. Hall and Mainprize 2005). Up to 90% of the total catch may be discarded from the Clyde *Nephrops* fishery , which often contains a high proportion of invertebrates and commercially important fish (Bergmann *et al.,* 2002a).

Reducing the amount of discarded material is particularly important for stocks of roundfish such as cod, haddock and whiting that are already overexploited. The minimum mesh size restriction for these fish is currently set at 120mm, while it is 70mm for *Nephrops* (ICES, 2005b). The *Nephrops* fishery is therefore more likely to retain juvenile fish, or individuals below the minimum landing size (MLS) (Stratoudakis *et al.,* 2001). Roundfish rarely survive trawling due to distension or rupturing of the swim bladder and stomach and estimated mortality rates for these species are typically around 100% (Catchpole *et al.,* 2005).

Several mitigation measures are already in place to reduce the amount of bycatch in the Scottish *Nephrops* fishery. These include the use of square-mesh panels, a minimum mesh size of 70mm in single-rig otter trawls (80mm in twin-rigs), a minimum landing size of 20mm (carapace length) and the closure of the fishery at weekends (ICES 2005a). However, alterations in trawling practise may also serve to reduce the quantity or alter the composition of the bycatch, and thereby reduce the effects on these threatened stocks.

This study aimed to determine whether trawl duration affected the physical condition of the *Nephrops* catch by measuring the extent of physical damage sustained by individuals. It also aimed to determine whether trawl duration had an effect on the total catch composition of each haul.

Methods

Between October 2005 and January 2006, nine trawls were carried out from the north Clyde Sea area by the *RV Aora*. The study area is shown in figure 1. Sampling took place on one or two days per month, and two hauls were made per day (one short and one long) when possible. The short trawls lasted approximately one hour, while the long trawls lasted between two and a half and four hours. A single-rig otter-trawl was used with a codend mesh size of 70mm to reflect local practise. All trawls were carried out during daylight hours. Summary data from each trawl is presented in table 1.

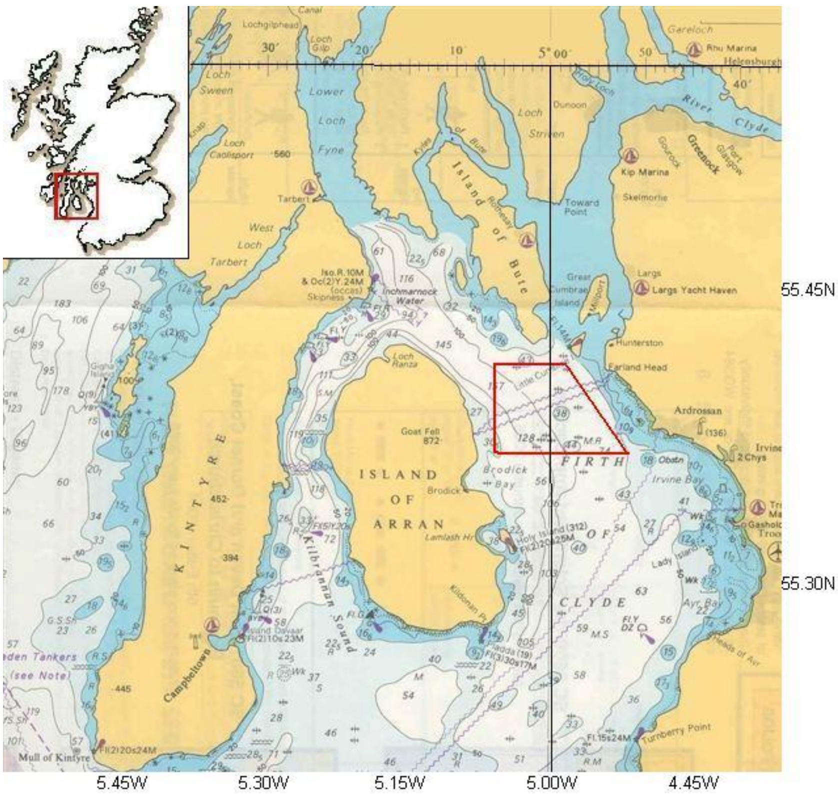

Figure 1: Map of the study area and surrounding waters. The red boxes indicate the regions from which the trawl samples were taken. Adapted from Admiralty Chart L(D3)2159

Table 1: Summary of trawl data showing locations and times of each

Trawl ID	**Date**	**Lat/Long Start**	**Lat/Long End**	**Time of trawl**	**Trawl Duration (mins)**	**Depth range (m)**
Aora1-S	12/10/2005	55° 41.582N 04° 57.201W	55° 38.789N 04° 54.762W	0939-1039	60	67.1 - 75.2
Aora1-L	12/10/2005	55° 34.593N 04° 53.283W	55° 41.874N 04° 59.592W	1138-1528	230	58.5 - 83.6
Aora2-S	18/10/2005	55° 41.932N 04° 57.047W	55° 39.097N 04° 55.260W	0924-1025	61	67.8 – 74.4
Aora3-S	16/11/2005	55° 42.540N 04° 56.493W	55° 39.404N 04° 55.570W	0905-1010	65	Not recorded
Aora3-L	16/11/2005	55° 36.591N 04° 52.664W	55° 40.072N 05° 01.782W	1057-1327	150	Not recorded
Aora4-S	06/12/2005	55° 41.887N 04° 57.067W	55° 39.295N 04° 55.607W	0922-1017	55	67.7-73.7
Aora5-L	18/01/2006	55° 36.654N 04° 52.990W	55° 42.713N 04° 59.763W	1139-1424	225	60.6-96.6
Aora6-S	19/01/2006	55° 41.744N 04° 56.874W	55° 38.539N 04° 54.0.23W	0933-1043	70	Not recorded
Aora6-S2	19/01/2006	55° 38.965N 04° 54.631W	55° 41.886N 04° 57.048W	1110-1210	60	Not recorded

Nephrops norvegicus is commonly targeted at approximately 50m by fishing vessels in the Firth of Clyde (Figueiredo and Thomas, 1967). At this depth, *N. norvegicus* displays a crepuscular pattern of emergence, during which times they are more vulnerable to trawling as they are exposed on the surface of the sediment (Chapman and Howard, 1979). An individual's vulnerability to trawling also depends on factors such as age, sex and maturity (Figueiredo and Thomas, 1967) which vary between populations (e.g. Figueiredo and Thomas, 1967, Briggs, 1995, Tuck *et al.,* 1997, Tuck *et al.,* 2000). Attempts were made to control for these factors by restricting the study area and avoiding sampling at dawn and dusk.

Following the recovery of each trawl onto the desk, the entire catch was shovelled into containers and the total wet weight was recorded. The catch was washed in seawater to remove excess mud from the organisms, and any weed or debris (e.g. plastics and rocks) were also removed before weighing. Care was taken to limit the amount of damage caused to *N. norvegicus* at this stage to avoid biasing the results. It was occasionally only possible to analyse a subsample of the catch due to time constraints and the large number of organisms that were often caught. In such cases, approximately half the containers were selected for complete analysis. It was assumed that these were representative of the entire catch, and were selected as randomly as possible.

Nephrops norvegicus was then separated from the rest of the catch into baskets and the wet weight was recorded. The remaining organisms were then sorted to the most appropriate taxonomic level, and the wet weights recorded for each group. All organisms were identified to species to produce a qualitative list. The invertebrate components were not weighed or identified from trawls Aora1-S and Aora1-L as a different sorting method was used (see appendix 1). This did not affect the analyses of *N. norvegicus* or fish species.

A subsample of approximately 5kg (300 individuals) of *Nephrops norvegicus* was taken from a single basket from each trawl for further analysis. This sample was taken by lifting several organisms at a time by hand, which would have avoided selecting for a particular size class. Additionally, the baskets contained individuals from the entire catch, and should not have been biased towards a particular section of the trawl. On return to the laboratory the carapace length, sex, carapace hardness and level of damage were recorded for the *N. norvegicus* sample.

Carapace length was measured from the base of the orbit to the mid dorsal posterior edge using callipers, as indicated in figure 2. Carapace hardness was estimated by squeezing the sides of the carapace just behind the head (figure 2). The carapace was considered to be 'hard' if there was no noticeable give when squeezed, and 'soft' if squeezing caused a clear distortion. The entire exoskeleton of 'jelly' animals was 'papery' and gave no resistance to pressure. This method is somewhat objective, but was suitable for this study as only one person was involved in the analysis.

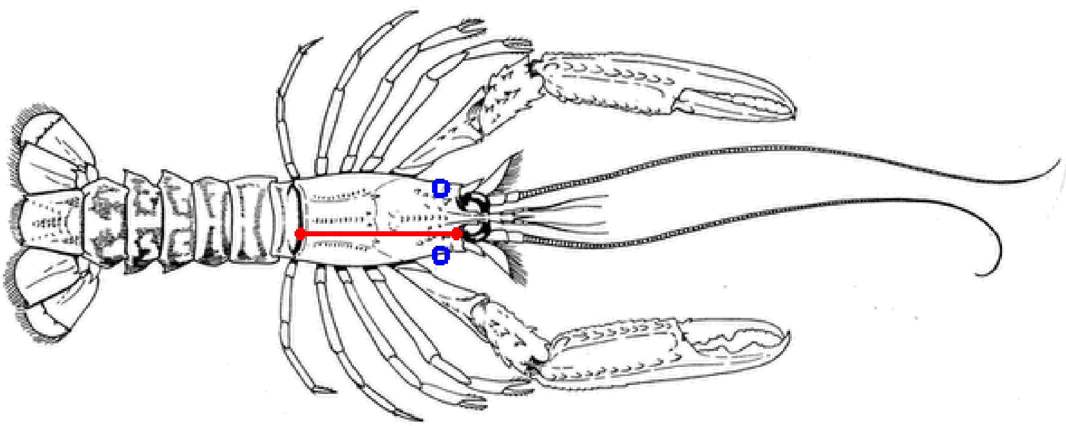

Figure 2: Diagram of *Nephrops norvegicus* (modified from FIGIS website). The red line shows the carapace length. The blue circles show the points that were tested to assess carapace hardness.

Damage was scored against a three-level index which is presented in table 2. A score of 0 indicated no damage, 1 indicated minor damage, and 2 indicated severe damage. Examples of each damage category are shown in figures 3 and 4.

Table 2: Damage index and criteria

Damage Category	**Criteria**
0 (No damage)	No visible damage to external structure and no loss of limbs
1 (Minor damage)	Exhibit no more than two of: • Loss of two or fewer walking legs • Loss of not more than one claw • Soft tissue punctures or small puncture to the shell • Loss of the tip of the rostrum
2 (Major damage)	Exhibit at least one of: • Loss of more than two walking legs • Loss of both claws • Loss of an eye • Compressed or cracked body parts\segments • Major soft tissue punctures • Exhibit three or more criteria of category one animals

Figure 3: Dorsal view showing an example of each damage category. From left to right: Undamaged (0), slightly damaged (1) and severely damaged individuals (2). The scale is indicated by a 10p piece.

Figure 4: Ventral view showing an example of each damage category. From left to right: undamaged (0), slightly damaged (1) and severely damaged individuals (2). The scale is indicated by a 10p piece.

Data Analysis

Comparisons between the *Nephrops norvegicus* data, trawl duration, trawl date and the mass of each catch were carried out using MINITAB software. A 95% significance level was used throughout, and all proportions were arcsine transformed before analysis. Parametric analyses were used whenever possible, but the test assumptions could not always be met. In these cases, non-parametric alternatives were used.

To simplify analysis, the catches were divided into five groups according to wet weight: ‘total catch’, ‘*Nephrops norvegicus*’, ‘commercial fish’, ‘non-commercial fish and Chondrychthes’ and ‘invertebrates’ (excluding *N. norvegicus*). ‘Commercial fish’ referred to fish species that are currently targeted by a demersal fishery in the UK, including haddock, cod, whiting, hake, plaice, witch flounder and sole (Hislop, 1986, Simmonds, 2004) . Commercial pelagic fish species (for example mackerel and herring) were rarely caught, and were therefore included as ‘non-commercial’ species. All non-target organisms were considered to be part of the bycatch.

