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THE EFFECT OF SEA BED TYPE ON THE DISTRIBUTION OF COD, HADDOCK AND WHITING IN THE NORTH SEA OFF THE NORTH EAST COAST OF ENGLAND.

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ABSTRACT

During February-March 1994, a localised fishing survey using a rock-hopper trawl was undertaken in order to investigate the influence of sea bed type on the distribution and feeding of cod, haddock and whiting in the North Sea off the North East coast of England. With the rock-hoppers it was possible to fish on a variety of grounds ranging from mud to bare rock. A mini-grab was used to sample the sea bed. The survey centred on ICES rectangle 39E8 off Blyth.

The distribution of cod was strongly related to sea bed type. Numbers caught in the rocky areas were tenfold greater (100.4 cod caught per tow) than on the smooth grounds (9.1 cod caught per tow). Feeding also varied, with a broader range of prey, particularly fish and Crustacea being consumed in rocky areas.

By contrast, the effect of sea bed type on the abundance of haddock and whiting was not significant. This is perhaps not so surprising in the case of whiting since they tend to feed on mobile prey, mainly fish and certain Crustacea. However, the distribution of haddock, which feed mainly on more sedentary invertebrates, might have been expected to be related to the nature of the sea bed. That this was not observed may have been due to the low numbers of haddock caught and the patchy nature of their distribution, which might have masked the influence of sea bed type. The size frequency distribution of all species was largely unaffected by sea bed type.

The possible broader implications of these finding for the interpretation of the results of fishing surveys are discussed.

INTRODUCTION

The relative abundance and feeding pattern of fish can vary depending on the nature of the substratum (Ehrich, 1988; Lough, 1989). The present study describes the distribution of cod, haddock and whiting on a variety of rough and smooth fishing grounds in the North Sea off the North East coast of England. These were obtained from a survey conducted during February-March 1994 in an area centred on ICES rectangle 39E8 adjacent to Blyth, using a chartered trawler operating a rock-hopper trawl. Possible implications of the findings for the interpretation of the results of fishing surveys are discussed. Feeding and prey selection were also investigated but will be reported in a later publication.

MATERIAL AND METHODS

Eleven days fishing were undertaken on the 'Girl Elma' over the period 1 February to 6 March 1994. The 'Girl Elma' is a 20m, ex-herring drifter fitted with a 300hp Caterpillar engine giving a towing speed of 2-3.5 knots.

The trawling gear consisted of a Boris Goshawk net with 86 feet of rock-hopper ground gear, enabling all types of sea bed in the area to be sampled, ranging from mud to bare rock. The rear 5m of the net was lined with 20mm stretched mesh netting to retain not only the larger predators but also a representative sample of their prey.

Typically, four, 1.5 hour tows were fished each day during daylight hours. The tides in the area run parallel to the coast, with the flood tide flowing southwards and the ebb tide northwards. Towing direction was generally parallel to the coast heading either with or against the tide. The preferred direction was against the tide when towing on very hard ground where there was a risk of coming fast. This avoided the danger of the net being flipped back over the headline by the tide. The area surveyed centred on ICES rectangle 39E8 adjacent to Blyth and extended offshore as far as rough ground on the western edge of the fishing ground known as the Graveyard in 39E9 (Fig 1).

Sampling was stratified by sea bed type. A series of transects starting from as close inshore as it was practicable to fish and running offshore was undertaken in order to give reasonably even coverage of the area. Some sites were fished more than once. The number of tows on the different types of sea bed were approximately in proportion to the area covered by the particular type of sea bed within the region studied. Included in the survey were the smooth ground areas routinely sampled by the ICES International Bottom Trawl Surveys (Anon 1990, 1992).

Ideally, a stratified random sampling procedure would have been used but this was precluded by a number of factors. These included the need to choose sites where it was possible to tow for 3-5 nautical miles on the same sea bed type, whilst at the same time avoiding static fishing gear. Other factors included adverse weather, the strength of the flood tides, and the logistics of fitting in four tows within daylight hours.

