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Relationships between herring school distribution and seabed substrate derived from RoxAnn

D. G. Reid and C. D. Maravelias

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A series of three fine-spatial-scale acoustic studies was carried out to study the relationships between herring-school distribution and the seabed substrate. The study was carried out on three separate bank areas east of Shetland in July 1993. The study areas were characterised respectively as: mainly mud with some hard ground; mixed mud, sand and hard ground; and mostly hard ground. Herring schools were identified from the echo-sounder record. The substrate was mapped using the RoxAnn seabed classification system interfaced to the same echo-sounder. The relationship between herring distribution and substrate was examined at two different levels; map-based, using contour plots of the important variables, and track-based, using individual herring schools in relation to the specific substrate type found on the survey track under the schools. Data are presented which show a strong tendency for schools to be found preferentially over hard seabeds, particularly in the track-based analysis. There also appears to be a strong relationship between herring aggregations and particular topographic features. This is discussed in relation to specific features, a low ridge and two escarpments, identified in two of the study areas.

Keywords: herring, acoustic surveys, seabed substrate, RoxAnn.

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D. G. Reid and C. D. Maravelias: SOAFD Marine Laboratory, PO Box 101, Victoria Road, Aberdeen AB11 9DB, Scotland, UK. Correspondence to D. G. Reid: tel: 01224 295363; fax: 01224 295511; e-mail: reiddg@marlab.ac.uk

Introduction

The North sea herring, *Clupea harengus*, which is a demersal-spawning species, is well known to be strongly selective for particular substrata on the spawning grounds. Most spawning takes place on gravel beds (Haegele and Schweigert, 1985; Morrison *et al.*, 1991). There is considerable anecdotal evidence that herring also display substrate preferences at other times of the year, although this has not been studied quantitatively.

An understanding of the distribution of herring in relation to the seabed substrate would be useful to the analysis of acoustic surveys on this species in two ways. First, if it could be demonstrated that herring have a general preference for a particular substrate or substrata, this could be used as a stratification parameter for the analysis of survey results. Bathymetric data have been shown to be useful in stratification during herring acoustic surveys (Staehr and Neudecker, 1991) and other parameters would clearly enhance the accuracy of the analysis (Simmonds *et al.*, 1992). Second, if herring show a preference for a particular substrate this could be used to enhance the process of species identification from echograms, a process which at present is relatively subjective. This type of analysis is, of course, also of basic biological and behavioural value in enhancing our understanding of the factors that control fish distribution.

The present study was made possible by the availability of the RoxAnn acoustic substrate classification system (Chivers *et al.*, 1990) coupled to a standard fisheries echo-sounder (SIMRAD EK500). This combination made it possible to collect acoustic data on herring distribution and substrate simultaneously and at survey speeds. This allowed not only the mapping of the substrate across the study area, but also the determination of the substrate type below each individual school (Greenstreet *et al.*, 1997). The surveys were carried out using a series of repeat acoustic transects across three bank areas east of the Shetlands. The study area was known to include a wide range of substrate from rock to soft mud. The herring population was assessed using standard acoustic survey techniques (Simmonds *et al.*, 1993).

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The study aimed to address three questions. 1. Could substrate type be used as an effort stratification parameter for the conduct of acoustic surveys for this species? 2. Could substrate type be used as a covariate parameter with fish abundance to improve the precision of acoustic abundance estimates for this species? 3. Was there any evidence that herring showed any substrate preference behaviour which could be useful in species identification?

Material and methods

The data used in this study were collected on a combined acoustic and fishing survey by the FRV "Clupea" in July 1993. The study was timed to coincide with the arrival of migrating herring in these waters and as close to the time of the ICES co-ordinated herring acoustic surveys as possible.

Survey areas

Three survey areas were examined. All three were located east of Shetland and were chosen as known areas of herring aggregations which also displayed a variety of substrate types.

Survey 1

This survey covered an area bounded by 60°39′ and 60°45′N and 0°39.90′ and 0°41.80′W, east of the island of Unst. Fifty-four repeat north/south transects were carried out over 48 hours. Transects were positioned randomly east/west, with approximately one nautical mile between the most easterly and the most westerly. Random transect positioning was used as the vessel was not fitted with differential GPS. It thus proved impossible to place the transects more accurately than ± 250 m. In some cases there was overlap of transects, which, given the reality of vessel navigation, was unavoidable.

Survey 2

This survey covered an area bounded by 60°35′ and 60°44′N and 0°31.20′ and 0°37.00′W, near Unst Bank, also east of the island of Unst. Forty-eight repeat north/south transects were carried out over 36 hours. Transects were positioned randomly east/west, with approximately three nautical miles between the most easterly and the most westerly.

Survey 3

This survey covered an area bounded by 60°44′ and 60°47′N and 0°02.00′ and 0°20.00′W, on Pobie Bank, further east of Unst, than surveys 1 and 2. Twenty-one repeat east/west transects were carried out over 30 hours. Transects were positioned randomly north/south, with approximately three nautical miles between the most northerly and the most southerly.

Data acquisition

The survey was carried out using a Simrad EK500 38 kHz split beam echo-sounder. This was interfaced to a SUN SPARC IPC running the Simrad BI500 integrator. The echo-sounder output was recorded on a colour-paper printout. Data from the echo-sounder were stored in 0.5-m samples, transmission by transmission, on digital audio tape (DAT) for subsequent analysis in the laboratory.

A RoxAnn system (Marine Microsystems, Cork, Ireland) was connected to one quadrant of the split-beam transducer. The system was interfaced to a PC running Microplot (Sea Information Systems, Aberdeen). Data on time, date, position (from GPS), depth, and E1 and E2 (from RoxAnn) were recorded in 15-s samples on a PC. For more information on RoxAnn see Chivers *et al.* (1990) and Schlagintweit (1993).