The species composition data and wet weights of the major taxa were analysed using PRIMER 5 software. For the wet-weight analysis, the fish were grouped as above into ‘commercial’ and ‘non-comercial’ categories. The similarity between catches was tested using the Bray-Curtis similarity index, and plotted as a dendrogram.

SIMPER (SIMilarity PERcentages) analysis was carried out to assess the relative contribution of each major taxon to the dissimilarity between the long and short trawls. A 90% limit was set on these data, and no transformations were carried out.

Results: *Nephrops* Data

Carapace Length

Overall, male *Nephrops norvegicus* were significantly larger (mean carapace length (MCL) = 28.8mm) than the females (MCL = 25.1mm), as shown in figure 5.

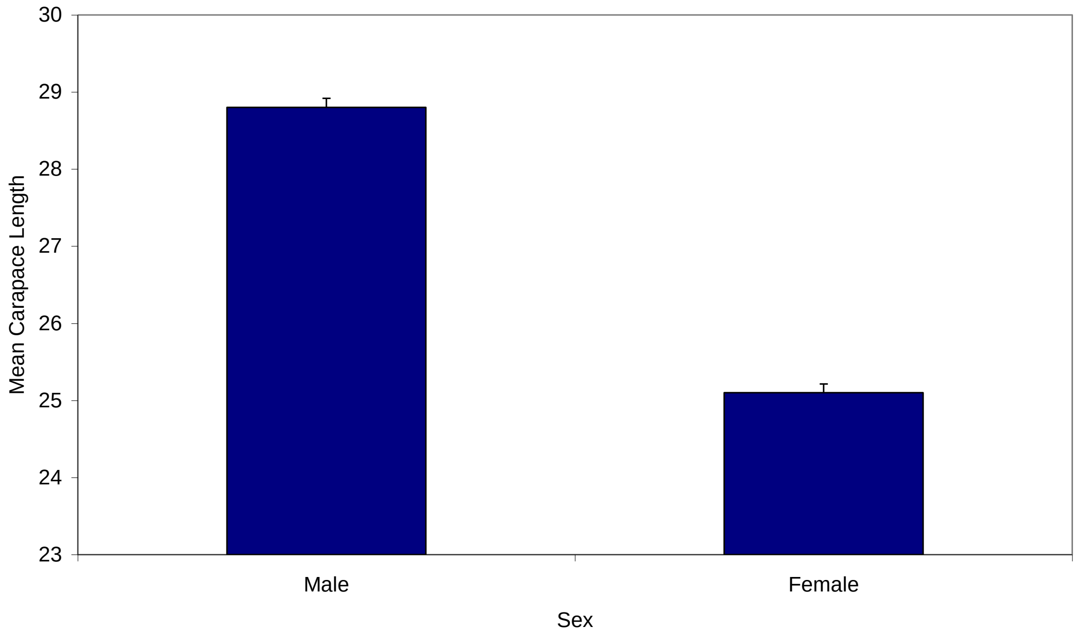

Figure 5: Mean carapace length of male and female *Nephrops norvegicus* from all trawls. Error bars = one standard error. Mann-Whitney test: W = 806300, p = 0.0000

Trawl duration appeared to affect the MCL of *N. norvegicus* (W = 2629200, p = 0.000). Individuals from long trawls were slightly smaller (MCL = 26.3mm) than those from short trawls (MCL = 27.3mm).

A Kruskal-Wallis test showed a significant relationship between carapace length and the extent of damage in both short and long trawls (H = 35.62, df = 2, p = 0.000 and H = 21.35, df = 2, p = 0.000 respectively). A *post hoc* analysis of the data using the Kruskal-Wallis multiple comparisons test showed that undamaged *Nephrops norvegicus* were significantly larger than damaged *N. norvegicus* (p = 0.000). The carapace lengths of slightly damaged and severely damaged individuals were not significantly different.

Short trawls were conducted during every trip and provide a time-series of data over the course of the study period. The distributions of male *Nephrops norvegicus* carapace lengths in each short trawl are shown in figure 6. The female lengths are not presented as they were significantly smaller in all trawls and comprised a much lower proportion of the *N. norvegicus* samples. There was a significant difference between the carapace lengths over time ($H = 35.9$, $df = 4$, $p = 0.000$). The Kruskal-Wallis multiple comparisons test showed a significant difference between December and January. December had a higher median carapace length (29.35mm) than any other month.

Sex

Male *Nephrops norvegicus* were more abundant than females in all trawls ($W = 121$, $p = 0.002$), comprising between 57% and 81% of each *N. norvegicus* sample. The mean numbers of each sex are shown in figure 7. The numbers of males and females did not vary significantly with trawl duration ($W = 29$, $p = 0.879$ and $W = 27.5$, $p = 0.604$ respectively).

Carapace Hardness

Carapace hardness appeared to vary over time, as shown in figure 8. A significantly higher proportion of 'jelly' animals were caught in January than any other month ($\chi^2 = 120.459$, $df = 6$, $p = 0.000$). There was no difference in carapace hardness between the sexes per month however ($W = 19.0$, $p = 0.88$).

A significant difference was found between the long and short trawls ($\chi^2 = 36.862$, $df = 2$, $p = 0.000$), with more 'hard' *Nephrops norvegicus* occurring in the long trawls than expected. The converse was true for short trawls.

Carapace hardness did not appear to vary with sex ($\chi^2 = 5.084$, $df = 2$, $p = 0.079$) or length ($H = 2.02$, $df = 2$, $p = 0.364$).

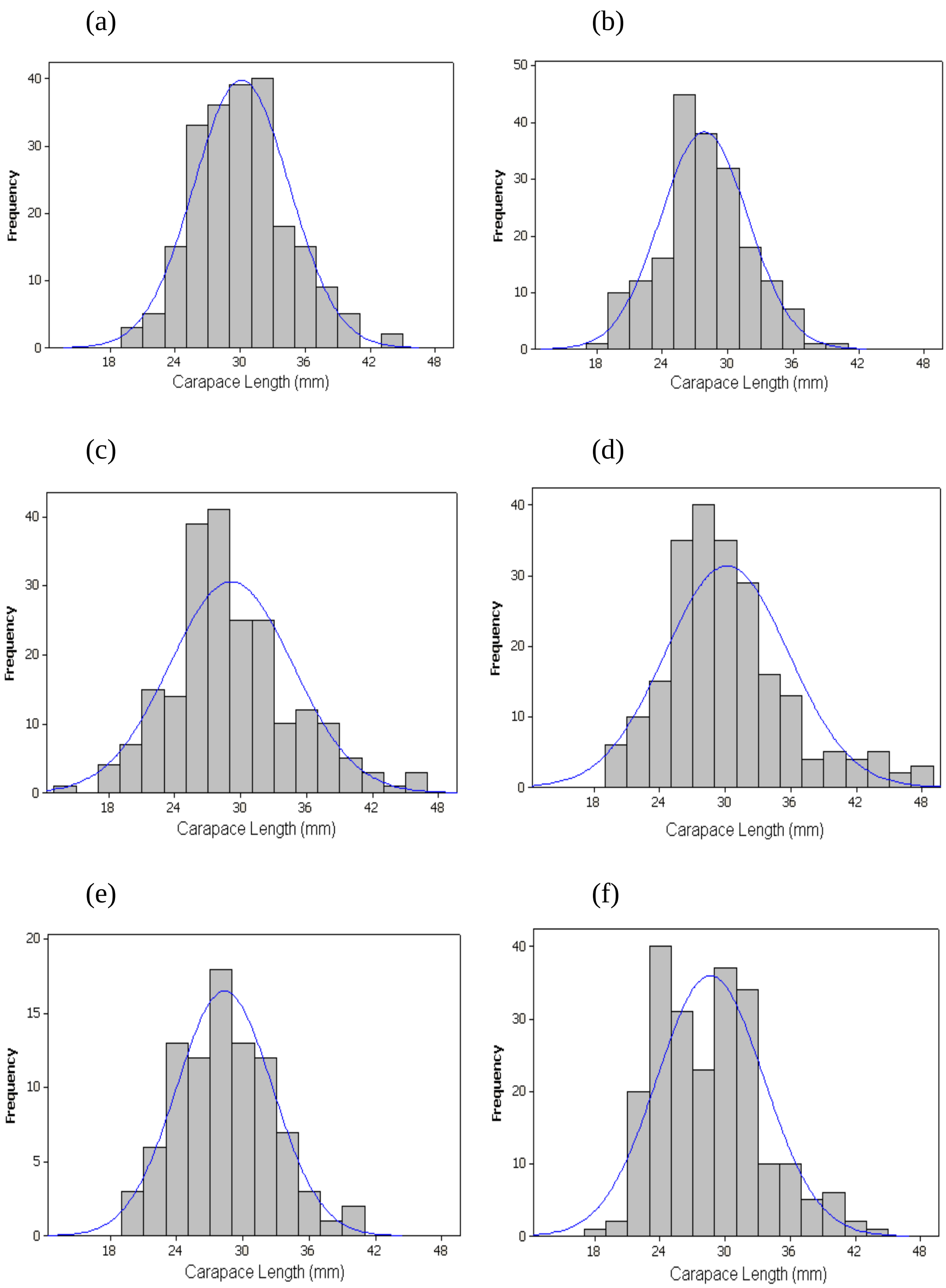

Figure 6: Carapace length distributions from each short trawl for male *Nephrops norvegicus* (a) Aora1-S, 12/10/05; (b) Aora2-S, 18/10/05; (c) Aora 3-S, 16/11/05; (d) Aora 4-S, 06/12/05; (e) Aora 6-S, 19/01/06 (AM); (f) Aora6-S2, 19/01/06 (PM). Trend lines are shown in blue.

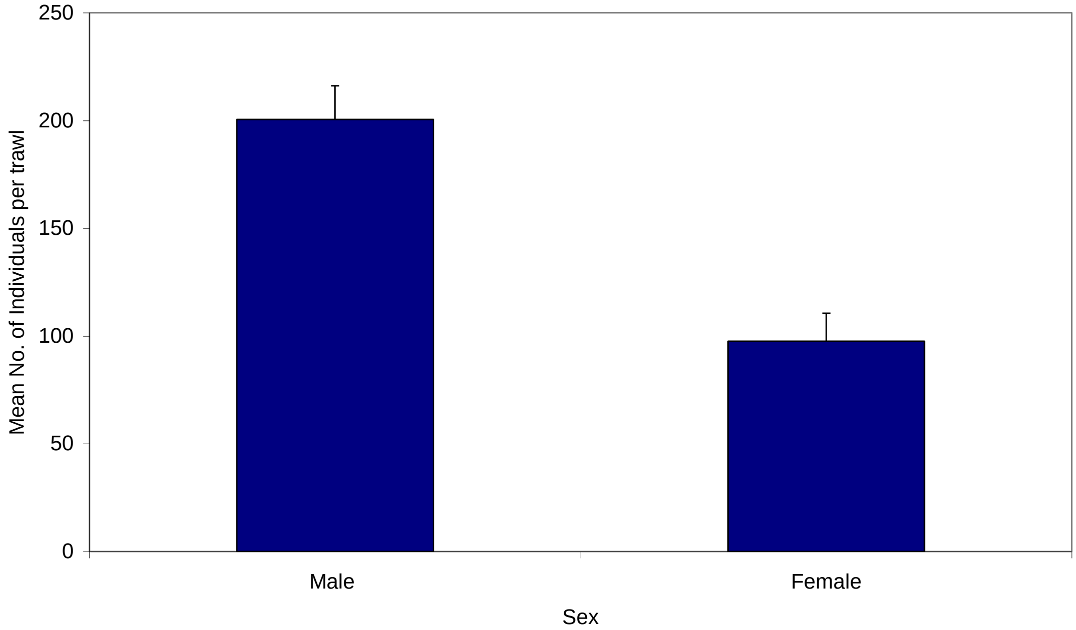

Figure 7: Mean number of males and females from all trawls. Error bars = one standard error. W = 121, p = 0.002.