Substratum type was classified on the basis of the experience of the fishing skipper and information from Admiralty charts, backed up by bottom samples collected in a mini-grab during the survey. The four categories of sea bed type identified were smooth, mixed, rough and very rough; the definitions of which are given in Table 1 and their distribution is shown in Fig 1. The rough ground tended to be nearest to the coast, but there was some rough ground 20 nautical miles offshore at the 'Graveyard'.

The information collected at each station included date, hour of day, surface temperature and salinity, depth of water, swell height, and sediment type. The distance of the tow from the coast and the distance the net travelled over the sea bed was recorded in nautical miles. The length of the cod, haddock and whiting was measured to the nearest cm below. Stomach contents were also collected. Catch rate results were interpreted using multiple regression techniques. Factor analysis using the method of maximum likelihood with variomax rotation was used to condense the environmental data into three new orthogonal variables.

RESULTS

A total of 43 tows were successfully completed, giving good coverage of the sampling area. There were 19 tows on smooth ground, 6 on mixed, 9 on hard and 9 on very hard ground. Four of the tows in the north east region of the survey were on the smooth ground sampled by the IBTS. Despite fishing on areas of bare rock, no significant gear damage was sustained.

The contents of the grab samples were generally consistent with the category of sea bed type that had previously been identified. In the rough ground areas the grab was usually empty or contained only stones: very occasionally mud or shell was taken, but this must be expected since even in the rough areas small patches of soft ground can be expected to occur.

A summary of the environmental and ancillary information collected during the survey is shown in Table 2. Preliminary examination of the data showed that some of the variables were correlated. Factor analysis was used to provide a set of orthogonal variables for use in multiple regression. Factors 1-3 accounted for over 99% of the variance in the original data. Several rotation methods were tested, all of which gave fairly similar results. The factor patterns are shown in Table 3. Factor 1 has large positive loadings for distance from the coast, depth, temperature, salinity and swell, all of which were positively correlated and tended to

increase going away from the coast. Factor 1 can therefore be interpreted as a measure of 'offshoreness'. Factor 2 shows a strong positive loading for day contrasted with a negative loading for temperature, which tended to decrease slightly during the cruise. Factor 2 can be regarded as a measure of 'time scale'. Factor 3 is dominated by a positive loading for swell, and can be considered to be a measure of 'sea state'.

Catch rates in relation to sea bed type

A total of 1647 cod, 179 haddock and 1137 whiting were caught, measured and the stomach contents sampled. The relation between sea bed type and the numbers caught is shown in Table 4. A multiple regression of the numbers of fish caught per haul against bottom type and the factor variables was computed for each species (Table 5). Numbers of fish rather than log-numbers were used in the regressions because the results were similar to those made with log transformed data, and using untransformed data avoids the need to take account of zero catch rates, particularly for haddock which were absent at 14 out of the 43 stations fished.

a) Cod

The distribution of cod was strongly related to sea bed type (Table 4). Numbers caught in the areas where there were rock outcrops were tenfold greater (100.4 cod caught per tow) than on the smooth grounds (9.1 cod caught per tow). Preliminary analysis of their stomach contents showed that a wider range of prey, particularly fish and Crustacea was consumed in the rocky areas.

The hard ground and the highest density of cod tended to be concentrated near the coast (Fig 2). However, multiple regression analysis (Table 5) indicates that sea bed type was the overriding factor governing the distribution of cod, accounting for 75% of the variance in numbers caught. The factor variables, including 'offshoreness', did not significantly influence catch rates (P=0.05). The inclusion of towing direction and tide as a class variable in the regression showed that towing with or against the tide did not significantly influence the catch rates.

b) Haddock and whiting

The picture for haddock and whiting was very different. Catch rates of the two species were correlated ($R=0.64$ $p<0.001$) showing a degree of association in their distribution patterns. Numbers caught tended to be greatest on the mixed ground. Whiting were also abundant on the very hard ground. However, the multiple regression models (Table 5) indicated

that sea bed type was not related significantly to the numbers of haddock and whiting caught. In the case of haddock, the multiple regression model showed that there was significant positive correlation between numbers caught and the 'offshoreness' (Factor 1), with reduced catch rates when the 'sea state' (Factor 3) was rough. These two variables accounted for 65% of the variance in catch rates of haddock.