Trawling (four hauls each for surveys 1 & 2, and three for survey 3) was carried out on selected schools to establish the identity of the marks seen on the echo-sounder and to determine the biological parameters of the herring in this location. There was also some commercial pelagic fishing vessels working in the area which were able to confirm echo-trace identification

Data analysis

Echo-sounder data

The echo-sounder record was processed using both visual examination of the colour printout and the BI500 "Scrutinise" programme. Herring schools were identified on the basis of the results of the trawl hauls and visual examination. For the purposes of this study herring schools were defined as having an integral greater than 20 and to appear in at least two consecutive transmissions. The technique is commonly used in the assessment of acoustic surveys for this species (Reid *et al.*, 1998; Reid, 2000). Herring represented approximately 90% of the fish biomass in the areas studied. The remainder of the fish were assorted small gadoids, mostly Norway pout and haddock. A total of 190 schools were identified as probably herring in survey 1, 172 schools in survey 2, and 293 schools in survey 3. All schools were scored for time, date, position, and echo-sounder integral. The schools were also scored as bottom schools (<10 m from seabed) or pelagic (>10 m from seabed). The schools were not scored for day/night because in this latitude in June the night is very short and light.

RoxAnn Data

In survey 1, 8025 valid RoxAnn samples were collected along the transects, 5388 were collected in survey 2 and 3717 in survey 3. These were assigned to substrate types based on grab samples conducted during the survey and from previous analyses. Initial analysis used the box-set technique available in Microplot for assigning different permutations of E1 and E2 to substrate type. Each box is assigned a unique colour and the output is presented on the plot of the cruise track, each sample being assigned to a unique substrate type. A monochrome representation of this can be seen in Figure 1. In this study we have used only the second RoxAnn parameter, E2, which represents substrate "hardness" (Chivers *et al.*, 1990). Engineer values (voltages) were used for E2 and no further processing was applied. For the purposes of this study only three substrate types were defined: soft ground (mud and silt: E2<0.6 V), sandy ground (sand and gravel: 0.6<E2<1.2) and hard ground (stones and rocks: E2>1.2 V).

Combination of herring and substrate data

The data on herring and substrate type were combined in two different ways. The first was an area-smoothed, map-based approach and the second, a school-specific, track-based approach.

Area-smoothed analysis

Maps of the large-scale distribution of substrate types within the survey area were constructed from the RoxAnn data collected along the survey tracks. Mapping was carried out using contour plotting based on interpolated 25 × 25 grids (Surfer for Windows v.7, Golden Software Inc.). Interpolation between observations was by inverse distance with a weighting power of two. Contour maps were developed for herring integrals, water depth and E2 values. The positions of all the schools in the study area were then plotted against this substrate map. Simple contour maps showing only the 0.6 and 1.2 V contours with school positions are presented. Data are presented only for those parts of the total study area where a good coverage of transects was available. The proportions of the areas of the different substrate types and number of schools on each substrate were then calculated. The null hypothesis that the schools were distributed randomly with respect to substrate was tested using a G-test (Sokal and Rohlf, 1969).

Track-based analysis

The substrate category (defined above) was determined for the seabed immediately under each school previously identified. This involved taking the mean of the E2 values recorded while the school was visible in the echogram and for 60 seconds before and after. The data on substrate were then included in the herring school database for further analysis. This analysis included all schools within the study area for which RoxAnn data were available, some of which will have been found outside the area covered by the map described above. The frequencies of the different ground types were calculated by sorting the RoxAnn samples into three categories by E2. This approach can be expected to produce different frequencies for the three substrata from the first analysis. The area from which the samples are drawn is slightly wider and small patches of one ground type inside larger areas of other types will be included with this approach. The null hypothesis that the schools were distributed randomly with respect to substrate was tested as above.

Specific study of ridge at 60°40′N in survey 1

An isolated ridge of hard substrate was identified in one part of the study area in survey 1, which was otherwise largely dominated by soft sediments. This area was bounded by 60°41.86′ and 60°42.36′N and 0°40.75′ and 0°41.33′W. The ridge ran east/west, at about 60°42′N. It was about 250 m wide and had a maximum elevation of 12 m above the surrounding terrain. All schools within 1 km of the ridge were recorded along with their distance to the nearest edge of the feature. No statistical analysis was attempted on these data.

Specific study of escarpments in survey 2

The study area in survey 2 was characterised by the presence of two escarpment features. These were areas showing rapid depth changes from around 120 m to approximately 90 m. These escarpments were also generally characterised by a generally high E2 value. All schools within 1 km of these escarpments were recorded along with their distance to the nearest edge of the feature. No statistical analysis was attempted on these data.

Results

Survey 1

Map-based analysis

The results of the mapping of the general distribution of the three substrate categories in the study area, the water depth (bottom topography), and the distribution of the herring integrals are presented in Figure 1. The area has no rapid depth changes and is relatively uniform in depth profile. There is a patch to the south of the study