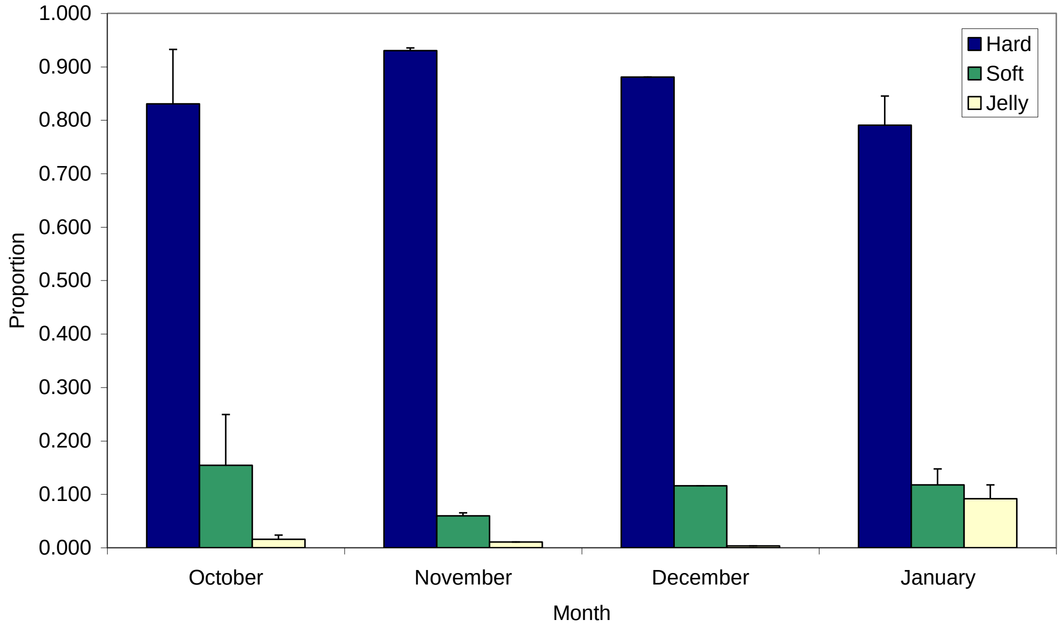

Figure 8: Mean proportion of each category of carapace hardness per month. Error bars = one standard error. χ^2 =36.862, df = 2, p = 0.000.

Damage

The mean damage scores (MDS) for short and long trawls are shown in figure 9. There was no significant difference between them (W = 27, p = 0.519). However, there was a difference in individual damage categories with trawl duration. More undamaged individuals were present in the short trawls than expected, while the converse was true for long trawls (χ^2 = 20.094, p = 0.000). The MDS of short trawls were more variable than long trawls, ranging from 0.514 (Aora1-S) to 1.007 (Aora3-S) which are both the lowest and highest values recorded.

A strong relationship was apparent between carapace hardness and the extent of damage to *Nephrops norvegicus* (χ^2 = 263.424, p = 0.000). 'Hard' *N. norvegicus* generally appeared less damaged than 'soft' or 'jelly' animals. In the case of 'jelly' animals, there were no undamaged individuals.

Since carapace hardness appeared to influence the amount of damage sustained by an individual and since the proportion of 'jelly' individuals varied significantly over the study period, it was necessary to analyse 'hard', 'soft' and 'jelly' animals separately against damage.

Figure 10 shows the proportion of *Nephrops norvegicus* in each damage category according to carapace hardness. Chi-squared analysis suggested that longer trawl durations resulted in greater damage to 'hard' *N. norvegicus* (χ^2 = 32.408, df = 2, p = 0.000). For long trawls, more animals than expected were found to have mild or severe damage, while in short trawls there were more undamaged animals than expected.

This trend was not seen in the 'soft' and 'jelly' *Nephrops norvegicus* however, and there did not appear to be a relationship between trawl duration and damage in these categories (χ^2 =5.058, df = 2, p = 0.08 for 'soft' *N. norvegicus* and χ^2 = 0.153, df = 1, p = 0.696 for 'jelly' *N. norvegicus.*).

There was a difference in the extent of damage between sexes (χ^2 =12.366, df = 2,

$p < 0.01$). More males occurred in the undamaged category than would be expected, while more females were slightly or severely damaged.

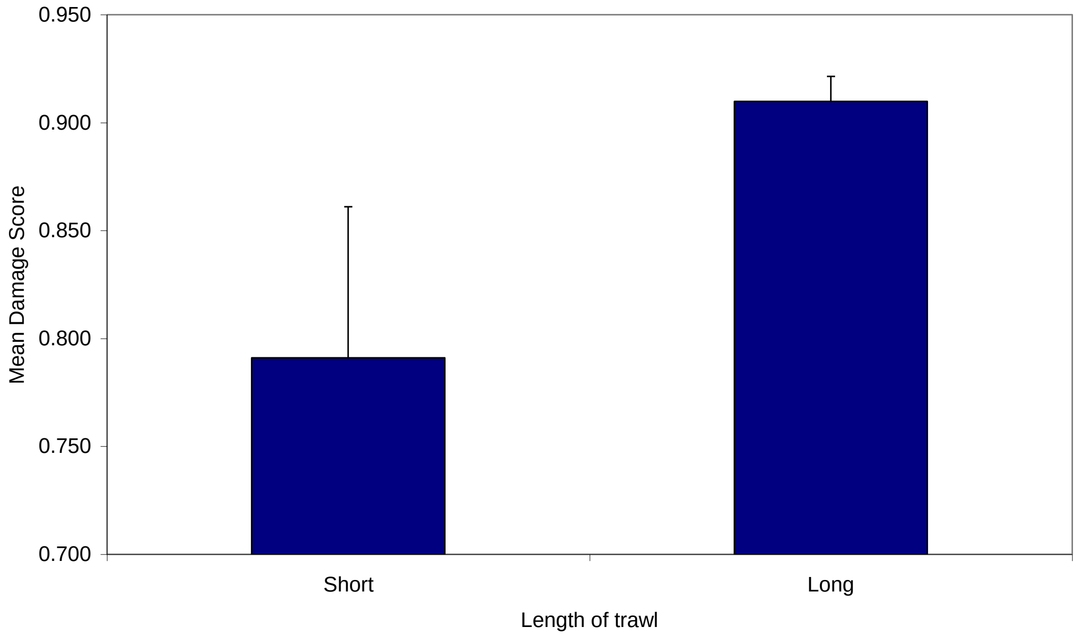

Figure 9: MDS for short and long trawls. Error bars show one standard error. $W = 27$, $p = 0.519$.

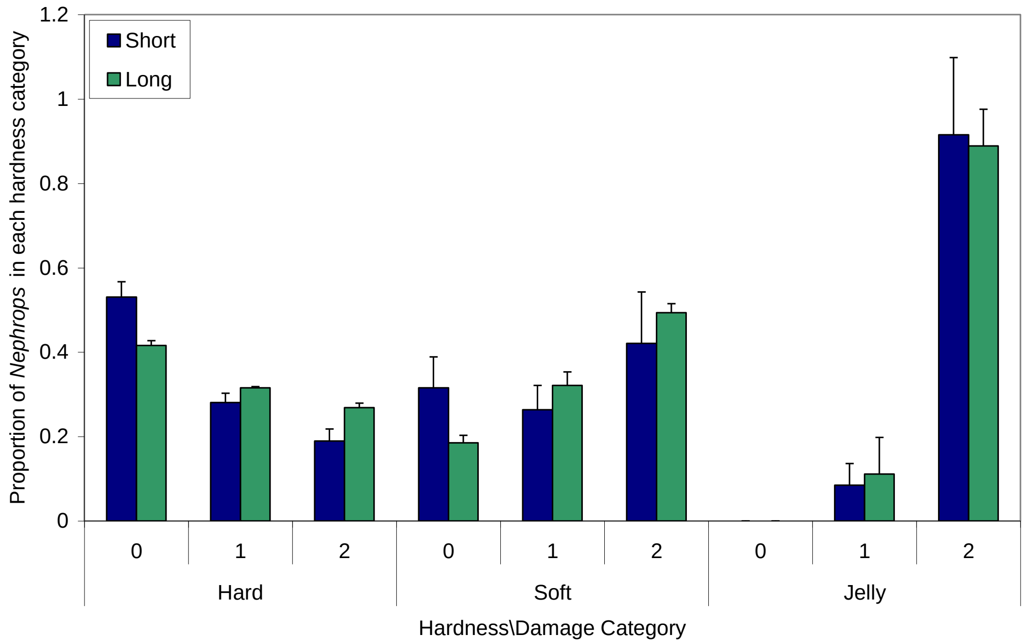

Figure 10: Mean proportion of *Nephrops norvegicus* in each damage category (0-2) according to carapace hardness in short and long trawls. Error bars show one standard error.

Catch Composition

A total of 52 species were identified from seven trawls (45 species in five short trawls; 40 species in two long trawls). Species data were not collected for Aora1-S and Aora1-L. The vertebrate and invertebrate species lists are presented in tables 3 and 4 respectively, along with the wet weights for each major taxon and for species of 'commercial fish'.

Figure 11 shows the total mass of each trawl, and the mass of each major group within them. Long trawls did not recover a significantly higher mass of organisms than the short trawls (T = 2.31, p = 0.147), but this appears to be due to the low mass recovered in Aora1-L. If Aora1-L is excluded, the difference is significant (T = 7.16, p = 0.002).

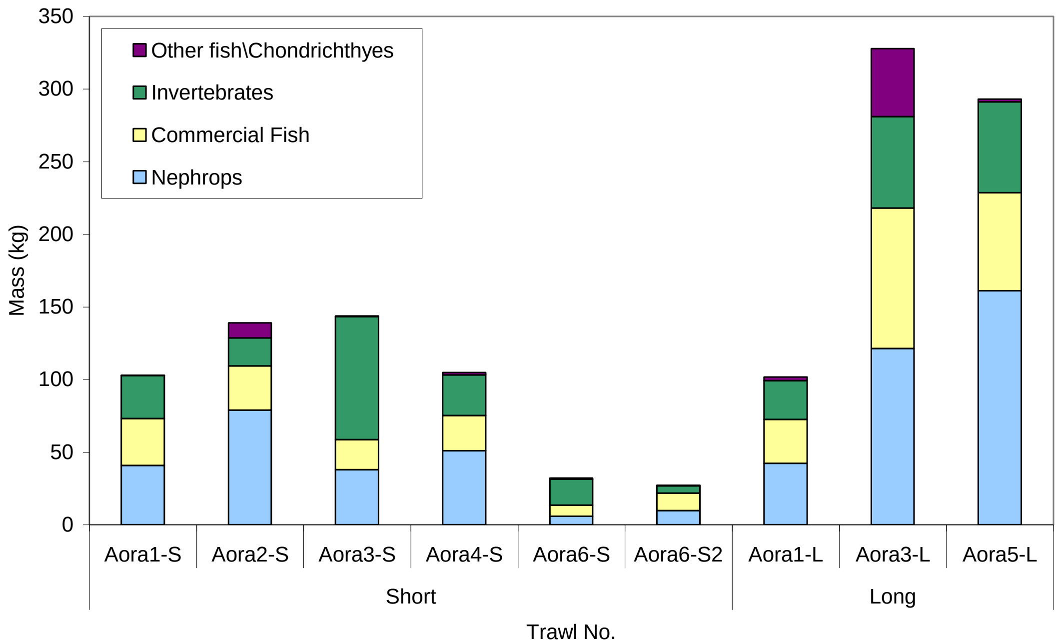

Figure 11: Total mass (wet weight) of each trawl, showing the major groups of organisms. T = 2.31, p = 0.147.