Whiting numbers were also positively correlated with the 'offshoreness' variable (Factor 1). Catch rates were not significantly influenced by 'sea state' (Factor 3), but there was significant negative correlation with the 'time scale' variable (Factor 2), reflecting the tendency for whiting to become less numerous later on in the survey. The model only explained 36% of the variance in the catch rates of whiting, indicating that whiting were more randomly distributed than the other species. The direction of towing in relation to the tide did not significantly influence catch rates of haddock or whiting.

c) Interrelationships between species

The combined catch of roundfish in relation to distance from the coast is shown in Fig 3. There appeared to be a band located 8-14 miles off the coast where the overall abundance of roundfish was persistently low.

d) Relation between sea bed type and the size frequency of the fish.

The length frequency distributions of the cod in relation to sea bed type are shown in Fig 4. There was no indication that the size frequency distribution of any of the fish species varied systematically between the different grounds.

DISCUSSION

The results indicate that the distribution of cod was heavily dependent on sea bed type. Numbers of cod caught in the rocky areas were ten fold higher (100.4 per tow) than on the smooth grounds (9.1 per tow). The average catch rates for the area as a whole was 38.3 cod per tow.

Multiple regression analysis (Table 5) showed that sea bed type (included as a class variable) appeared to be of overriding importance in governing the distribution of cod. The factor variables did not significantly (P=0.05) influence catch rates, indicating that factors such as 'offshoreness' (Factor 1) were not the primary driving force governing the distribution of cod.

It is possible that catchability varied between grounds, but it is to be expected that the trawl will be less efficient on rough ground since the ground gear is less likely to be tight on the

sea bed. Preliminary analysis of stomach contents showed that cod ate a broader range of prey in the rocky areas, indicating that the preference of the cod for hard ground was possibly related to food availability. Rough ground might also give better cover for hunting. Conversely, there may be increased opportunity for cod to conceal themselves from predators. The risk of capture by man is also reduced since there is generally less fishing activity on rough grounds.

There was no significant relationship between sea bed type and the relative abundance of whiting and haddock (Table 5). This is perhaps not so surprising in the case of whiting since they tend to feed on mobile prey, mainly fish and certain Crustacea. The haddock result is surprising since they tend to feed on more sedentary invertebrates, the distribution of which is likely to be highly dependent on the nature of the substratum. Relatively low numbers of haddock were caught and the patchy nature of their distribution might have masked the influence of sea bed type.

The drop in catch rates of haddock in relation to 'sea state' (Factor 3) could reflect a tendency for the fish to rise off the sea bed when turbulence increases, but might also indicate a drop in the efficiency of the fishing gear during bad weather. The drop in numbers of whiting over the course of the sampling period is possibly related to migration out of the area.

The distribution of the cod appeared to be strongly related to sea bed type and independent of the other two species. The distribution of haddock and whiting showed some affinity with each other. The catch rates responded positively to the environmental variables which contributed to the 'offshoreness' variable (Factor 1), although they differed in their response to the other factor variables. Differences in response to a range of environmental variables enable species to generate their own particular distribution patterns.

The combined catch of roundfish in relation to distance from the coast (Fig 3) shows that there is a band, 8-14 miles off the coast, where the overall abundance of roundfish is low. This possibly indicates an area on the smooth ground where food availability is low. By contrast, the higher total loading of roundfish on the rough grounds might indicate that these are generally more productive areas in providing food for gadoids..

The present study was localised, both in area and season and is not necessarily representative of the North Sea as a whole. In reality there are likely to be fluctuations in the distribution patterns of fish populations which change spatially and temporally. Fishing patterns off the NE coast, for example, change seasonally, presumably in response to changes in fish distribution. In April the pattern of fish distribution seen in the first quarter of the year changes and fishing effort is concentrated on large cod on fine grounds. By July, fishing reverts to the rough ground on a mixture of haddock, cod and saithe. By the end of the year the haddock have gone and fishing on rough ground targets cod. This gives a picture of dynamic

change in the distribution of fish, probably reflecting seasonal changes in feeding and reproductive migrations (Harden-Jones, 1968).