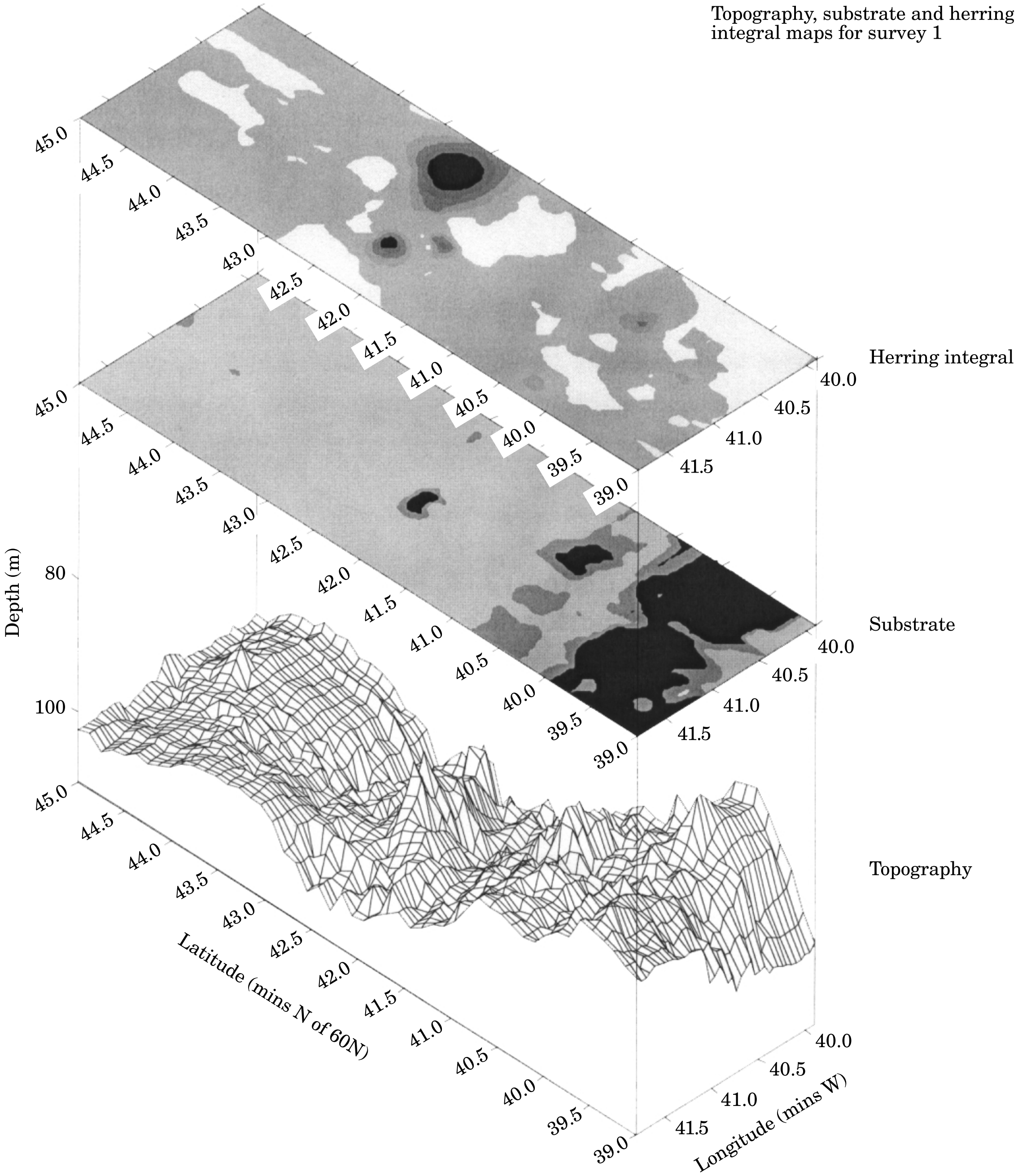


Figure 1. Geographical contour plots of (a) five minute herring integrals, (b) E2: seabed hardness (volts) and (c) water depth (m) for survey area 1.

area dominated by hard ground, and there is a small patch of hard ground associated with a shallow ridge in the centre of the area. The main feature of the herring distribution is a strong concentration of fish in the centre of the study area, adjacent to the ridge (see below). The distribution of the bottom and pelagic herring schools in relation to the substrate map are presented in Figure 2. It is clear that the bottom schools (Figure 2a) tended to be associated with the main areas of hard ground, particularly the ridge at 60°42′N. No such relationship is apparent for the pelagic schools (Table 1). This interpretation is supported by the data in Table 2, which shows a significant relationship between substrate and the bottom schools only.

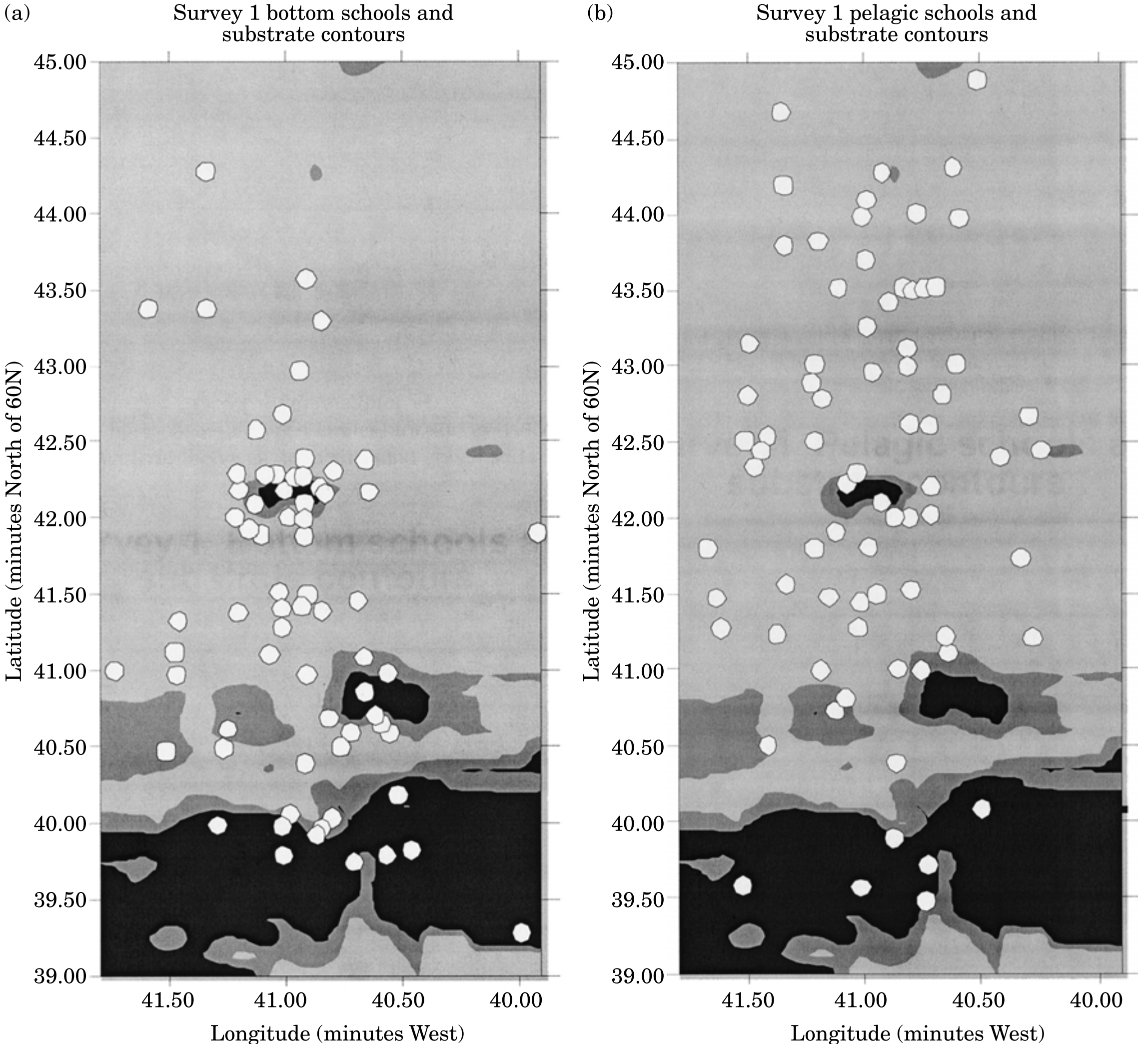


Figure 2. Simplified geographical contour plot of E2: seabed hardness (volts) and observed school positions(open circles) for survey 1. Contours are plotted at 0.6 and 1.2 V, as the boundaries between; mud/silt, sand/gravel and rocks/stones (see the text).