Nephrops norvegicus was recovered in all trawls, comprising 18-56% (mean = 37%) of the total catch from short trawls, and 34-55% (mean = 42%) of the catch from long trawls by wet weight. There was no significant difference in the proportion of *N. norvegicus* caught during different trawl durations (W = 16.5, p = 0.796).

The commercial fish species were generally the next most common group, and comprised 14-44% (mean = 22.5%) of the total catch from short trawls, and 23-31% (mean = 28.0%) of the total catch from long trawls. *Merlangius merlangus* (whiting), *Merluccius merluccius* (hake), *Melanogrammus aeglefinus* (haddock) and *Pleuronectes platessa* (plaice) were caught in every trawl. *Solea solea* (sole) was present in six of the nine trawls, and cod was present in five. *Glyptocephalus cynoglossus* (witch flounder) was also caught, but only in two trawls.

Of the non-commercial fish species, *Hippoglossoides platessoides* (long rough dab) was caught in all nine trawls, *Scyliorhynus canicula* (dogfish) in seven, and *Clupea harengus* (herring) in five trawls. No other species were collected in more than three trawls.

The invertebrates (excluding *Nephrops norvegicus*) comprised 12-59% (mean = 33.4%) of the total catch from short trawls and 19-22% (mean = 21%) of the long trawls by wet weight. The proportions of each major taxon varied considerably between trawls, although bivalves, crabs, urchins and starfish often made up a relatively large proportion of the total catch.

Table 3: Species composition of vertebrates from short and long trawls. Wet weights for each major taxon and species of 'commercial fish' are shown in kg. √ = species present.

Major Taxon	Short Trawls					Long Trawls	
	Aora2-S	Aora3-S	Aora4-S	Aora6-S	Aora6-S2	Aora3-L	Aora5-L
Osteichthyes							
'Commercial Fish' (kg)	30.32	20.54	24.38	7.64	12.00	96.75	67.54
Gadus morhua Linnaeus 1758	0	0	2.46	0.18	0.62	5.72	5.81
Melanogrammus aeglefinus (Linnaeus 1758)	11.4	7.18	6.46	0.96	8.26	31.27	28.44
Merluccius merluccius (Linnaeus 1758)	2.8	0.42	0.82	3.06	1.04	5.5	4.69
Pleuronectes platessa Linnaeus 1758	3.4	1.22	2.58	1.12	0.66	4.32	5.25
Solea solea (Linnaeus 1758)	0	2.03	1.4	1.16	0	3.84	2.12
Merlangius merlangus (Linnaeus 1758)	10.4	9.69	10.66	1.02	8.26	46.9	21.23
Glyptocephalus cynoglossus (Linnaeus 1758)	2.2	0	0	0	0	0	0
'Non-Commercial Fish' (kg)	1.20	0.38	1.36	0.76	0.22	9.61	1.79
Agonus cataphractus (Linnaeis 1758)				√			
Aspitrigla cuculus (Linnaeus 1758)							√
Callionymus lyra Linnaeus 1758			√	√			√
Clupea harengus Linnaeus 1758		√		√	√	√	
Enchelyopus cimbrius (Linnaeus, 1766)	√		√			√	
Hippoglossoides platessoides (Fabricius 1790)	√	√	√	√	√	√	√
Lumpenus lampretaeformis (Walbaum, 1792)	√						
Pollachius pollachius (Linnaeus 1758)						√	
Trisopterus esmarkii (Nilson, 1855)			√				√
Trisopterus minutus (Linnaeus 1758)	√						
Chondrichthyes (kg)	9.00	0	0.36	0	0.18	37.12	Not recorded
Leucoraja garmani (Whitley, 1939)						√	
Scyliorhinus canicula (Linnaeus, 1758)	√		√		√	√	√

Table 4: Species composition of invertebrates from short and long trawls. Wet weights for each major taxon are shown in kg. √ = species present.

	Short Trawls					Long Trawls	
Major Taxon	**Aora2-S**	**Aora3-S**	**Aora4-S**	**Aora6-S**	**Aora6-S2**	**Aora3-L**	**Aora5-L**
Cnidaria (kg)	0.1	0	0	0	0	0	0.5
Rhizostoma octopus (Linnaeus 1758)			√				
Urticina eques (Gosse 1859)	√						√
Mollusca							
Bivalvia (kg)	0.02	20.39	0.56	1.06	0.12	14.32	3.02
Acanthocardia echinata (Linnaeus 1758)	√	√		√			
Aequipecten opercularis (Linnaeus 1758)	√	√	√		√	√	√
Arctica sp. Schumacher 1817			√	√		√	
Gastropoda (kg)	2.57	5.19	3.12	0.56	1.16	7.82	27.88
Aporrhais pespelecani (Linnaeus 1758)		√					
Buccinum undatum Linnaeus 1758	√	√	√	√	√	√	√
Neptunea antiqua (Linnaeus 1758)	√	√	√	√	√	√	√
Cephalopoda (kg)	1.30	0	2	0	0	1.75	0
Eledone cirrhosa (Lamarck 1798)	√						
Loligo forbesii Steenstrup 1856			√				
Sepietta oweniana (D'Orbigny 1839-1841)	√					√	
Annelida (kg)	0	1.18	0.26	0	0.16	3.93	0
Aphrodita aculeata Linnaeus 1761		√	√		√	√	
Crustacea							
Anomura: Nephropidae (kg)	79.00	38	50.9	5.72	9.72	121.40	161.17
Nephrops norvegicus (Linnaeus 1758)	√	√	√	√	√	√	√
Anomura: Paguridae (kg)	2.66	2.03	2.32	0.2	0.42	6.03	4.47
Pagurus bernhardus (Linnaeus)	√	√	√	√	√	√	√
Pagurus prideauxi Leach	√	√					
Anomura: Galatheidae (kg)	0.62	0	0.42	0.2	0	4.41	2.74
Munida rugosa (Fabricius 1775)	√		√	√		√	√
Caridea (kg)	0.30	0	0.44	0	0	1.00	1.06
Crangon sp. Fabricius 1798	√		√				
Dichelopandalus sp. Caullery 1896	√		√			√	
Pandalus sp. Leach 1814							√
Brachyura (kg)	7.64	10.05	9.38	2.76	0.64	12.14	5.25
Cancer pagurus		√	√	√	√	√	√
Carcinus maenas (Linnaeus 1758)							√
Liocarcinus depurator (Linnaeus 1758)	√	√	√	√	√	√	√
Majidae sp. 1 Samouelle 1819							√
Necora puber (Linnaeus 1767)	√					√	√
Echinodermata							
Asteroidea (kg)	2.10	4.43	2.72	3.46	2.06	6.38	14.47
Asterias rubens Linnaeus 1758	√	√	√	√	√	√	√
Astropecten irregularis (Pennant)	√	√	√	√	√	√	√
Luidia ciliaris (Philippi)		√					
Marthasterias glacialis (Linnaeus)	√	√	√	√	√	√	√
Porania sp (Muller)	√			√			
Ophiuroidea (kg)	2.05	10.47	1.78	0	0.38	5.15	1.45
Ophiura ophiura (Linnaeus 1758)	√	√	√		√	√	√
Echinoidea (kg)	0	30.99	4.86	9.76	0	0	1.62
Brissopsis lyrifera (Forbes)		√	√	√			√
Echinus esculentus Linnaeus 1758							√

Dendrograms showing the similarity between the trawls are presented in figures 12 and 13. Figure 12 shows the similarity based on the wet weights of the major taxa, while figure 13 is based on the species composition of each catch (using presence-absence data). Short and long trawls appear to cluster in figure 12, although trawls Aora6-S and Aora6-S2 are noticeably distinct. No trends are obvious in figure 13.

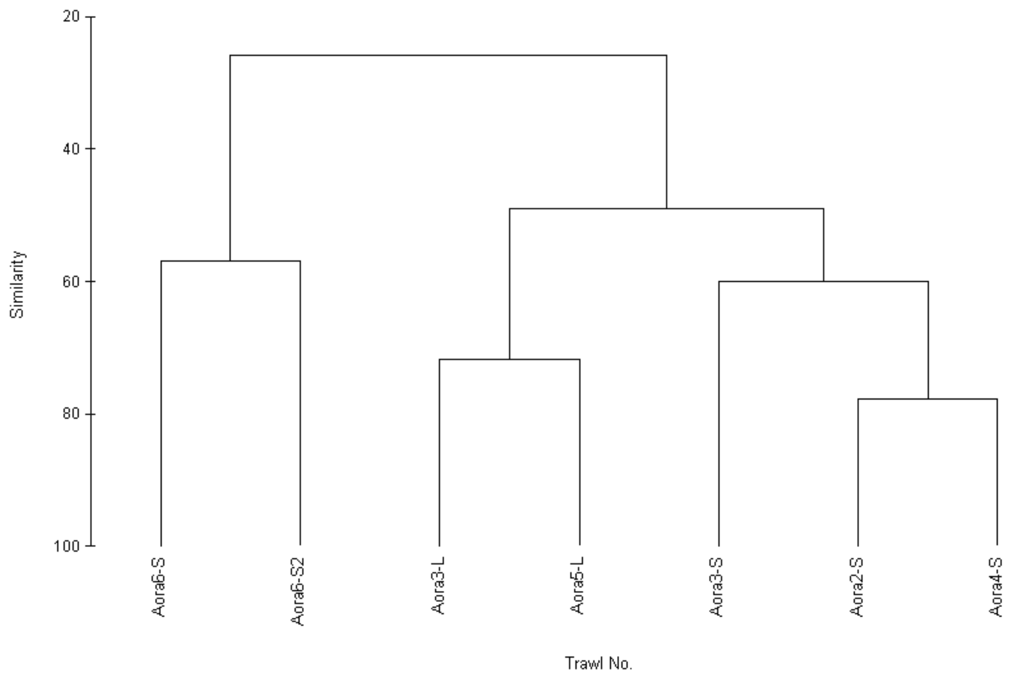

Figure 12: Dendrogram showing the similarity between trawls based on wet weight of the major taxa.

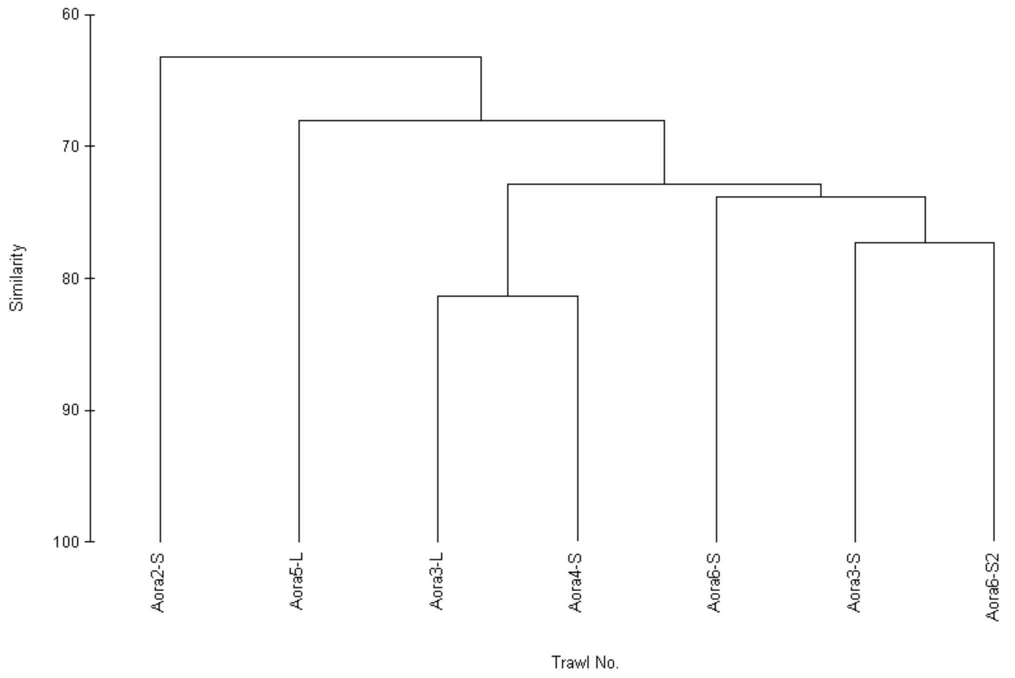

Figure 13: Dendrogram showing similarity between trawls based on the presence or absence of species.