Most international fishing surveys presently concentrate sampling on the finer grounds in order to limit gear damage. The results presented here indicate that stratified sampling in relation to sea bed type is desirable, particularly for cod. For all species, the size frequency of the fish was unrelated to ground type. Concentrating sampling on the smooth ground is therefore likely to under estimates the relative abundance of cod but would not bias estimates of fish size. A problem with using stratified sampling in the North Sea as a whole is the difficulty of ascribing the different areas into particular categories of sea bed type. Fishing on rough ground requires specialist fishing gear such as rockhoppers, combined with local knowledge in order to minimise gear damage. Even with rockhoppers it is therefore probably not practical to conduct completely random stratified sampling in the North Sea. It might be possible to conduct stratified fixed point sampling on rough ground once the sites have been proved to be fishable.

Differences in catch rates on different grounds will obviously effect swept area estimates of abundance. However, it is possible to use catch rates from smooth grounds as an index of abundance in a time series if the pattern of fish distribution on the various grounds persists from year to year, regardless of annual fluctuations in absolute numbers of fish. If the patterns do not persist then restricting sampling to fine grounds may provide an index of abundance which does not respond in a systematic fashion to annual changes in fish abundance. Evidence form fishing surveys of the North Sea indicates that there is reasonably good correlation between survey indices of cod abundance and analytical estimates stock size derived from Virtual Population Analysis using commercial fishing statistics (Anon. 1994a). This suggests that the distribution patterns of fish on the various grounds do tend to persist from year to year.

There is preliminary evidence from the International Bottom trawl survey of the North Sea (Anon. 1994b) that the index of abundance of 1-group cod was less in the first quarter of 1993 than later on in the year. This was ascribed to young cod inhabiting coastal waters which are not comprehensively sampled by the IBTS. The present study shows that the high concentrations of cod in coastal waters off the NE coast of England during the first quarter of the year are mainly on rough ground and are not accessible to capture by smooth ground gear.

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Key words: FISH, FISHING GROUND, SEA BED, DISTRIBUTION, ABUNDANCE, SIZE, COD, HADDOCK, WHITING, NORTH SEA .

Table 1 . Definition of sea bed type.

Sea bed type	Definition
Smooth	Flat, mud or sandy mud. Can be safely fished with smooth ground gear.
Mixed	Generally flat with a mixture of mud, sand, shells and stones interspersed with patches of exposed rock. This type of ground is found along an approximately 500-1000m strip marking the boundary between smooth and hard ground. Cannot be safely fished with smooth ground gear.
Rough	Reasonably flat with long expanses of sandstone, coal or rock outcrops, areas of stones or moderately sized boulders. Cannot be fished with smooth ground gear.
Very rough	Tends to be inshore, similar to hard ground but with angled ridges projecting up from the sea bed. Cannot be fished with smooth ground gear.

Table 2. Summary of environmental variables and towing distance.

Variable	Mean	Std Dev	Minimum	Maximum
Distance from coast (Nautical miles)	7.6	5.3	2	19
Distance towed (Nautical miles)	4.19	0.57	3	5.4
Depth (metres)	60.8	17.4	37	95
Swell height (metres)	1.8	1.6	0	5
Salinity (‰)	34.169	0.398	32.655	34.558
Temperature (°C)	6.7	0.4	6	7.5

Table 3. The Rotated Factor Pattern generated by factor analysis using the method of maximum likelihood with variomax rotation

Variable	Factor 1	Factor 2	Factor 3
Hour	0.023	-0.046	-0.212
Distance towed	-0.073	0.009	-0.192
Depth	0.874	-0.053	0.484
Day	-0.075	0.884	0.355
Swell	0.359	0.344	0.736
Salinity	0.482	-0.313	0.253
Temperature	0.660	-0.579	0.030
Miles from coast	1.000	0.005	-0.021