Track-based analysis

Visual examination of the RoxAnn track data and the echosounder record indicate that while the bulk of the hard (rocks/stones) or sandy ground is found in reasonably large, discrete areas there are small patches of harder ground throughout the study area. The area-smoothed approach adopted above tends to lose such small and isolated patches. The second approach to the analysis was to determine the substrate type (defined from the RoxAnn data set) found under each herring school. The results of this analysis are presented in Table 1b.

The most striking observation is that almost 60% of the bottom schools are found over hard substrate, although this represents only 13% of the total area. Although the relationship is less marked the pelagic schools are also found preferentially over hard ground (27.4%). This is not due to the schools being smaller over the hard ground, as 65% of the total echo-integral for the study area was found over hard ground. So the schools were actually slightly larger over hard ground.

Survey 2

Map-based analysis

Unlike the area covered in survey 1, this survey included larger areas of hard ground, and also had some areas of rapid depth change Figure 3a–c. There appeared to be an association in some places between the areas of rapid depth change and the harder ground. This was most noticeable on the two south-facing slopes in the north and the central parts of the study area. In other parts of

Table 1. Contingency table and G-test for goodness of fit of observed school distribution to that expected with no substrate preferendum. Survey 1.

Substrate type	Frequency (%)	Observed school frequency	Expected school frequency
(a) Map-based analysis			
Mud/silt	70.50	81	90.94
Sand/gravel	16.50	31	21.30
Rock/stones	13.00	17	16.76
G value		5.00	
d.f.		2	
G_{crit} $p<0.05$		5.99	
Significance		Not significant	
(b) School-based analysis			
Mud/silt	76.16	77	143.17
Sand/gravel	10.53	33	19.80
Rock/stones	13.31	78	25.03
G value		115.53	
d.f.		2	
G_{crit} $p<0.001$		13.82	
Significance		Highly significant	

Table 2. Survey 1 contingency table for goodness of fit of observed herring echo-integral distribution to that expected with no substrate preferendum. School based analysis.

Substrate type	Substrate frequency (%)	Observed summed echo-integral	Mean	Integral frequency (%)	Expected summed echo-integral
Mud/silt	76.16	18 520	240.52	42.85	32 920
Sand/gravel	10.53	3 500	106.06	8.10	4 552
Rock/stones	13.31	21 205	271.86	49.05	5 753

the area large changes in E2 and hence substrate were not related to depth change, for instance the plateau in the north of the study area. There was also evidence that the herring were concentrated on or around these areas (Figures 3a and 4). The statistical analysis of the herring integral distribution in relation to substrate clearly indicated a significant association between herring and the hard ground (Table 3a).

School-based analysis

The same relationship between herring and the substrate was apparent from the school-based analysis. As in survey 1 it would appear that some of the schools which were found in areas dominated by softer substrata were found over small patches of harder ground. It is interesting to note that this occurs even when more of the area is dominated by hard ground. As in survey 1, the analysis by summed echo-integral demonstrates that as well as more schools there are also more fish over the harder ground (Table 4).

Survey 3

Survey 3 was complicated by the presence of a large number of herring schools found very high in the water column, between 10 and 20 m. This type of school has been reliably identified as herring (Simmonds *et al.*, 1994; Reid *et al.*, 1998) during ICES herring acoustic surveys in the 1990s. They are generally more common in the north and east of ICES Area IVa. In terms of number these schools represented 60% of the total, and 49% in terms of school integral.

Map-based analysis

Unlike the previous two surveys the area covered by survey 3 contained very little soft ground and was largely made up of stony/rock ground (Figure 5a–c). As with survey 2 there was a steep slope in one part. This faced west and ran down into the only muddy part of the study area. No clear relationship is visible between the herring distribution and either the substrate or the topography. Large concentrations of fish were found in