The results of the SIMPER analysis are summarised in tables 5 and 6, and are based on the dissimilarity between the short and long trawls by wet weight and proportion of each taxon respectively. The dissimilarity is highest when comparing the wet weights of the taxa, which is a similar trend to that seen in figures 12 and 13.

The results suggest that *Nephrops norvegicus* is the most important species in determining the dissimilarity between short and long trawls when comparing both wet weights and proportions of the catches (42.73% and 25.6% respectively).

'Commercial fish and Chondrychthyes' are the next most important groups by wet weight, and account for 25.9% and 7% of the dissimilarity between short and long trawls respectively. The remaining taxa are less significant, and no single group accounts for more than 7% of the difference. Altogether, the invertebrates are responsible for 23.67% of the dissimilarity.

Table 5: SIMPER analysis of dissimilarities between long and short trawls based on the wet weight of major taxa. Species are listed according to decreasing contribution to the dissimilarity. Average dissimilarity = 64.71%.

Major Taxon	**Mean Wet Weight: Short trawls (kg)** (± 1 standard error)	**Mean Wet Weight: Long trawl (kg)** (± 1 standard error)	**Cumulative percentage**
Nephrops	36.67 ± 13.57	141.29 ± 19.88	42.73
Commercial fish	20.10 ± 4.56	85.67 ± 16.85	68.63
Chondrichthyes	1.91 ± 1.77	18.56 ± 18.56	75.63
Gastropoda	2.41 ± 0.88	17.85 ± 10.03	81.96
Bivalvia	4.43 ± 3.99	8.67 ± 5.65	85.36
Echinoidea	9.12 ± 5.76	0.81 ± 0.81	88.65
Asteroidea	2.95 ± 0.45	10.43 ± 4.05	91.68

Table 6: SIMPER analysis of dissimilarities between long and short trawls based on the proportions of major taxa. Species are listed according to decreasing contribution to the dissimilarity. Average dissimilarity = 30.54%.

Major Taxon	**Mean Proportion: Short trawls** (± 1 standard error)	**Mean Proportion: Long trawl (kg)** (± 1 standard error)	**Cumulative percentage**
Nephrops	0.37	0.46	25.60
Echinoidea	0.11	0.01	44.10
Commercial Fish	0.26	0.27	57.93
Chondrichthyes	0.01	0.06	66.99
Gastropoda	0.03	0.06	73.56
Bivalvia	0.04	0.03	79.97
Brachyura	0.06	0.03	86.20
Asteroidea	0.05	0.04	91.62

Bycatch

The mass of bycatch organisms was generally high, comprising 44-82% (mean = 61%) of the total catch by wet weight. Long trawls returned a greater mass of bycatch than short trawls (W = 15, p = 0.037), but there was no difference between the proportions of bycatch (W = 31.5, p = 0.796).

There was no significant correlation between the MDS for *Nephrops norvegicus* and the total wet weight (F = 0.92, p = 0.369, R^2 = 0.116), the wet weight of *N. norvegicus* (F = 0.06, p = 0.818, R^2 = 0.012), or the wet weight of commercial fish in each trawl (F = 0.11, p = 0.758, R^2 = 0.021). There was a slight positive correlation between the mass of invertebrates per trawl and the mean damage score (R^2 = 0.569, p = 0.05), which is shown in figure 14. This relationship could not be attributed to any single invertebrate taxon.

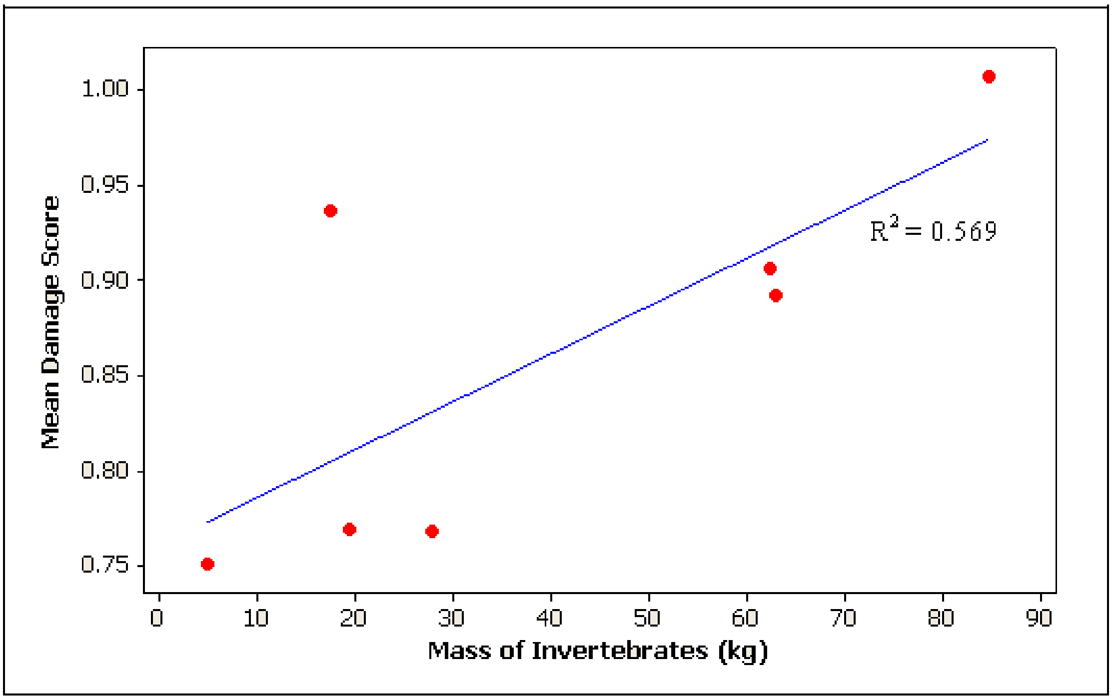

Figure 14: Correlation between MDS and the total mass of invertebrates per trawl. $F = 6.59$, $p = 0.05$, $R^2 = 0.569$.

Undersize Nephrops norvegicus and 'Heads'

The minimum landing size for *Nephrops norvegicus* is 20mm, and undersize individuals were present in all trawl samples. These animals were not included as part of the bycatch, although they would have been discarded from the haul. However, the proportion of undersize individuals did not vary between short and long trawls ($W = 26.0$, $p = 0.366$), and they were unlikely to influence the trends seen in the levels of bycatch.

Trawled *Nephrops norvegicus* often have the cephalothorax removed onboard the fishing vessel, while the tails are kept and sold as 'scampi' (D.M. Neil, *pers. comm.*). This was not done during the study as there was not enough time, and is likely to lead to an underestimation of the total bycatch.

Commercial Fish

The mass of commercial fish species in each trawl is shown in figure 15. Whiting and haddock typically made up the highest proportion of the commercial fish in each trawl (mean = 39% and 32% respectively).

The total mass of commercial fish varied between long and short trawls ($W = 21$, $p = 0.028$). However, this was not necessarily true for individual species. The wet weights of whiting were significantly greater in long trawls than short trawls ($W = 21$, $p = 0.028$), but the wet weights of other species were not linked with trawl duration ($p > 0.05$).

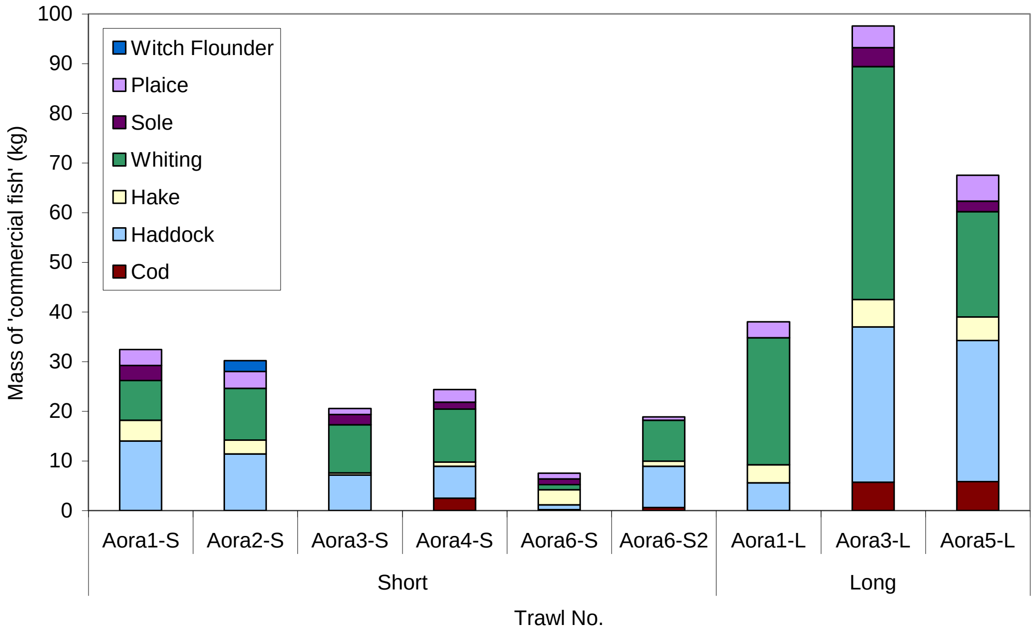

Figure 15: The wet weight of 'commercial fish' in each trawl, showing individual species. $W = 21$, $p = 0.028$.

Discussion

Nephrops norvegicus

The results of this study suggest that there is a link between trawl duration and the level of damage in 'hard' *Nephrops norvegicus*. Longer trawls may increase the likelihood of an individual coming into contact with both the trawl gear and other organisms in the haul as well as increasing the frequency of such contacts. Both would potentially increase the level of damage to *N. norvegicus.* The long trawls generally contained a greater total mass of organisms than short trawls, so *N. norvegicus* may have been more likely to become crushed or damaged by the weight.

These are similar to results reported by Ridgway (2005), who reported a positive correlation between trawl duration and the extent of damage. Bergmann *et al.* (2001) also found a positive relationship between trawl duration and damage in certain bycatch organisms from the Firth of Clyde *Nephrops* fishery, although the total mass of each catch was also important. This trend was not seen in all species however, suggesting that vulnerability to trawling may be quite variable between species.

Carapace hardness was important in determining the level of damage sustained by an individual. 'Hard' *Nephrops norvegicus* were the most common group in all samples, and trawl duration is therefore likely to be an important factor in influencing the overall level of damage. The lack of any correlation between 'soft' and 'jelly' animals and trawl duration suggests that these animals may simply be more vulnerable to damage during trawling.

The fact that this trend was not reflected in the MDS for short and long trawls could be explained by the higher numbers of 'hard' *Nephrops norvegicus* in the long trawls. This could have lowered the MDS for the long trawls, while increasing it for short trawls. There is no obvious reason why short trawls should be biased against 'hard' animals, and further study would be required to determine whether this is a genuine trend.

Carapace hardness also varied over time, with a higher proportion of 'jelly' animals occurring in January than any other month. At a population level, male *Nephrops* *norvegicus* generally moult early in the year, followed by females shortly after their eggs from the previous season have hatched (Figueiredo and Thomas, 1967, Aguzzi *et al.,* 2004). Females become more vulnerable to trawling during this period as they spend more time outside their burrows, and can be observed indirectly by a shift in the sex ratio of catches (Figueiredo and Thomas, 1967). Records from the Firth of Clyde suggest moulting takes place between February and April (Stentiford *et al.,* 2001). The higher occurrence of 'jelly' animals in January could therefore represent the start of the moulting period in the Clyde Sea. No significant difference was found between the carapace hardness of males and females or in the sex ratio over time however, suggesting that a longer study period may be necessary to confirm this trend.