Table 4. Relationships between catch rates and sea bed type

Species	Sea bed type	Number of tows	mean number caught per tow	Std Dev	Minimum	Maximum
Cod	Soft	19	9.1	9.2	0	34
	Mixed	6	43.0	13.2	22	58
	Hard	9	34.7	29.5	6	91
	Very hard	9	100.4	36.3	36	144
	All	43	38.3	41.1	0	144
Haddock	Soft	19	3.6	7.2	0	32
	Mixed	6	8.5	13.7	0	36
	Hard	9	3.2	3.7	0	11
	Very hard	9	3.3	4.6	0	12
	All	43	4.1	7.4	0	36
Whiting	Soft	19	21.6	20.4	1	87
	Mixed	6	36.5	35.7	6	103
	Hard	9	18.3	18.8	0	49
	Very hard	9	38.0	48.5	1	154
	All	43	26.4	30.2	0	154

Table 5. Analysis of the catch data using General Linear Modeling. The dependent variable is numbers of fish caught per tow.

a) COD

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F value	P
Model	6	53243.00	8873.83	17.79	0.0001
Error	36	17956.44	498.79		
Corrected Total	42	71199.44			

R-Square= 0.75

Source	DF	Type III SS*	Mean Square	F value	P
Sea bed type	3	18320.78	6106.93	12.24	0.0001
Factor 1	1	1232.53	1232.53	2.47	0.1247
Factor 2	1	490.71	490.71	0.98	0.3279
Factor 3	1	1113.48	1113.48	2.23	0.1439

* Equivalent to fitting each parameter last.

Table 5.0 (continued).

LINEAR REGRESSION MODEL

Parameter	Estimate	T for H0 Parameter=0	P	SE of Estimate
Intercept	89.8	9.75	0.0001	9.2028
Sea bed- hard	-57.3	-4.99	0.0001	11.476
mixed	-48.9	-3.85	0.0005	12.695
soft	-73.8	-5.83	0.0001	12.668
very hard	0	.	.	.
Factor 1	-6.14	-1.57	0.1247	3.903
Factor 2	3.82	0.99	0.3279	3.8507
Factor 3	-6.69	-1.49	0.1439	4.4766

b) HADDOCK

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F value	P
Model	6	1502.37	250.39	11.07	0.0001
Error	36	814.13	22.6148		
Corrected Total	42	2316.51			
R- Square=0.65					

Source	DF	Type III SS	Mean Square	F value	P
Sea bed type	3	44.26	14. 75	0.65	0.5867
Factor 1	1	416.41	416.41	18.41	0.0001
Factor 2	1	74.14	74.14	3.28	0.0785
Factor 3	1	491.95	491.95	21.75	0.0001

LINEAR REGRESSION MODEL

Parameter	Estimate	T for h0 parameter=0	P	SE of Estimate
Intercept	2.60	1.33	0.1931	1.96
Sea bed- hard	0.55	0.23	0.8221	2.44
mixed	3.30	1.22	0.2307	2.70
soft	2.29	0.85	0.4017	2.70
very hard	0			
Factor 1	3.57	4.29	0.0001	0.83
Factor 2	-1.48	-1.81	0.0785	0.82
Factor 3	-4.45	-4.66	0.0001	0.95

Table 5.0 (continued).

c) WHITING

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F value	P
Model	6	13758.98	2293.16	3.35	0.0101
Error	36	24669.72	685.27		
Corrected Total	42	38428.70			

R-Square=0.36

Source	DF	Type III SS	Mean square	F value	P
Sea bed type	3	4002.974518	1334.324839	1.95	0.1394
Factor 1	1	5610.303531	5610.303531	8.19	0.007
Factor 2	1	4334.555784	4334.555784	6.33	0.0165
Factor 3	1	230.6581783	230.6581783	0.34	0.5654

LINEAR REGRESSION MODEL

Parameter	Estimate	T for h0 parameter=0	P	SE of Estimate
Intercept	49.15	4.56	0.0001	10.79
Sea bed- hard	-29.56	-2.2	0.0345	13.45
mixed	-17.62	-1.18	0.2442	14.88
soft	-31.78	-2.14	0.0392	14.85
very hard	0	.		.
Factor 1	13.09	2.86	0.007	4.57
Factor 2	-11.35	-2.52	0.0165	4.51
Factor 3	-3.04	-0.58	0.5654	5.25

Figure 1. Chart of the survey area and sea bed type.