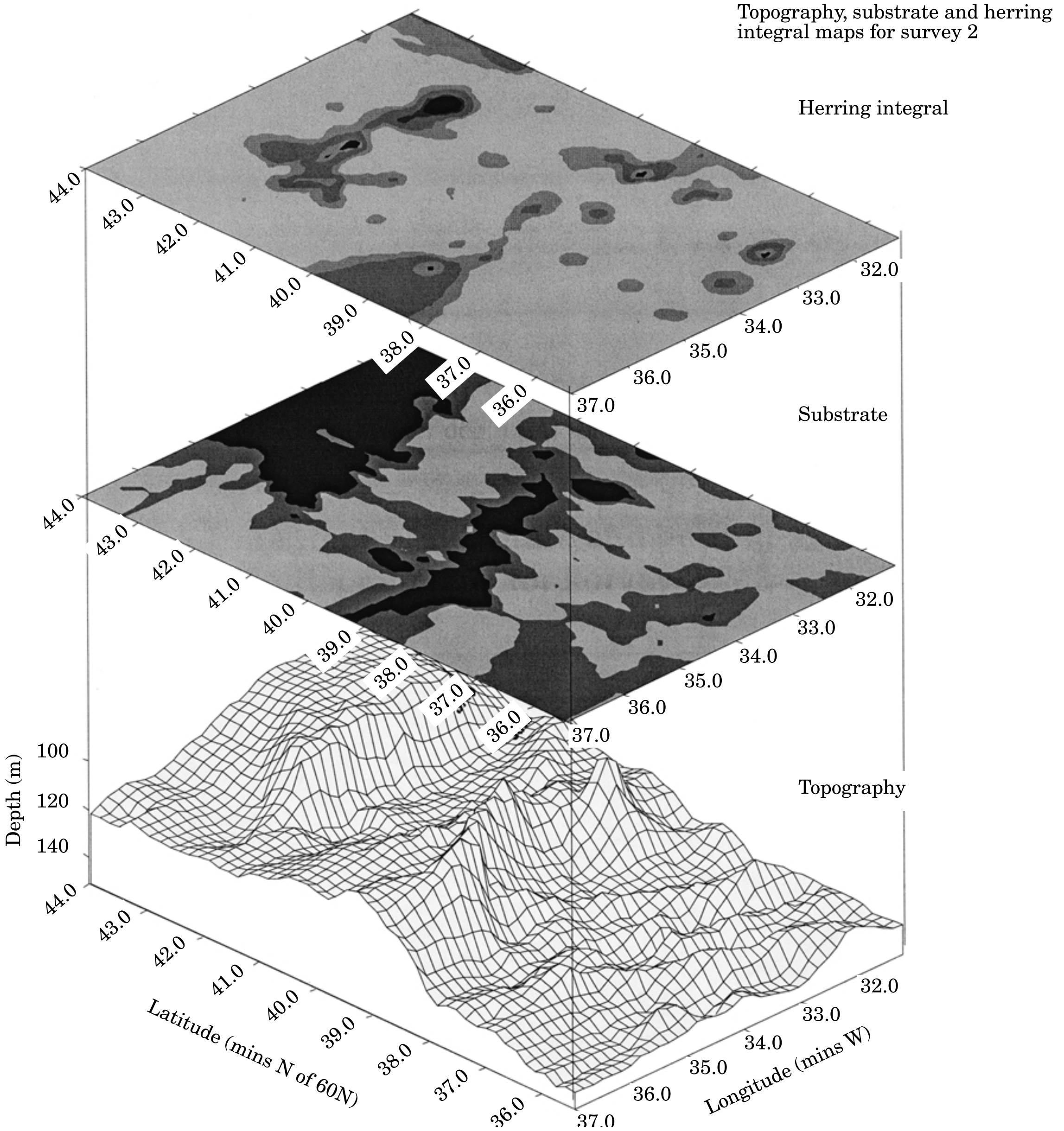


Figure 3. Geographical contour plots of (a) five minute herring integrals, (b) E2: seabed hardness (volts) and (c) water depth (m) for survey area 2.

the centre of the hard ground, but there were also concentrations of fish to the west of the area over the softer substrate (Figure 6). The statistical analysis of school distribution also suggests that there was no relationship with substrate (Table 5a).

School-based analysis

This analysis technique also shows that there was no relationship between substrate and herring schools (Table 5b).

Specific cases

Study of ridge in survey 1

The analysis of survey 1 indicated that if there was a relationship between substrate and herring distribution it worked at a very local level. The fish were not preferentially aggregating over large areas of hard ground. However, when the school-based analysis was used there was a relationship between harder ground and the herring distribution. Some of these fish will be

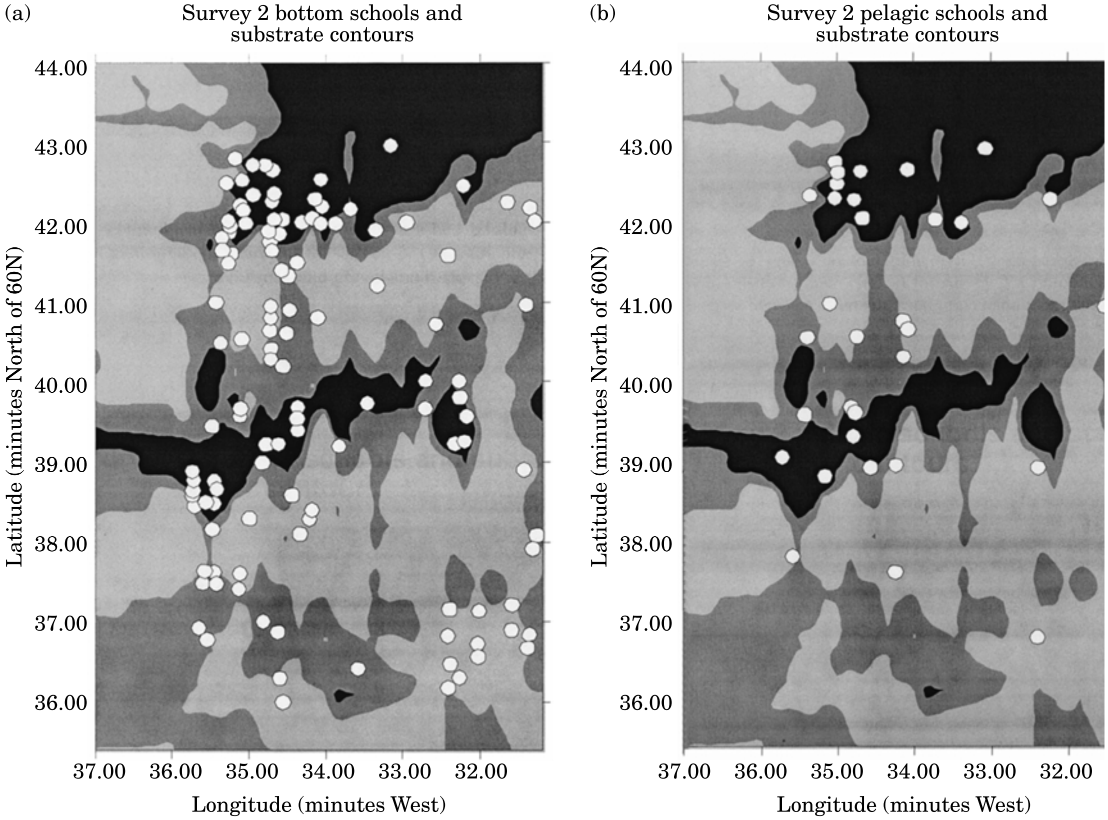


Figure 4. Simplified geographical contour plot of E2: seabed hardness (volts) and observed school positions(open circles) for survey 2. Contours are plotted at 0.6 and 1.2 V, as the boundaries between; mud/silt, sand/gravel and rocks/stones (see the text).

Table 3. Contingency table and G-test for goodness of fit of observed school distribution to that expected with no substrate preferendum. Survey 2.