Moulting in *Nephrops norvegicus* from the Firth of Clyde is believed to occur approximately monthly in the smallest individuals, decreasing to annually in animals with a carapace length greater than 40mm (Bailey *et al.*, 1986). This variability would explain the occurrence of 'soft' and 'jelly' individuals throughout the sampling period, although too few individuals were studied to draw any firm conclusions on this aspect of the data.

It has been suggested that higher temperatures advance the reproductive state of female *Nephrops norvegicus* (Maynou and Sarda, 1997), so it is possible that moulting does not occur simultaneously over a range of latitudes. If this is the case, it may be possible to avoid 'soft' and 'jelly' animals during this period by focussing fishing effort on alternative fishing grounds where moulting is not occurring.

Any apparent trends in these data should be viewed with caution however, as the sample sizes are small and it was not possible to use powerful statistical techniques to analyse them. The study period is also relatively limited, and should ideally be extended over an entire year.

The extent of damage also varied between the sexes, with males being less damaged than the females. Similar results have been recorded in the swimming crab, *Liocarcinus holsatus* (Fabricius) (Bergmann *et al.*, 2001). This could be a result of the females being smaller than the males overall, and therefore more likely to be damaged, or could reflect differences in behaviour.

The extent of damage also appeared to be correlated to the mass of invertebrates in a haul. This is perhaps not surprising considering the high mass of hard-bodied or shelled organisms, such as bivalves, gastropods and echinoids that were often recovered. This may also explain some of the variability seen in the damage scores from short trawls. Aora-3S for example, captured an unusually high proportion of invertebrates and had the highest MDS of any of the trawls (1.007).

The carapace length of *Nephrops norvegicus* varied with trawl duration, with slightly smaller individuals being caught in the long trawls. Diamond trawl nets are known to distort under strain, and can become blocked by debris (Jennings *et al.*, 2004), reducing the effective mesh size. Long trawls generally recovered a greater mass of catch than short trawls and could therefore have increased the strain on the net more than short trawls. The larger catch could also have physically prevented animals from reaching the edges of the net and escaping.

However, the difference in MCL between short and long trawls was small (1 mm) and it is unclear whether such a slight difference could have been caused by such alterations in the net. Additionally, there was no significant difference in the proportion of undersize *Nephrops norvegicus* between long and short trawls, which suggests that very small individuals were still able to escape. Given the small number of trawls sampled in this study, it is difficult to determine whether this is a genuine trend, and sampling should therefore be continued to increase the sample size, particularly of long trawls.

Nonetheless, there are clearly implications for the fishing industry if it is important to maximise the quality of *Nephrops norvegicus* in catches. The results of this study suggest that a series of short trawls would produce a higher quality catch than fewer long trawls. Additionally, the animals caught would be larger, and potentially more valuable, particularly if sold as whole animals (Bailey *et al.*, 1986).

Additional research is needed to determine whether there would be a benefit in fishing different grounds or implementing a 'closed-season' policy during the moulting period. 'Jelly' animals are unlikely to be saleable due to the high levels of damage these animals sustain during trawling. Moving to an alternative fishing ground until the moult is over could maintain the quality of the catch throughout the year.

Catch Composition

The mass of long and short trawls were no different overall, although this appeared to be due to the low mass of Aora1-L. There was no difference in the proportions of major taxa between long and short trawls, and no evidence to suggest that either long or short trawls were selective towards a particular taxon or community of species. The proportion of bycatch did not vary with trawl duration.

The mean percentage of bycatch recorded in this study was 61%. Bergmann *et al.* (2002a) reported a mean bycatch rate of 84% by volume between 1997 and 1998 in the north Clyde Sea using similar gear. The difference between the studies may be due to different measurement techniques, or due to the inclusion of undersize *Nephrops norvegicus* and *N. norvegicus* 'heads' in the bycatch in the Bergmann study. The 'heads' could therefore contribute significantly to the total bycatch from the fishery.

The effects of trawling on benthic organisms and the implications of high levels of bycatch and discards have been widely studied in recent years (e.g. Hall *et al.*, 2000, Hall and Mainprize, 2005). Several previous studies have focussed on the proportion of discarded fish in the *Nephrops* fishery. It is difficult to make any direct comparisons between them and the present study due to differences in sampling techniques, trawl gear and the methods used for measuring the biomass or abundance of the species present. Nonetheless, the overall trends in these data are similar to the results presented here.

Fisheries in the Firth of Clyde, North Sea and the Celtic Sea have all reported high catches of whiting in the discards (e.g. Bergmann *et al*, 2002a, Rochet *et al.*, 2002, Stratoudakis *et al.*, 2002, Borges *et al.*, 2005, Catchpole *et al.*, 2005). Previous catches of haddock appeared to be more variable (Bergmann *et al,* 2002a, Stratoudakis *et al.,* 2002) than was suggested by the current study however. Hake was only discarded from the Celtic and Clyde Sea fisheries, suggesting its distribution may be limited to the Atlantic.

Flatfish (sole, witch and plaice) were well represented in this study. Identification of certain species is relatively difficult, and could have led to over- or underestimation in the weights of some species. However, this does not appear to have significantly affected the overall results, which are similar to those previously reported (Bergmann *et al.,* 2002a).

Shorter trawl durations appeared to produce higher quality catches of *Nephrops norvegicus*, but they may have a greater impact on certain commercial fish species. The lack of any relationship between trawl duration and the mass of virtually all commercial fish species (with the exception of whiting) could suggest that these fish are better able to escape during long trawls than short ones. This could have consequences for the successful management of both *N. norvegicus* and roundfish stocks in Scotland, and highlights the need for continuous monitoring of these species. However, these trends could simply reflect their rarity in the sample area, and additional data from long trawls would be required to confirm this.

The non-commercial fish were typically demersal species, which most likely reflects the type of gear used. With the exception of long-rough dab, which was always present, the species composition was highly variable between trawls. This supports the hypothesis that trawl duration does not affect the selectivity of the trawl gear. Although non-commercial fish did not constitute a large proportion of the catches, dogfish were likely to be underrepresented. The chondrychthyes were generally alive when the trawls were recovered and were kept in water before being returned to the sea. Unfortunately, this was occasionally done before they had been recorded and weighed which may bias the data.

The invertebrate species recovered in this study are similar to previous records from the Firth of Clyde, and appeared to be typical of a disturbed benthic environment (Bergmann *et al.,* 2001, 2002a). The Firth of Clyde is subject to intensive trawling pressure, which can cause a shift in the benthic community towards species that can tolerate trawling damage or disturbance (Tuck *et al.,* 1998, Bergmann *et al.,* 2002a). More 'fragile' species such as soft corals (Hexacorallia) (Bergmann *et al.,* 2002a, Blyth *et al.,* 2004) were absent from this study, which also supports this hypothesis.

The high discard rate of the *Nephrops* fishery may partly explain the presence of many scavenging species in the trawls, such as *Asterias rubens, Pagurus bernhardus* and *Buccinum undatum* (Moore and Howarth, 1996, Bergmann *et al.* 2002b). It is possible that discarding may also benefit *Nephrops norvegicus* which is an opportunistic, generalist feeder (Figuierdo and Thomas, 1967, Bailey *et al.,* 1986). The addition of large amounts of organic material to the benthos may provide a valuable food source for *N. norvegicus* stocks (Bergmann *et al.* 2002b), and any reductions in food availability could negatively impact the populations and potentially lead to serious consequences for the fishery. Populations should therefore be closely monitored if any mitigation measures are introduced to reduce bycatch and discards at sea.

Conclusions

Shorter trawl durations appeared to improve the quality of *Nephrops norvegicus* by reducing the physical damage suffered by individuals. Animals that had recently moulted appeared to be most vulnerable to physical damage regardless of duration and there may be grounds for reducing fishing effort during the moulting season to maintain the quality of catches. *N. norvegicus* from catches with a high proportion of invertebrates were also more damaged, so techniques that reduce bycatch rates are likely to improve the quality of *N. norvegicus*.

Reducing the mass of bycatch organisms is likely to benefit other fisheries in this area, by reducing pressure on stocks of roundfish and flatfish that are already overexploited. Continual monitoring of *Nephrops norvegicus* stocks would nonetheless be required to ensure that any reduction in discarding did not have negative effects on the populations, such as recruitment failure or reduced growth as a result of reduced food availability.

Recommendations for Further Study

Continuing to increase the number of trawls (particularly long trawls) from the study area would improve the data on the *Nephrops norvegicus* population, and potentially strengthen the relationships reported between trawl duration and damage. The results presented in this study are based on a relatively small number of samples, which should be increased to strengthen the data set.

Increasing the number of long trawls would also improve the analysis of the catch composition. Although no significant relationship was apparent between trawl duration and catch composition, there were potentially a number of confounding variables which were not controlled. Adding additional data would allow this relationship to be tested more fully.

Additional variability could have been caused by large quantities of mud and weed that were recovered in Aora3-S, and the very small catches from Aora6-S and Aora6-S2. Determining whether this was a result of trawl duration or other variables would require further study.

The data here is also limited to the north Clyde Sea area. Populations of *Nephrops norvegicus* are known to vary between different regions and the study could be extended to include comparisons between other commercial fishing grounds.

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References

Aguzzi, J., Sarda, F., Allue, R. (2004). Seasonal dynamics in *Nephrops norvegicus* (Decapoda: Nephropidae) catches off the Catalan coasts (western Mediterranean). *Fisheries Research* **69:** 293-300.

Bailey, N., Howard, F.G., Chapman, C.J. (1986). Clyde *Nephrops*: biology and fisheries. *Proceedings of the Royal Society of Edinburgh* **90B:** 501-518.

Bergmann, M., Moore, P.G. (2001). Survival of decapod crustaceans discarded in the *Nephrops* fishery of the Clyde Sea area, Scotland. *ICES Journal of Marine Science* **58**: 163-171.

Bergmann, M., Beare, D.J., Moore, P.G. (2001). Damage sustained by epibenthic invertebrates discarded in the *Nephrops* fishery of the Clyde Sea area, Scotland. *Journal of Sea Research* **45**: 105-118.

Bergmann, M., Wieczorek, S.K., Moore, P.G., Atkinson, R.J.A. (2002a). Discard composition of the Clyde Sea area, Scotland. *Fisheries Research* **57:** 169-183.

Bergmann, M., Wieczorek, S.K., Moore, P.G., Atkinson, R.J.A. (2002b). Utilisation of invertebrates discarded from the *Nephrops* fishery by variously selective benthic scavengers in the west of Scotland. *Marine Ecology Progress Series* **233:** 185-198.

Blyth, R.E., Kaiser, M.J., Edward-Jones, G., Hart, P.J.B. (2004). Implications of a zoned fishery management system for marine benthic communities. *Journal of Applied Ecology* **41:** 951-961.

Borges, L., Rogan, E., Officer, R. (2005). Discarding by the demersal fishery in the waters around Ireland. *Fisheries Research* **76:** 1-13.

Briggs, R.P. (1995). Variability in northwest Irish Sea *Nephrops* populations. *Fisheries Research* **23:** 175-187.

Catchpole, T.L., Frid, C.L.J., Gray, T.S. (2005). Discards in North Sea fisheries: causes, consequences and solutions. *Marine Policy* **29:** 421-430.

Chapman, C.J., Howard, F.G. (1979). Field observations on the emergence rhythm of the Norway lobster *Nephrops norvegicus*, using different methods. *Marine Biology* **51:** 157-165.

Collie, J.S., Hall, S.J., Kaiser, M.J., Poiner, I.R. (2000). A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology* **69(5):** 785-798.