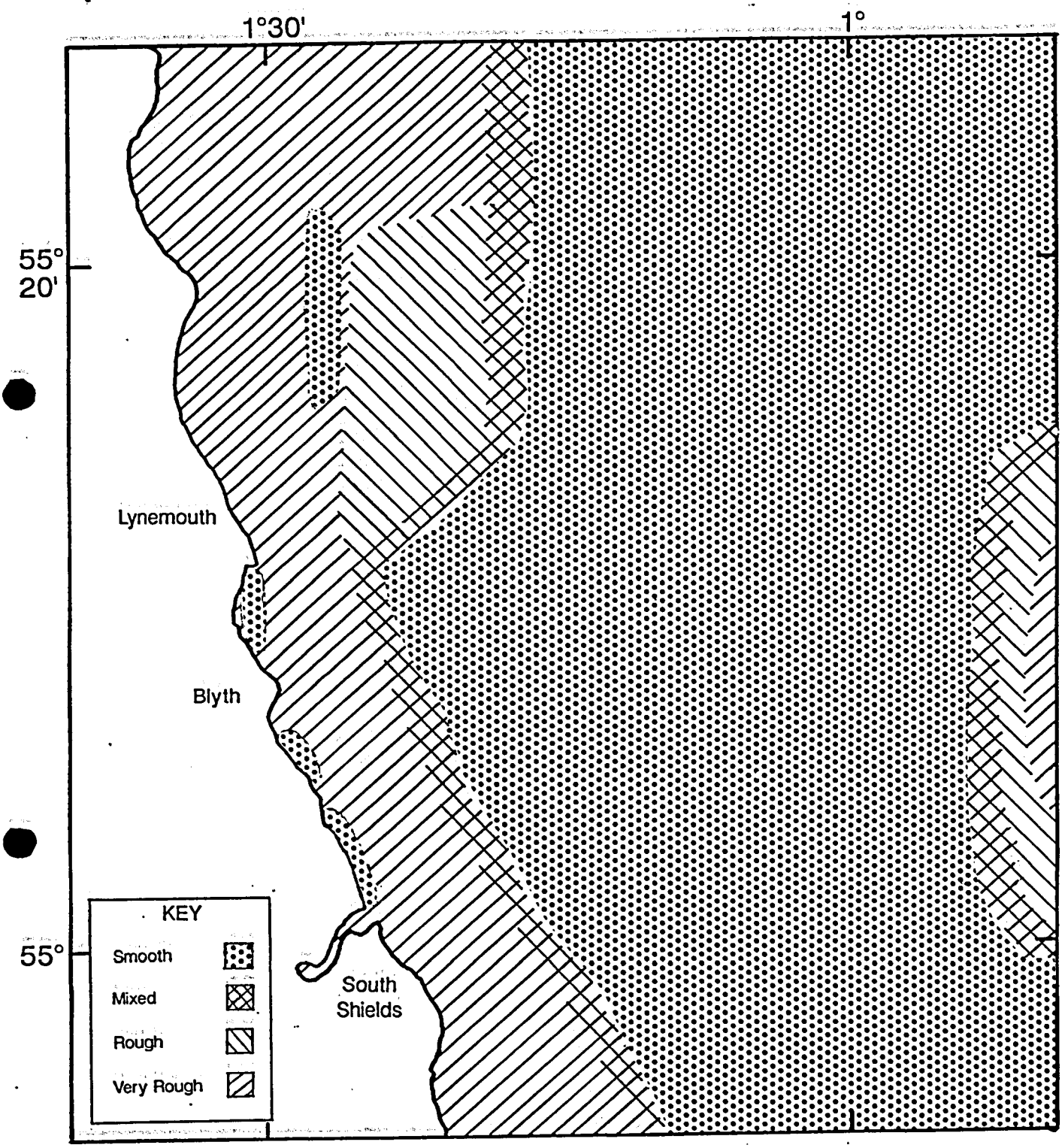

Figure 2. The numbers of cod caught per tow in relation to sea bed type and distance from the coast (nautical miles).