Substrate type	Frequency (%)	Observed school frequency	Expected school frequency
Map-based analysis			
Mud/silt	29.98	30	53.66
Sand/gravel	50.13	90	89.94
Rock/stones	19.89	59	35.61
G value		25.23	
d.f.		2	
G_{crit} $p<0.001$		13.82	
Significance		Significant	
School-based analysis			
Mud/silt	37.18	30	66.55
Sand/gravel	42.89	77	76.78
Rock/stones	19.93	72	35.67
G value		53.78	
d.f.		2	
G_{crit} $p<0.001$		13.82	
Significance		Highly significant	

over the large areas of hard ground and some over smaller patches of hard ground. A specific examination was made of one seabed feature observed in the study area to study this relationship more closely. This was a ridge running east/west, at about 60°42′N. The presence of schools on or within 1 km of this ridge was recorded

Table 4. Survey 2 contingency table for goodness of fit of observed herring echo-integral distribution to that expected with no substrate preferendum. School based analysis.

Substrate type	Substrate frequency (%)	Observed summed echo-integral	Mean	Integral frequency (%)	Expected summed echo-integral
Mud/Silt	37.18	2465	100.50	11.65	7867
Sand/gravel	42.89	7420	120.52	35.07	9076
Rock/stones	19.93	11 275	136.38	53.28	417

on 48 transects on which the ridge was apparent. Each transect across the ridge was treated as nine 250-m bins, comprising one bin centered on the ridge, and four bins covering the kilometre of track north and south of the ridge, respectively. These data are presented in Figure 7. Herring schools were observed on the ridge on 41 of the 48 transects (85%). The mean number of observations per bin away from the ridge was approximately 10 (20.5%). Additionally there was no evidence that herring schools were more likely to be seen over soft ground closer to the ridge.

Escarpments in survey 2

Two areas of rapid depth-change were identified in survey 2. In both cases these were also characterised by the presence of harder substrata. The two features were found respectively at approximately 60°42′N and 60°39′N. Particularly in the case of the more northerly of these two features it was apparent that large numbers of herring were found along the edge of the escarpment. On the southerly escarpment there is also a clear coincidence of the edge with a denser band of herring. It was not possible to perform the analysis carried out for the ridge in survey 1 in this case because the features were not as easily collapsed to a single dimension. However, the coincidence should be noted.

Discussion

The main conclusion from this study is that there is definite evidence in this region that herring do sometimes show a preference for a particular substrate type, in this case stones and rocks. Three questions were posed in the introduction. 1. Could substrate type be used as an effort stratification parameter for the conduct of acoustic surveys for this species? 2. Could substrate type be used as a covariate parameter with fish abundance to improve the precision of acoustic abundance estimates for this species? 3. Was there any evidence that herring showed any substrate preference behaviour which could be useful in species identification?

The answer to the first question would appear to be equivocal. For survey 1, when the substrate was mapped with area-smoothing for large-scale variation, there was no significant relationship between the herring distribution and the underlying substrate. In survey 2 there was a relationship between the herring and substrate in the map-based analysis. In survey 3 no relationship could be seen. It is difficult to draw a definite conclusion from this. The most appropriate action would be to conduct further surveys with the same strategy but covering a wider area. The primary difference between surveys 1 and 2 was the presence of more hard ground in survey 2. Survey 3 was largely dominated by the harder ground. It is clear that herring do display a preference for harder ground. In those areas (e.g. survey 2) where hard ground is relatively common a general relationship is apparent. The herring in this general area are in mid-migration at this time of year. As the fish move southwards they may aggregate over the patches of hard ground but must necessarily pass over the softer areas. It would appear from both surveys 1 and 2 that even in such areas they will still show a preference for the harder patches where those occur, e.g. the ridge in survey 1 or the escarpments in survey 2. Thus, substrate type or topography may be useful effort stratification parameters for an acoustic survey but that this should be confirmed by wider-scale survey data.

The answer to the second question is probably positive. There is a strong covariance between substrate and fish density. In both the first two survey areas, where there was a large proportion of soft substrate, the herring showed a clear preference for the harder ground. However, a greater understanding of the variance of the substrate analysis would be required before its utility could be assessed for improving the precision of the herring abundance estimates.

This conclusion may appear to be contradicted by the evidence of survey 3 but this survey was the most difficult to interpret for several reasons. Firstly, the presence of significant numbers of schools very high in the water column might be expected to diminish the likelihood of any relationship with the seabed substrate and topography. Secondly, the bulk of the survey area was made up of hard ground. The remainder was, therefore, close to the edge of that hard ground. It is impossible to tell from these results whether coverage of a wider area would have given a clearer picture.