Figueiredo, M.J., Thomas, H.J. (1967). *Nephrops norvegicus* (Linnaeus, 1758) Leach – a review. *Oceanography and Marine Biology Annual Review* **5:** 371-407.

FRS (2004). Scottish *Nephrops* Stocks: West Coast. http://www.frs-scotland.gov.uk/Uploads/Documents/FM17Nephropswest%20coast .pdf. (Last accessed 10/03/06)

Hall, S., Mainprize, B. (2005). Managing by-catch and discards: how much progress are we making and how can we do better? *Fish and Fisheries* **6**: 134-155.

Hall, M.A., Alverson, D.L., Metuzals, K.I. (2000). By-catch: problems and solutions. *Marine Pollution Bulletin* **41(1-6):** 204-219.

Harris, R.R., Lowry, N., Moth-Poulsen, T., Sangster, G.I., Soldal, A.V., Ulmestrand. M., Valentinsson. D. (1997). Damage and physiology analysis of Nephrops cod-end escapes and discards. Presented at the ICES Fishing Technology and Fish Behaviour (FTFB) working group meeting in Hamburg on 14-17 April 1997.

Hislop, J.R.G. (1986). The demersal fishery in the Clyde Sea area. *Proceedings of the Royal Society of Edinburgh* **90B:** 423-437.

ICES (2005a) Quality Handbook Annex: WGNSDS-Clyde Nephrops (FU13). http://www.ices.dk/reports/ACFM/2005/WGNSDS/FU13%20Clyde%20Nephrops%20stock%20Annex.pdf (Last accessed 10/03/06).

ICES (2005b). Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2005. ICES Advice. Volumes 1 - 11 1418 pp.

Jennings, S., Kaiser, M.J., Reynolds, J.D. (2004). *Marine Fisheries Ecology,* Blackwell Publishing, Oxford.

Juanes, F., Smith, L.D. (1995). The ecological consequences of limb damage and loss in decapod crustaceans: a review and prospectus. *Journal of Experimental Marine Biology and Ecology* **193:** 197-223.

Kaiser, M.J., Spencer, B.E. (1996). The effects of beam-trawl disturbance on infaunal communities in different habitats**.** *Journal of Animal Ecology* **65(3):** 348-358.
Ridgway, I.R. 2005. Post-capture physiology and pathology of the Norway lobster *Nephrops norvegicus.* Ph.D. Thesis, University of Glasgow.

Maynou, F., Sarda, F. (1997). *Nephrops norvegicus* population and morphometrical characteristics in relation to substrate heterogeneity. *Fisheries Research* **30(1-2):** 139-149.

Moore, P.G., Howarth, J. (1996). Foraging by marine scavengers: effects of relatedness, bait damage and hunger. *Journal of Sea Research* **36(3):** 267-273.

Ridgway, I.R. 2005. Post-capture physiology and pathology of the Norway lobster *Nephrops norvegicus.* Ph.D. Thesis, University of Glasgow.

Rochet, M.J., Peronnet, I., Trenkel, V.M. (2002). An analysis of discards from the French trawler fleet in the Celtic Sea. *ICES Journal of Marine Science* **59:** 538-552.

Simmonds, J. (2004). Scottish fisheries briefing, 2004 scientific advice from ICES. www.marlab.ac.uk/Uploads/Documents/Information%20sheets.pdf (last accessed 10/03/06).

Stentiford, G.D., Neil, D.M. (2000). A rapid onset post-capture muscle necrosis in the Norway lobster, *Nephrops norvegicus* (L.) from the west coast of Scotland. *Journal of Fish Diseases* **23:** 251-263.

Stentiford, G.D., Neil, D.M., Atkinson, R.J.A. (2001). The relationship of *Hematodinium* infection prevalence in a Scottish *Nephrops norvegicus* population to season, moulting and sex. *ICES Journal of Marine Science* **58:** 814-823.

Stratoudakis, Y., Fryer, R.J., Cook, R.M., Pierce, G.J., Coull, K.A. (2001). Fish bycatch and discarding in *Nephrops* trawlers in the Firth of Clyde (west of Scotland). *Aquatic Living Resources* **14:** 283-291.

Tuck, I.D., Atkinson, R.J.A., Chapman, C.J. (2000). Population biology of the Norway lobster, *Nephrops norvegicus* (L.) in the Firth of Clyde, Scotland – II: Fecundity and size at onset of sexual maturity. *ICES Journal of Marine Science* **57(4):** 1227-1239.

Tuck, I.D., Chapman, C.J., Atkinson, R.J.A. (1997). Population biology of the Norway lobster, *Nephrops norvegicus* (L.) in the Firth of Clyde, Scotland – I: Growth and Density. *ICES Journal of Marine Science* **54:** 125-135.

Tuck, I.D., Hall, S.J., Robertson, M.R., Armstrong, E., Basford, D.J. (1998). Effects of physical trawling disturbance in a previously unfished sheltered Scottish sea loch. *Marine Ecology Progress Series* **162:** 227-242.

Wileman, D.A., Sangster, G.I., Breen, M., Ulmestrand, M., Soldal, A.V., Harris, R.R. (1999). Roundfish and Nephrops survival after escape from commercial fishing gear. Final report to the EC (FAIR-CT95-0753), Brussels.

Appendix 1: Development of the Project

The methods used in this project were developed through discussions with my supervisor and researchers from the University Marine Biological Station at Millport (UMBSM). The damage index was based on a previous study by Ridgway (2005), and analysis of the catch composition was based on previous work by Melanie Bergmann and advice from Dr. Jim Atkinson. Since all data collection had to be done at sea, the methods were deliberately kept simple.

There were no major problems with the methods, which generally worked well, although some minor changes were made following collection of the first samples (trawls Aora1-S and Aora1-L). During these first trawls the subsamples of *Nephrops norvegicus* were analysed on board the vessel. This was too time consuming however, and samples were subsequently taken back to Glasgow University for analysis the following day. They were stored at approximately 8°C overnight.

This change allowed more time to analyse the remainder of the catch, and it was then possible to identify all species recovered in the trawls, rather than just the fish. Ideally, the total abundance and wet weight would have been recorded for each species to improve the accuracy of the results, but this was not possible in the time available.

Due to the nature of the field work involved in this project, it was not possible to design a complete experimental regime. The project therefore lacks control data for variables such as weather conditions, tides, substrate type and day length for example, which could have affected the availability of *Nephrops norvegicus* to the trawl gear. However, this was not a designed experiment and the *RV Aora* was only available on certain dates. Additionally, some trawl samples were required for other projects, which meant that shorter trawls were generally favoured in order to complete the work on time, and return any live samples to the University aquarium as quickly as possible. This is a continuing project, and analysis has begun on a subsample of *Nephrops norvegicus* from a short trawl in February. This could not be completed in time unfortunately, and so these data were no included.

Appendix 2: Summary Data for *Nephrops norvegicus* per Trawl

The complete data lists for the subsamples of *Nephrops norvegicus* are too large to be included here, so summary data are presented for each trawl instead. The full records are available electronically on request.

Aora1-S

Males	220	Mass *Nephrops* sampled (kg):	5.5
Females	99	No. *Nephrops* sampled:	319
'Hard'	319	Mean Length of Males	30.1
'Soft'	0	Mean Length of Females	26.5
'Jelly'	0		
		No. below MLS (20mm)	2
Damage 0	199		
Damage 1	76		
Damage 2	44		

Aora1-L

Males	185	Mass *Nephrops* sampled (kg):	6
Females	136	No. *Nephrops* sampled:	321
'Hard'	127	Mean Length of Males	28.1
'Soft'	43	Mean Length of Females	24.5
'Jelly'	7		
		No. below MLS (20mm)	18
Damage 0	121		
Damage 1	101		
Damage 2	99		

Aora2-S

Males	184	Mass *Nephrops* sampled (kg):	5.8
Females	136	No. *Nephrops* sampled:	320
'Hard'	207	Mean Length of Males	27.8
'Soft'	105	Mean Length of Females	24.8
'Jelly'	8		
		No. below MLS (20mm)	12
Damage 0	145		
Damage 1	104		
Damage 2	71		

Aora3-S

Males	216	Mass *Nephrops* sampled (kg):	5.4
Females	76	No. *Nephrops* sampled:	292
'Hard'	270	Mean Length of Males	29.1
'Soft'	19	Mean Length of Females	24.6
'Jelly'	3		
		No. below MLS (20mm)	11
Damage 0	105		
Damage 1	80		
Damage 2	107		

Aora3-L

Males	256	Mass *Nephrops* sampled (kg):	5.4
Females	115	No. *Nephrops* sampled:	371
'Hard'	347	Mean Length of Males	27.4
'Soft'	20	Mean Length of Females	24.7
'Jelly'	4		
		No. below MLS (20mm)	13
Damage 0	148		
Damage 1	115		
Damage 2	108		

Aora4-S

Males	223	Mass *Nephrops* sampled (kg):	6
Females	53	No. *Nephrops* sampled:	276
'Hard'	243	Mean Length of Males	30.1
'Soft'	32	Mean Length of Females	25.1
'Jelly'	1		
		No. below MLS (20mm)	7
Damage 0	124		
Damage 1	94		
Damage 2	58		

Aora5-L

Males	208	Mass *Nephrops* sampled (kg):	5.5
Females	79	No. *Nephrops* sampled:	287
'Hard'	253	Mean Length of Males	28.9
'Soft'	18	Mean Length of Females	25.7
'Jelly'	16		
		No. below MLS (20mm)	4
Damage 0	113		
Damage 1	88		
Damage 2	86		

Aora6-S

Males	90	Mass *Nephrops* sampled (kg):	2.7
Females	37	No. *Nephrops* sampled:	127
'Hard'	88	Mean Length of Males	27.6
'Soft'	21	Mean Length of Females	26.3
'Jelly'	18		
		No. below MLS (20mm)	1
Damage 0	51		
Damage 1	33		
Damage 2	43		

Aora6-S2

Males	223	Mass *Nephrops* sampled (kg):	6
Females	147	No. *Nephrops* sampled:	370
'Hard'	295	Mean Length of Males	28.6
'Soft'	46	Mean Length of Females	25.1
'Jelly'	29		
		No. below MLS (20mm)	4
Damage 0	192		
Damage 1	78		
Damage 2	100		

Appendix 3: Catch Composition Raw Data

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora1-S	**Nephrops**	***Nephrops***	48.5	40.8	0.397	100	40.80
	Crustacea	not recorded	10.4	8.4	0.082		8.40
	Echinodermata	not recorded	15	13.4	0.130		13.40
	Mollusca	not recorded	8.5	7.7	0.075		7.70
	Fish	Haddock	na	14	0.136		14.00
		Hake	na	4.2	0.041		4.20
		Plaice	na	3.2	0.031		3.20
		Sole	na	3	0.029		3.00
		Whiting	na	8	0.078		8.00
	Other Fish	Mackeral	na	0.2	0.002		0.20
		Red Gurnard					
		Four-beard Rockling					
		Herring					
	Elasmobranchs	Dogfish	na	not recorded			
		Total		**102.9**	**1.000**		**102.90**
Aora1-L	**Nephrops**	***Nephrops***	66	42.2	0.348	100	42.20
	Crustacea	not recorded	10	8.4	0.069		8.40
	Echinodermata	not recorded	10	8.4	0.069		8.40
	Mollusca	not recorded	14	10	0.082		10.00
	Fish	Haddock	7.2	5.6	0.046		5.60
		Hake	5.2	3.6	0.030		3.60
		Dab	6.6	5	0.041		5.00
		Plaice	4.8	3.2	0.026		3.20
		Whiting	27.2	25.6	0.211		25.60
	Other fish	Mackeral	4	2.4	0.020		2.40
		Herring					
		Bullhead					
	Elasmobranchs	Dogfish	9	7	0.058		7.00
		Total		**121.4**	**1.000**		**121.40**