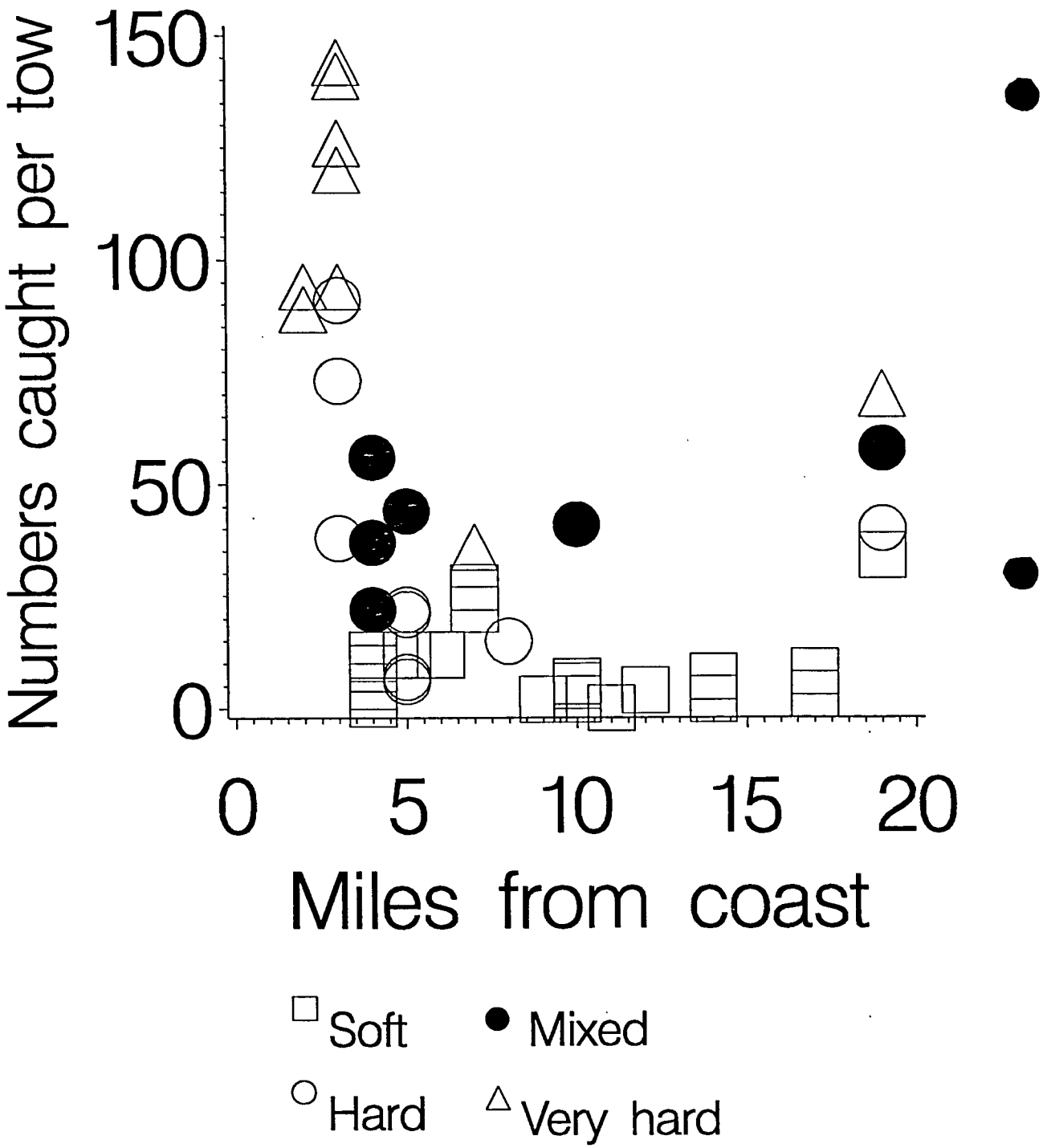

Figure 3. The combined catch rates (numbers per tow) of cod, haddock and whiting in relation to distance from the coast (nautical miles).

