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FOREWORD

Since the first major Symposium on Echinoderm Biology was held in London in 1966, sponsored by the Royal Zoological Society, at least six subsequent meetings have been organised by echinodermologists. These have been held in Washington D.C., U.S.A. (2), Rovinj, Yugoslavia (1), Sydney, Australia (1), London (1); the last two meetings (Sydney and London), within the same year (1978), and Brussels, Belgium. Also, at least four meetings are known to have been held in U.S.S.R. Such has been the surge of interest in the study of echinoderms over the past decade, that there is now a demand for the organisation of regular, and more frequent, meetings. The international representation at these meetings indicates the enormous involvement and co-operation which now exists between colleagues working in this exciting field, the world over.

It is more than evident that the satisfaction and pleasure expressed by Professor Norman Millott, in his foreword to the first Symposium volume (1967), at the resurgence of interest in Echinoderm Biology has been clearly justified and can continue so to be.

This volume presents twelve of the forty-one contributions offered at the Echinoderm Conference, Sydney, 1978. The papers are representative of the wide coverage of topics dealt with during the Conference, including echinoderm palaeontology, physiology, reproduction, ecology, behaviour and taxonomy.

To the speakers and chairmen, and to all those who attended the Sydney Conference, I convey my thanks. I must also thank my Technical Officer, Ms Jan Marshall, and Dr Susan Oldfield (Queen's Fellow at The Australian Museum, February, 1977-1979) for their unstinting assistance in the organisation of the Conference. Thanks are also due to the Department of State Fisheries (N.S.W.), Taronga Park Zoo, McWilliams Wines Pty, Leo Buring Wines Pty, Qantas Airways Ltd, and Trans-Australia Airlines (T.A.A.). To The Australian Museum Society (TAMS) I extend a special thanks for assistance.

This Conference could not have been held without the tremendous support and encouragement afforded to the organiser by Dr D. J. G. Griffin, Director, The Australian Museum, and the very generous financial support of the Trustees of the Museum, to both of whom I offer my very sincere thanks.

DECEMBER 1979 FRANCIS W. E. ROWE

CONTENTS

9. A BIOMETRICAL STUDY OF POPULATIONS OF THE EUROPEAN SEA-URCHIN *ECHINUS ESCULENTUS* (ECHINODERMATA: ECHINOIDEA) FROM FOUR AREAS OF THE BRITISH ISLES

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SUMMARY

Results submitted by mainly amateur diving groups during Underwater Conservation Year 1977 in the United Kingdom show that there are regional differences in the relationship between both size and shape of specimens of the European sea-urchin *Echinus esculentus* Linnaeus and the depth at which they occur. Populations from South-West England are significantly bigger at all depths than those from the other areas surveyed, those from Western Scotland increase in size more rapidly with increasing depth of water, and those from the North Sea decrease in size with increasing depth. Two sites surveyed in South-West Ireland show that exposure may affect the size of urchins inhabiting shallow waters. The results are compared with those of a similar survey by Larsson (1968) on the same species in Swedish waters.

INTRODUCTION

The European sea-urchin, *Echinus esculentus* Linnaeus, was the subject of a nationwide survey during 1977 as part of a special project for amateur divers during Underwater Conservation Year (UCY 77) in the United Kingdom. The project was timely, since there has been unsupported evidence over the past few years that populations of the animal have been suffering at the hands of collectors for the curio trade (see, for instance, Natural Environment Research Council, 1973). It is possible that the animal may also become the subject of additional pressure from the luxury food trade, since the roe is considered a delicacy by some (Southward and Southward, 1975). In addition, there is contradiction in the results of previous studies that have examined the population structure of this animal in European seas: Moore (1935) and Reid (1935), working on dredged material from the Isle of Man and Scotland, both state that the largest urchins inhabit shallow water, while Larsson (1968), who used SCUBA techniques to study populations in the Koster Fjord region of Sweden, found larger specimens in deeper water.

Studies of extensive populations, and over a wide geographical area, require larger teams of investigators than are usually available in the normal course of scientific work, and for this reason the opportunity to use the diving expertise of competent amateurs during a year of special effort was welcomed. Before the start of the project, standardised instructions were prepared which outlined in straightforward terms the procedures to be adopted. Several different observational and experimental projects were suggested (Nichols, 1978a), and this paper describes the results of one, an investigation of the size and shape of the urchins relative to the depth of water at which they live.