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora2-S	**Nephrops**	***Nephrops***		**79**	0.562	100	79.00
	Cnidaria	*Urticina eques*	0.66	0.1	0.001		0.10
	Bivalvia	*Aequipectin opercularis*	0.58	0.02	0.000		0.02
	Gastropoda	*Buccina undatum*	3.125	2.565	0.018		2.57
	Cephalopoda	*Sepietta oweniana*	1.86	1.3	0.009		1.30
		Eledone cirrhosa					
	Crabs	*Necora puber*	8.2	7.64	0.054		7.64
		Liocarcinus depurator					
	Hermit crabs	*Pagurus bernhardus*	3.22	2.66	0.019		2.66
		Pagurus prideaux					
	Prawns	*Dichelopandalus sp*	0.86	0.3	0.002		0.30
		Crangon sp					
	Squat Lobsters	*Munida rugosa*	1.18	0.62	0.004		0.62
	Starfish	*Asterias rubens*	2.66	2.1	0.015		2.10
		Astropecten irregularis					
		Marthasterias glacialis					
		Porania sp					
	Brittle Stars	*Ophiura ophiura*	2.61	2.05	0.015		2.05
	Fish	Haddock	13.2	11.4	0.081		11.40
		Whiting	12.2	10.4	0.074		10.40
		Hake	6.8	2.8	0.020		2.80
		Plaice	7.4	3.4	0.024		3.40
		Witch	5.2	2.2	0.016		2.20
	Other fish	Four-beard Rockling	7.8	3	0.021		1.20
		Long rough Dab	3.6				
		Snake Blenny					
		Poor Cod					
	Elasmobranchs	Dogfish	10.8	9	0.064		9.00
		Total		**140.555**	**1.000**		**140.56**

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora3-S	**Nephrops**	***Nephrops***		**18**	0.2645	47.37	38.00
	Bivalvia	*Aequipectin opercularis*	10.1	9.66	0.1420		20.39
		Acanthocardia echinata					
	Gastropoda	*Aporrhais pespelecani*	2.9	2.46			
		Buccina undatum			0.0361		5.19
	Annelida	*Aphrodita aculeata*	1	0.56	0.0082		1.18
	Crabs	*Cancer pagurus*	5.2	4.76	0.0699		10.05
		Liocarcinus depurator					
	Hermit crabs	*Pagurus bernhardus*	1.4	0.96	0.0141		2.03
		Pagurus prideauxi					
	Starfish	*Asterias rubens*	2.54	2.1	0.0309		4.43
		Astropecten irregularis					
		Marthasterias glacialis					
		Luidia cilaris					
	Brittle Stars	*Ophiura ophiura*	5.4	4.96	0.0729		10.47
	Echinoidea	*Brissopsis lyrifera*	16	14.68	0.2157		30.99
	Fish	Haddock	3.84	3.4	0.0500		7.18
		Whiting	5.03	4.59	0.0675		9.69
		Hake	0.64	0.2	0.0029		0.42
		Plaice	1.02	0.58	0.0085		1.22
		Sole	1.4	0.96	0.0141		2.03
	Other fish	Herring	1.06	0.18	0.0026		0.38
		Long rough Dab	0.6				0.00
		Total		**68.05**	**1.000**		**143.66**

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora3-L	**Nephrops**	***Nephrops***	**63**	**55.6**	0.370	45.8	121.40
	Bivalvia	*Arctica sp*	7	6.56	0.044		14.32
		Aequipectin opercularis					
	Gastropoda	*Buccina undatum*	4.02	3.58	0.024		7.82
		Neptunea antiqua					
	Cephalopoda	*Sepietta oweniana*	na	0.8	0.005		1.75
	Annelida	*Aphrodita aculeata*	na	1.8	0.012		3.93
	Crabs	*Cancer pagurus*	6	5.56	0.037		12.14
		Liocarcinus depurator					
		Necora puber					
	Hermit crabs	*Pagurus bernhardus*	3.2	2.76	0.018		6.03
	Prawns	*Dichelopandalus sp*	0.9	0.46	0.003		1.00
	Squat Lobsters	*Munida rugosa*	2.46	2.02	0.013		4.41
	Starfish	*Asterias rubens*	3.8	2.92	0.019		6.38
		Astropecten irregularis					
		Marthasterias glacialis					
		Luidia ciliaris					
	Brittle Stars	*Ophiura ophiura*	2.8	2.36	0.016		5.15
	Fish	Cod	3.5	2.62	0.017		5.72
		Haddock	15.2	14.32	0.095		31.27
		Whiting	23.25	21.11	0.141		46.09
		Hake	3.4	2.52	0.017		5.50
		Plaice	2.42	1.98	0.013		4.32
		Sole	2.2	1.76	0.012		3.84
	Other fish	Four-beard Rockling	5.28	4.4	0.029		9.61
		Long rough Dab	3.08				0.00
		Pollack					
		Herring					
	Elasmobranchs	Dogfish	21	17	0.113		37.12
		Leopard Skate					
		Total		**150.13**	**1.000**		**327.79**

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora4-S	**Nephrops**	***Nephrops***	**61.1**	**50.9**	0.482	100	50.90
	Cnidaria	*Rhizostoma octopus*	na	na			na
	Bivalvia	*Aequipectin opercularis*	1.1	0.56	0.005		0.56
		Arctica sp.					
	Gastropoda	*Buccina undatum*	4.2	3.12	0.030		3.12
		Neptunea antiqua					
	Cephalopoda	*Loligo forbesii*	na	2	0.019		2.00
	Annelida	*Aphrodita aculeata*	0.8	0.26	0.002		0.26
	Crabs	*Cancer pagurus*	10.46	9.38	0.089		9.38
		Liocarcinus depurator					
	Hermit crabs	*Pagurus bernhardus*	2.86	2.32	0.022		2.32
	Prawns	*Dichelopandalus sp*	0.98	0.44	0.004		0.44
		Crangon sp.					
	Squat Lobsters	*Munida rugosa*	0.96	0.42	0.004		0.42
	Starfish	*Asterias rubens*	3.26	2.72	0.026		2.72
		Astropecten irregularis					
		Marthasterias glacialis					
	Brittle Stars	*Ophiura ophiura*	2.32	1.78	0.017		1.78
	Urchins	*Brissopsis lyrifera*	5.4	4.86	0.046		4.86
	Fish	Cod	3	2.46	0.023		2.46
		Haddock	7	6.46	0.061		6.46
		Whiting	11.2	10.66	0.101		10.66
		Hake	1.36	0.82	0.008		0.82
		Plaice	3.12	2.58	0.024		2.58
		Sole	1.94	1.4	0.013		1.40
	Other fish	Long rough Dab	3.7	2.08	0.020		1.36
		Norway Pout	0.88				
		Four-beard Rockling	0.92				
		Dragonnet					
	Elasmobranchs	Dogfish	0.9	0.36	0.003		0.36
		Total		**105.58**	**1.000**		**105.58**

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora5-L	**Nephrops**	***Nephrops***	66.5	57.7	0.550	35.8	161.17
	Cnidaria	*Urtisina eques*	0.8	0.18	0.002		0.50
	Bivalvia	*Aequipectin opercularis*	1.8	1.08	0.010		3.02
		Arctica sp.					
	Gastropoda	*Buccina undatum*	10.6	9.98	0.095		27.88
		Neptunea antiqua					
	Crabs	*Cancer pagurus*	2.5	1.88	0.018		5.25
		Liocarcinus depurator					
		Carcinas maenas					
		Necora puber					
		Majidae sp. 1					
	Hermit crabs	*Pagurus bernhardus*	6	1.6	0.015		4.47
	Prawns	*Pandalus sp.*	1	0.38	0.004		1.06
	Squat Lobsters	*Munida rugosa*	1.6	0.98	0.009		2.74
	Starfish	*Asterias rubens*	5.8	5.18	0.049		14.47
		Astropecten irregularis					
		Marthasterias glacialis					
	Brittle Stars	*Ophiura ophiura*	1.14	0.52	0.005		1.45
	Urchins	*Brissopsis lyrifera*	1.2	0.58	0.006		1.62
		Echinus esculentus					
	Fish	Cod	2.7	2.08	0.020		5.81
		Haddock	12	10.18	0.097		28.44
		Whiting	12	7.6	0.072		21.23
		Hake	2.3	1.68	0.016		4.69
		Plaice	2.5	1.88	0.018		5.25
		Sole	2	0.76	0.007		2.12
	Other fish	Norway Pout	2.5	0.64	0.006		1.79
		Long rough Dab	0.95				0.00
		Red Gurnard	0.8				0.00
		Dragonnet					
	Elasmobranchs	Dogfish	not recorded	not recorded			
		Total		**104.88**	**1.000**		**292.96**

Trawl No.	Major Taxon	Species	Wet Weight + Container (kg)	Wet Weight -Container (kg)	Proportion of Total Catch	%age catch analysed	Total (Estimated) Weight of Catch
Aora6-S	**Nephrops**	***Nephrops***	7.5	5.72	0.177	100	5.72
	Bivalvia	*Acanthocardia echinata*	1.7	1.06	0.033		1.06
		Arctica sp.					
	Gastropoda	*Buccina undatum*	1.2	0.56	0.017		0.56
		Neptunea antiqua					
	Crabs	*Cancer pagurus*	3.4	2.76	0.085		2.76
		Liocarcinus depurator					
	Hermit crabs	*Pagurus bernhardus*	0.84	0.2	0.006		0.2
	Squat Lobsters	*Munida rugosa*	0.84	0.2	0.006		0.2
	Starfish	*Asterias rubens*	4.1	3.46	0.107		3.46
		Astropecten irregularis					
		Marthasterias glacialis					
		Porania sp.					
	Urchins	*Brissopsis lyrifera*	12	9.76	0.301		9.76
	Fish	Cod	0.82	0.18	0.006		0.18
		Haddock	1.6	0.96	0.030		0.96
		Whiting	1.66	1.02	0.031		1.02
		Hake	3.7	3.06	0.094		3.06
		Plaice	1.9	1.26	0.039		1.26
		Sole	1.8	1.16	0.036		1.16
	Other fish	Bullhead	2.32	1.04	0.032		0.76
		Long rough Dab	0.92				0.28
		Dragonnet					
		Herring					
		Total		**32.4**	**1**		**32.4**

Trawl No.	**Major Taxon**	**Species**	**Wet Weight + Container (kg)**	**Wet Weight -Container (kg)**	**Proportion of Total Catch**	**%age catch analysed**	**Total (Estimated) Weight of Catch**
Aora6-S2	**Nephrops**	***Nephrops***	11.5	9.72	0.354	100	**9.72**
	Bivalvia	*Aequipectin opercularis*	0.76	0.12	0.004		0.12
	Gastropoda	*Buccina undatum*	1.8	1.16	0.042		1.16
		Neptunea antiqua					
	Annelida	*Aphrodita aculeata*	0.8	0.16	0.006		0.16
	Crabs	*Cancer pagurus*	1.28	0.64	0.023		0.64
		Liocarcinus depurator					
	Hermit crabs	*Pagurus bernhardus*	1.06	0.42	0.015		0.42
	Starfish	*Asterias rubens*	2.7	2.06	0.075		2.06
		Astropecten irregularis					
		Marthasterias glacialis					
	Brittle Stars	*Ophiura ophiura*	1.02	0.38	0.014		0.38
	Fish	Cod	2.4	0.62	0.023		0.62
		Haddock	8.9	8.26	0.301		8.26
		Whiting	3.2	1.42	0.052		1.42
		Hake	1.68	1.04	0.038		1.04
		Plaice	1.3	0.66	0.024		0.66
	Other fish	Bullhead	1.92	0.64	0.023		0.22
		Long rough Dab	1.06				
		Herring					
	Elasmobranchs	Dogfish	0.82	0.18	0.007		0.18
		Total		**27.48**	**1**		**27.48**