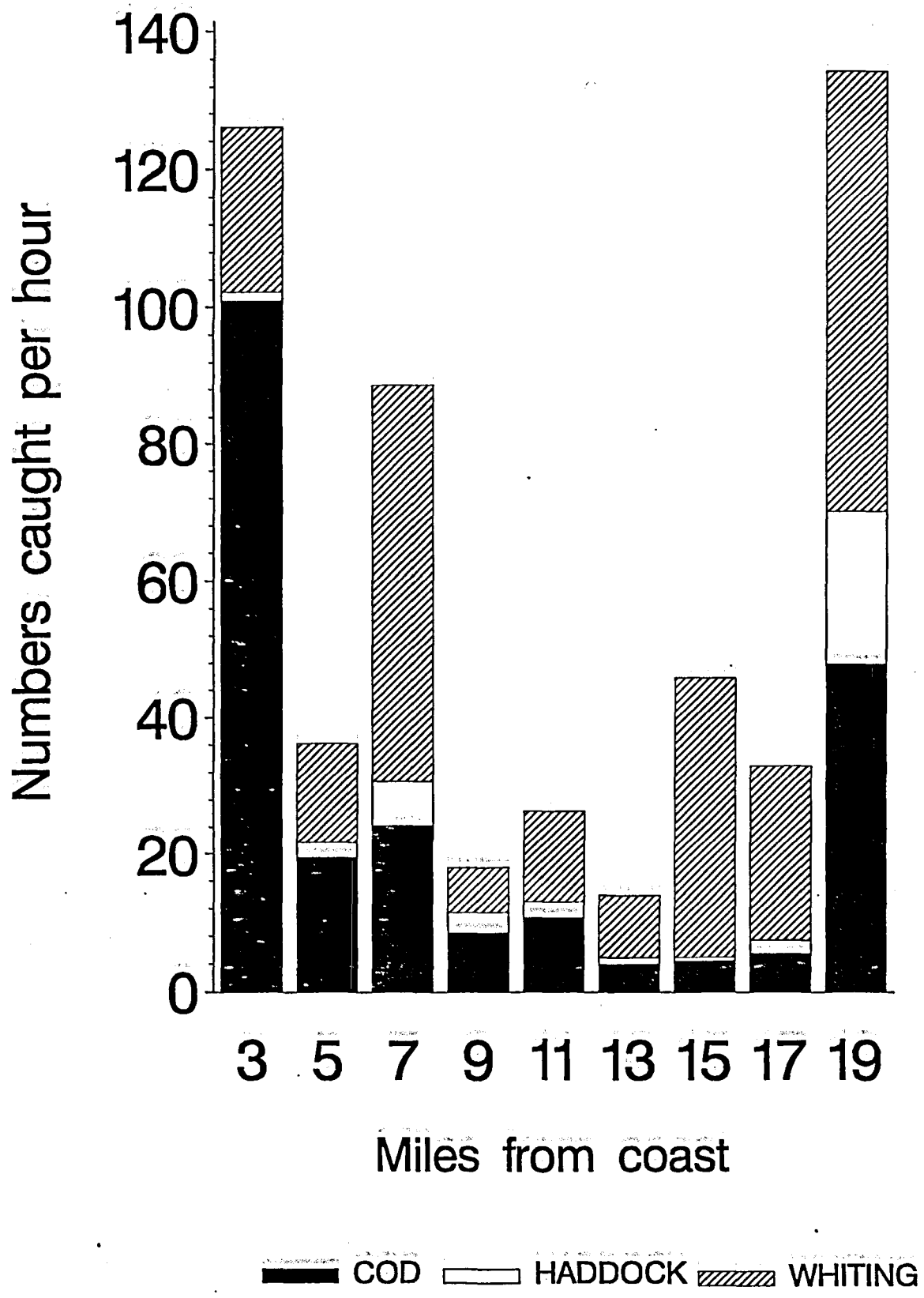

Figure 4. The size frequency distributions of cod caught on the various types of sea bed.