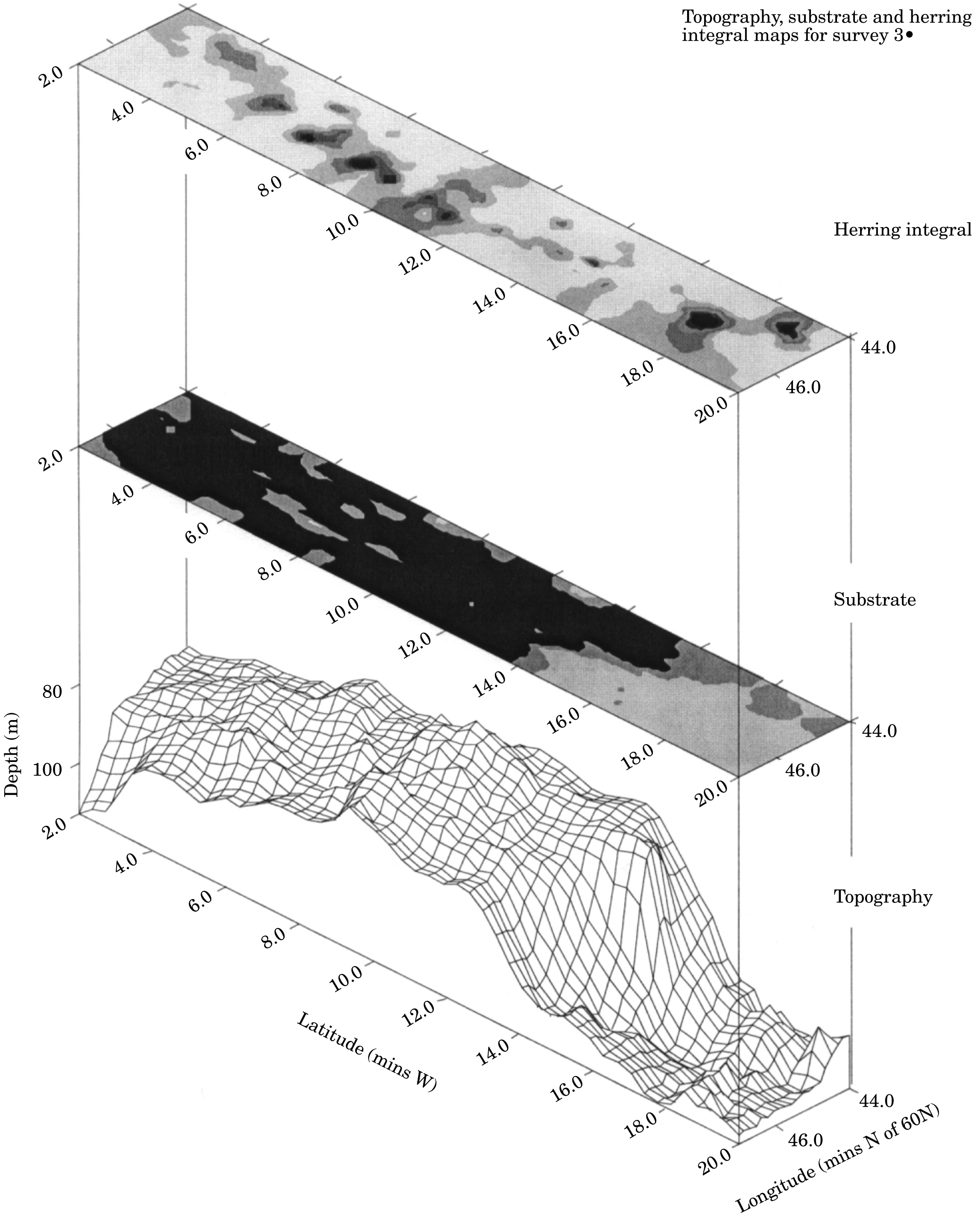


Figure 5. Geographical contour plots of (a) five minute herring integrals, (b) E2: seabed hardness (volts) and (c) water depth (m) for survey area 3.

The locations where there was a clear relationship between the herring distribution and the substrate and topography in surveys 1 and 2 were along hard substrate features running from east to west (the ridge in survey 1 and the escarpments in survey 2). It could be suggested that herring migrating from north to south would be more likely to encounter these features than those running in the same axis as the migration.

Table 5. Contingency table and G-test for goodness of fit of observed school distribution to that expected with no substrate preferendum. Survey 3.

Substrate type	Frequency (%)	Observed school frequency	Expected school frequency
Map-based analysis			
Mud/silt	19.38	69	61.81
Sand/gravel	8.75	33	27.91
Rock/stones	71.88	217	229.28
G value		2.38	
d.f.		2	
G_{crit} $p<0.05$		5.99	
Significance		Not significant	
School-based analysis			
Mud/silt	10.20	45	40.30
Sand/gravel	15.02	76	59.33
Rock/stones	74.78	274	295.37
G value		3.61	
d.f.		2	
G_{crit} $p<0.05$		5.99	
Significance		Not significant	

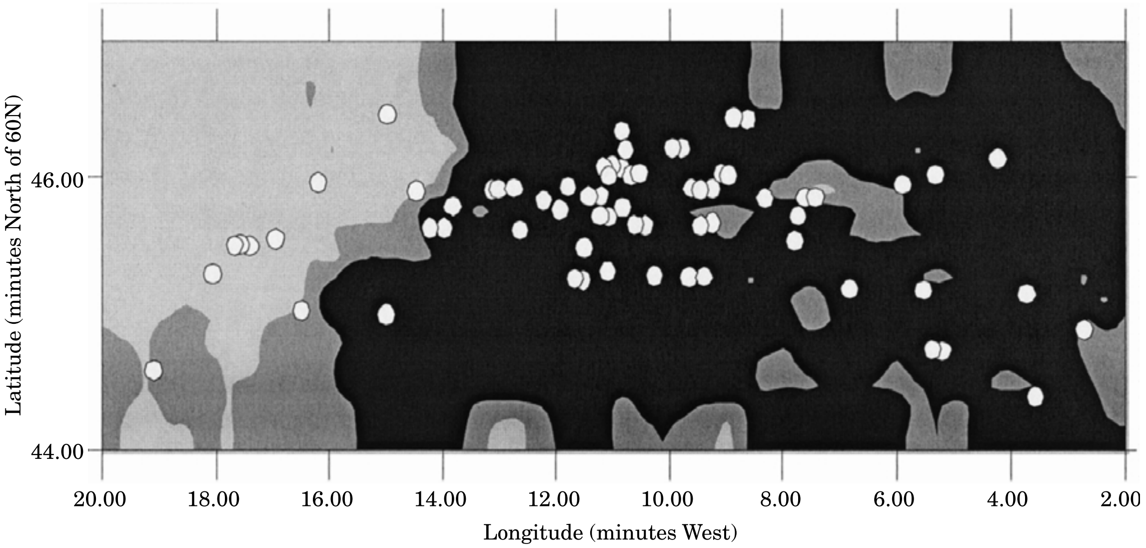
The answer to the third question is probably positive. There is a very strong tendency for herring schools to be found over hard ground, particularly when this ground is found in smaller patches in an area dominated by soft substrate. However this relationship needs to be studied further in different areas and under different conditions before it can be used as a diagnostic for herring schools. It would also be necessary to know whether other species with which herring can be confused show similar preferences. For example, Norway pout is often found in the same areas as herring and forms schools which look very similar to small herring schools on the echogram. Pout is principally a demersal species and is also likely to prefer the harder ground. Horse mackerel can also be easily confused with herring on an echogram but, being found in deeper waters, may have different substrate preferenda to herring. Further work would be required to clarify this.