METHODS

Details of the instructions sent out to diving groups prior to the start of the project are given in Nichols (1979). Diving groups were advised to construct a simple pair of calipers with which the two dimensions of diameter and height could be taken on the animal while underwater and read off along the side of a recording board. Since this was also a conservation exercise, a more elaborate design of calipers was suggested to some teams which obviated the need to disturb the urchins, even when taking the *height* measurement.

Teams were asked to record the measurements of all urchins encountered within a convenient area at any depth. Where possible, depth gauges were calibrated or corrected in pressure chambers, and all depth readings were corrected to Lowest Astronomical Tide. The surveys were conducted within four months of each other (Table 1). Results were transferred to a standard form for return to the project co-ordinator, and data were processed using a desk computer to provide standard statistical treatment.

In his study of a Swedish population of the same species of sea-urchin in 1966, Larsson recorded only the diameter of individual urchins and plotted this dimension against depth of water as a histogram (see Larsson, 1968, fig. 15). The time of year that Larsson made his survey is not given. These results have been replotted in the present paper in a comparable form to those of the British specimens and standard statistical treatment applied to them.

RESULTS

Of the total results submitted, those from four localities have been selected for the purposes of this paper, to provide as wide a geographical spread around the British Isles as possible (Fig. 1). Details of the sites in each area, the survey teams and the numbers of urchins measured in each case are given in Table 1. The test dimensions of *diameter* and *height* are plotted separately for each site, and the *ratio* of height to diameter also plotted on a separate axis on the same graph (figs 2 to 4).

Table 1. Summary of the surveys included in this paper.

Location	Survey team and Leaders	Dates	No. of urchins measured	
1. W. Scotland, Isle of Skye	Army Air Corps, Middle Wallop, Sub-Aqua Club Sgt. R. Perren	10-24 August 1977	a. Black Is b. Crowlin Is c. Eilean Ban d. Eileanan Dubha e. Tulm Is Total	103 84 107 255 154 703
2. S. W. England, Lamorna Cove	University of Exeter Sub- Aqua Club Deborah Garner Andrew Smith	30 June to 8 July 1977		151
3. S. W. Ireland, Bantry Bay	University of Cambridge Sub-Aqua Club Alasdair Edwards Alison Morris	16 June to 17 July 1977	i. Carrigavaddra ii. Sheelane Is Total	504 504 1008
4. North Sea, St. Abb's and Newton	University of Durham Sub-Aqua Club Christine Howson Charles Anderson	8 May to 16 June 1977		40