It is not immediately clear why herring, a pelagic species, should display a schooling behaviour which is, to some extent, related to the seabed substrate. One hypothesis could be that there are water flow changes over the harder ground, which also tends to be elevated (sometimes only slightly) with respect to the adjacent softer ground. It is likely that the features such as the ridge or the escarpments described in this study will affect water flow and may result in a greater degree of mixing and, hence plankton productivity. The herring are actively feeding at this time and may then prefer these areas. A similar association with hard seabeds and topographic features has also been reported for Pacific herring (Mackinson, 1999). Alternatively, it may be that, as these fish will spawn in the near future, they may already be showing substrate preferences in anticipation of that event (Maravelias *et al.*, 2000). It should be noted that while herring are a pelagic species they are often found schooling close to the seabed.

Neither of these explanations is completely satisfactory. There may well be an increase in turbulence in the harder, elevated areas, and hence increased nutrient availability. However, for this to become available to herring, which are zooplankton feeders, it would have to pass through primary and secondary producers. This process would tend to disperse any ‘‘benefit’’ from the feature over a wider area. The close spatial association noted here would then be unlikely. Herring do spawn on hard substrates but these are usually gravel (Haegele and Schweigert, 1985), while the preferences shown here are for rocky substrates. Furthermore, anecdotal evidence would suggest that many pelagic spawning species are found associated with seabed features (Corten, pers. comm.).

In our opinion, and that of an independent referee, the best explanation is that the hard and prominent features represent ‘‘islands’’ on their migration route. The herring are migrating through this area at this time which is probably not a spawning ground for these fish. They are not yet ready to spawn and are likely to do so further south (Corten, 1988). An acoustic survey can be considered as a ‘‘snap-shot’’ of the population in an area at any one time. Even if the herring do prefer a particular substrate or topography, they must necessarily traverse the less preferred, muddy, areas as well. It is likely, therefore, that any relationship observed will only be partial, as seen here, and will also vary from area to area. It may be that patches of hard

(a) Survey 3 bottom schools and substrate contours



(b) Survey 3 pelagic schools and substrate contours

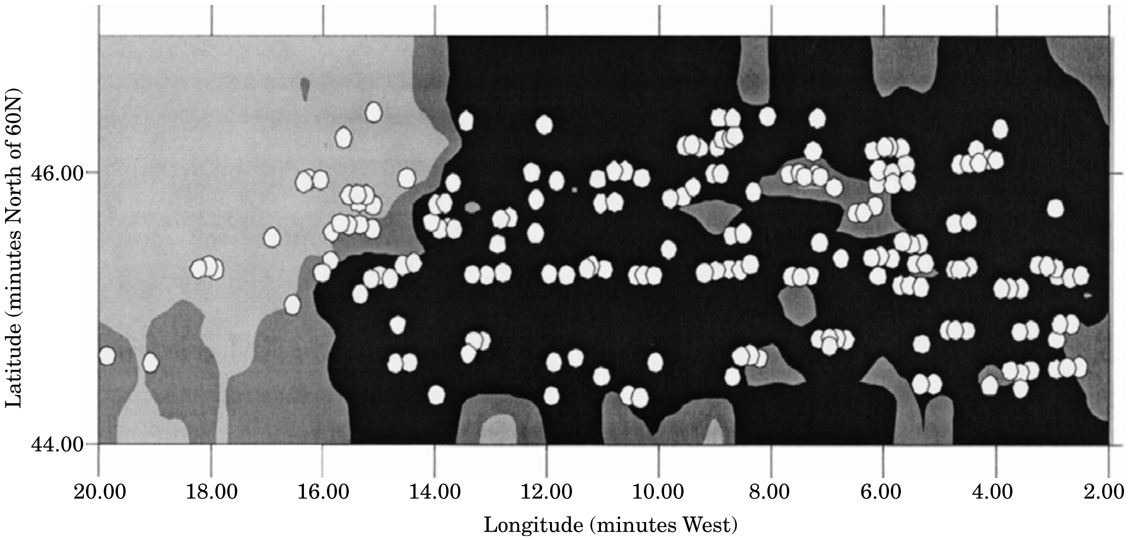


Figure 6. Simplified geographical contour plot of E2: seabed hardness (volts) and observed school positions (open circles) for survey 3. Contours are plotted at 0.6 and 1.2 V, as the boundaries between; mud/silt, sand/gravel and rocks/stones (see the text).

ground represent convenient “islands” to pause at. A similar phenomenon has been observed in tuna in open waters where the fish will aggregate, often in large numbers, close to an apparently irrelevant cue such as a floating log (Dagorn and Freon, 1999). The fish schools may be migrating in a general direction but this is unlikely to be a continuous process, and the features described may simply be convenient places at which to pause. The higher productivity postulated above for such areas may be an added benefit.

In conclusion the present study has revealed compelling evidence that herring distribution can be affected by substrate and topography. It is not possible to determine from the present evidence how general this phenomenon may be. There is a clear need to conduct further research both on the fine scale described in the present study and on the wider scale. In this context the database available from the annual ICES international herring acoustic surveys should prove very valuable. RoxAnn data has been collected on acoustic surveys of ICES Area IVa

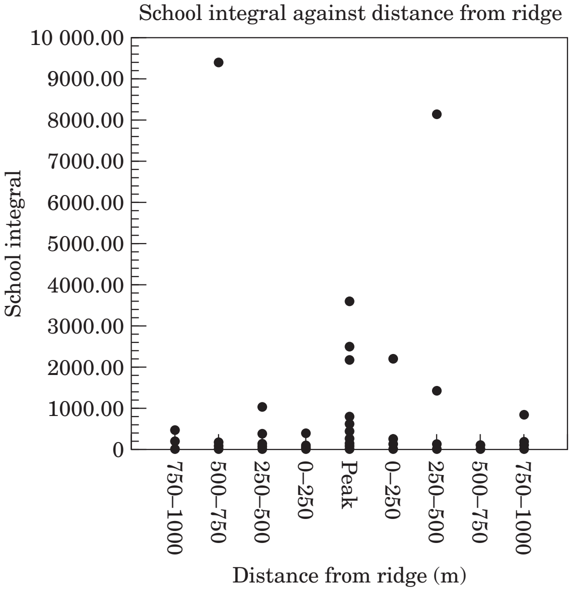


Figure 7. Bar chart of the number of transects across the ridge feature in survey 1. Bars represent the number of transects across the ridge in which herring schools were present on the ridge or in 250-m bins north and south of the ridge. The total number of passes was 48.

conducted by the Marine Laboratory Aberdeen since 1992. These data are being analysed at present.

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