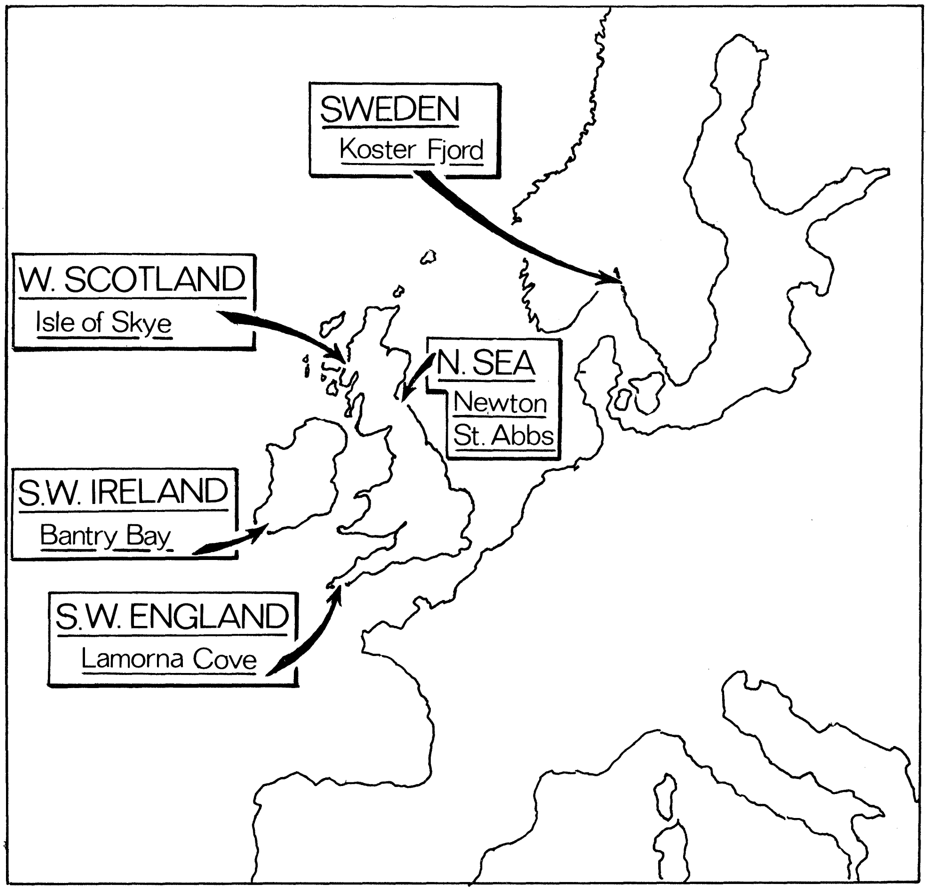


Fig. 1. Map of part of Europe, to show the location of the four areas around the British Isles surveyed in this study, and the location of the area in Sweden surveyed by Larsson in 1966.

Figure 2 shows a summary of results from five separate sites in Western Scotland; four of the sites were within a radius of 5 km, while the fifth, Tulm Island, was about 30 km away from the main group of sites. Figure 2f plots the mean values for all five sites. Confidence limits (standard errors) are included as vertical bars about the mean values at each depth, where these limits extend beyond the size of the symbols. In each case linear regressions of best fit are drawn through the points.

The graphs in figure 2 show that for all sites in Western Scotland the dimensions of diameter and height increase with depth of water, and there is no significant difference between rate of increase in the two dimensions except in the case of Tulm Island (fig. 2e). So far as the ratios of the two dimensions are concerned, Tulm Island (fig. 2e) is the only one to show a negative slope, meaning that at this site alone the animals may become squatter in deeper water. However, it must be added that only two animals were measured at each of the depths 17 and 18 m, and without the results from these small samples the regression for the ratio, like the others, shows a positive slope.

In South-West Ireland (fig. 3), two sites were surveyed. The one (Carrigavaddra) was

Fig. 2. Graphs showing the relationship between mean dimensions (diameter, open circles; height, open triangles) and depth of water in which they occur of populations of the sea-urchin *Echinus esculentus* from five separate sites near the Isle of Skye, Western Scotland (a to e), and the mean values for all sites (f). The mean values for the ratio of height to diameter for each individual are plotted (solid squares) on the same graphs, the left-hand axis being the dimensions and the right-hand axis being the ratio in each case. Calculated linear regressions are drawn in as solid lines, and the confidence limits (standard error) are drawn as vertical lines about the mean values where these limits extend beyond the symbols.

Regression equations are as follows:

a.	Black Island.	Diameter:	$y = 7.38 + 0.15x$
		Height:	$y = 4.60 + 0.18x$
		Ratio:	$y = 0.64 + 0.0073x$
b.	Crowlin Island.	Diameter:	$y = 6.47 + 0.264x$
		Height:	$y = 4.55 + 0.269x$
		Ratio:	$y = 0.57 + 0.017x$
c.	Eilean Ban.	Diameter:	$y = 7.04 + 0.245x$
		Height:	$y = 5.27 + 0.237x$
		Ratio:	$y = 0.74 + 0.007x$
d.	Eileanan Dubha.	Diameter:	$y = 7.81 + 0.036x$
		Height:	$y = 5.17 + 0.077x$
		Ratio:	$y = 0.63 + 0.01x$
e.	Tulm Island.	Diameter:	$y = 6.13 + 0.345x$
		Height:	$y = 5.44 + 0.209x$
		Ratio:	$y = 0.83 - 0.004x$
f.	Mean of all sites.	Diameter:	$y = 7.05 + 0.176x$
		Height:	$y = 4.91 + 0.182x$
		Ratio:	$y = 0.69 + 0.007x$

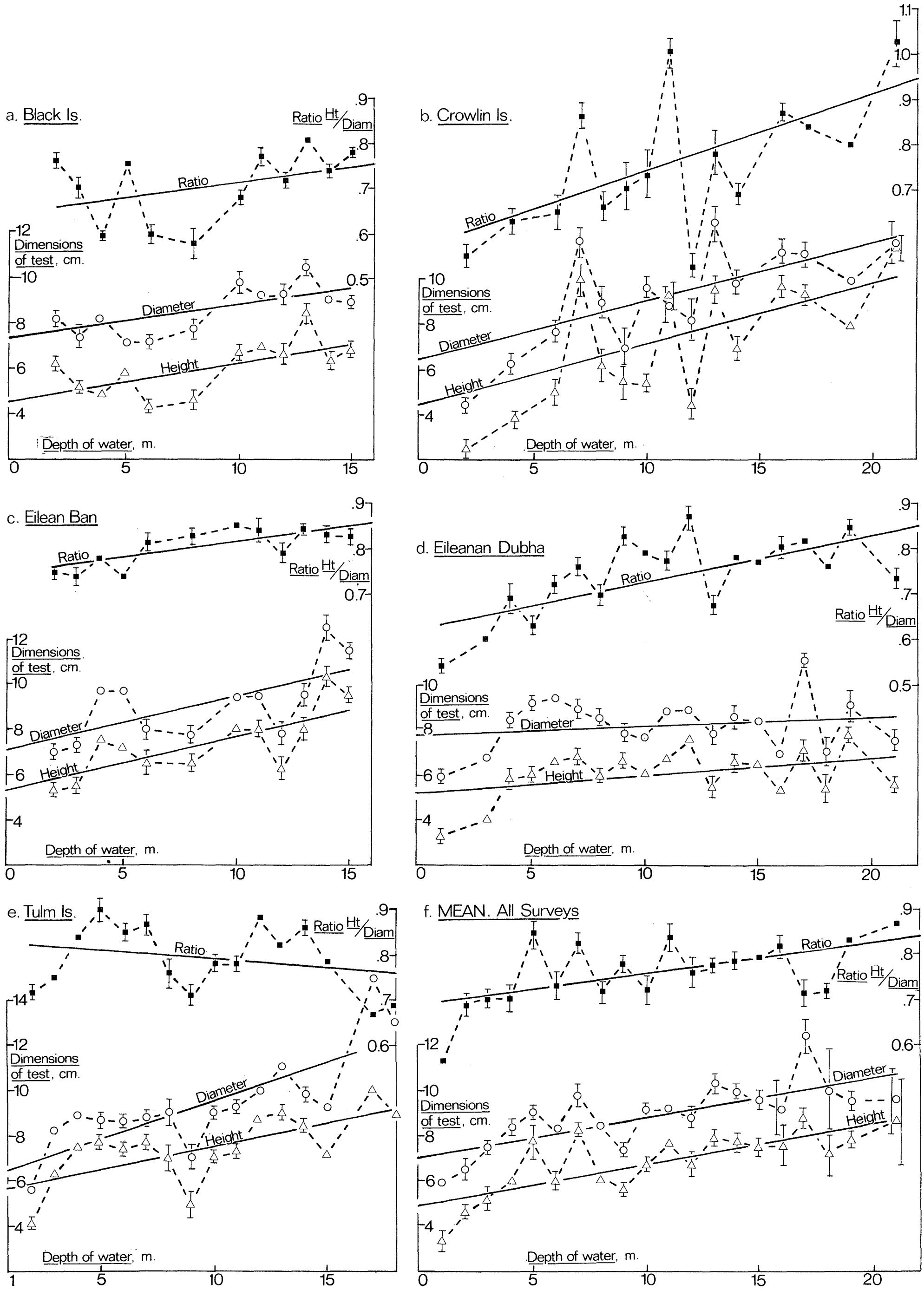

a. Black Is.
Ratio Ht/Diam
Ratio
Dimensions of test, cm.
Diameter
Height
Depth of water, m.
b. Crowlin Is.
Ratio
Dimensions of test, cm.
Diameter
Height
Depth of water, m.
c. Eilean Ban
Ratio
Ratio Ht/Diam
Dimensions of test, cm.
Diameter
Height
Depth of water, m.
d. Eileanan Dubha
Ratio
Ratio Ht/Diam
Dimensions of test, cm.
Diameter
Height
Depth of water, m.
e. Tulm Is.
Ratio Ht/Diam
Ratio
Dimensions of test, cm.
Diameter
Height
Depth of water, m.
f. MEAN, All Surveys
Ratio
Ratio Ht/Diam
Dimensions of test, cm.
Diameter
Height
Depth of water, m.

Fig. 3. Graphs showing the relationship between mean values of diameter, height and ratio to depth of water for specimens of *Echinus esculentus* from two sites in Bantry Bay, South-West Ireland. Conventions as for Figure 2.

Regression equations are as follows:

a.	Carrigavaddra.	Diameter:	$y = 8.45 + 0.031x$
		Height:	$y = 6.52 + 0.047x$
		Ratio:	$y = 0.768 + 0.003x$
b.	Sheelane Island.	Diameter:	$y = 8.013 - 0.012x$
		Height:	$y = 6.078 + 0.010x$
		Ratio:	$y = 0.762 + 0.0025x$

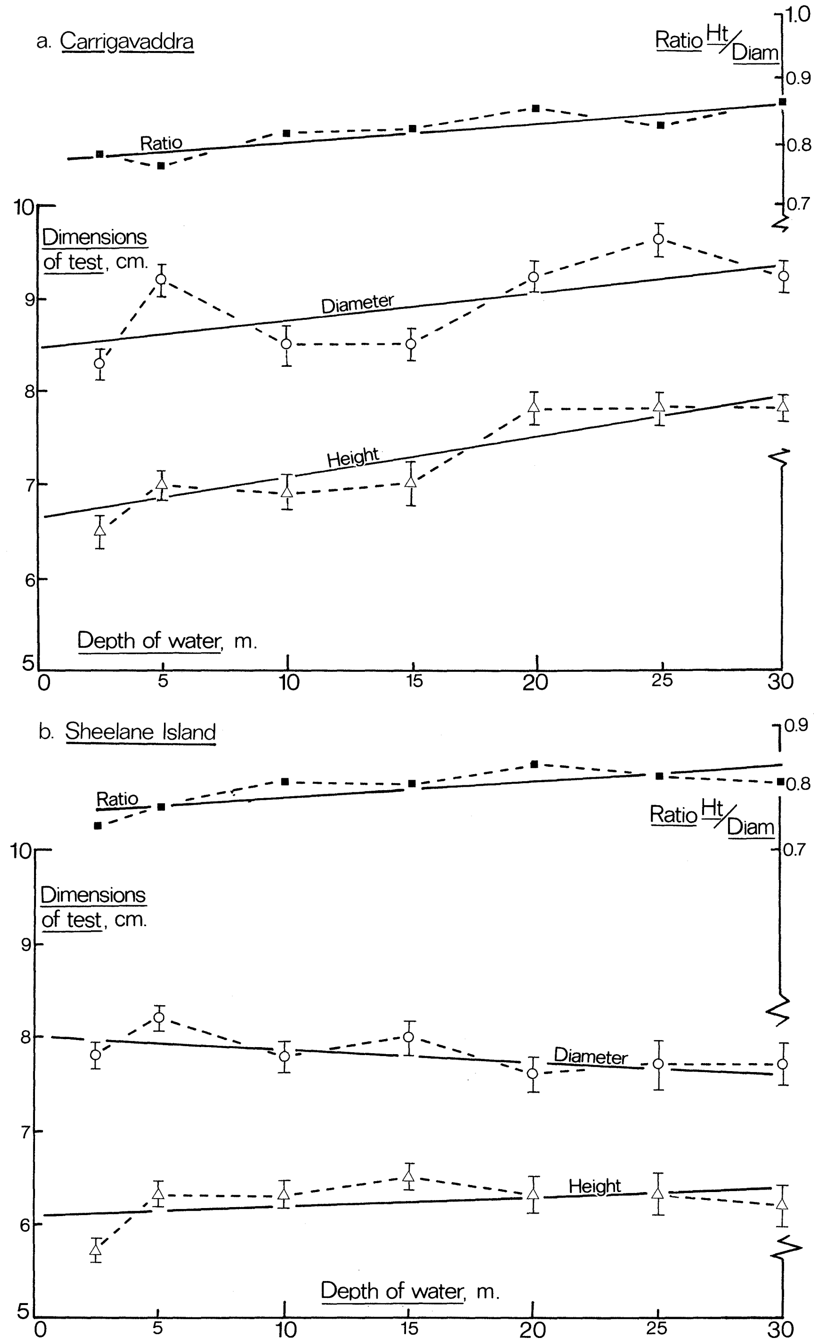
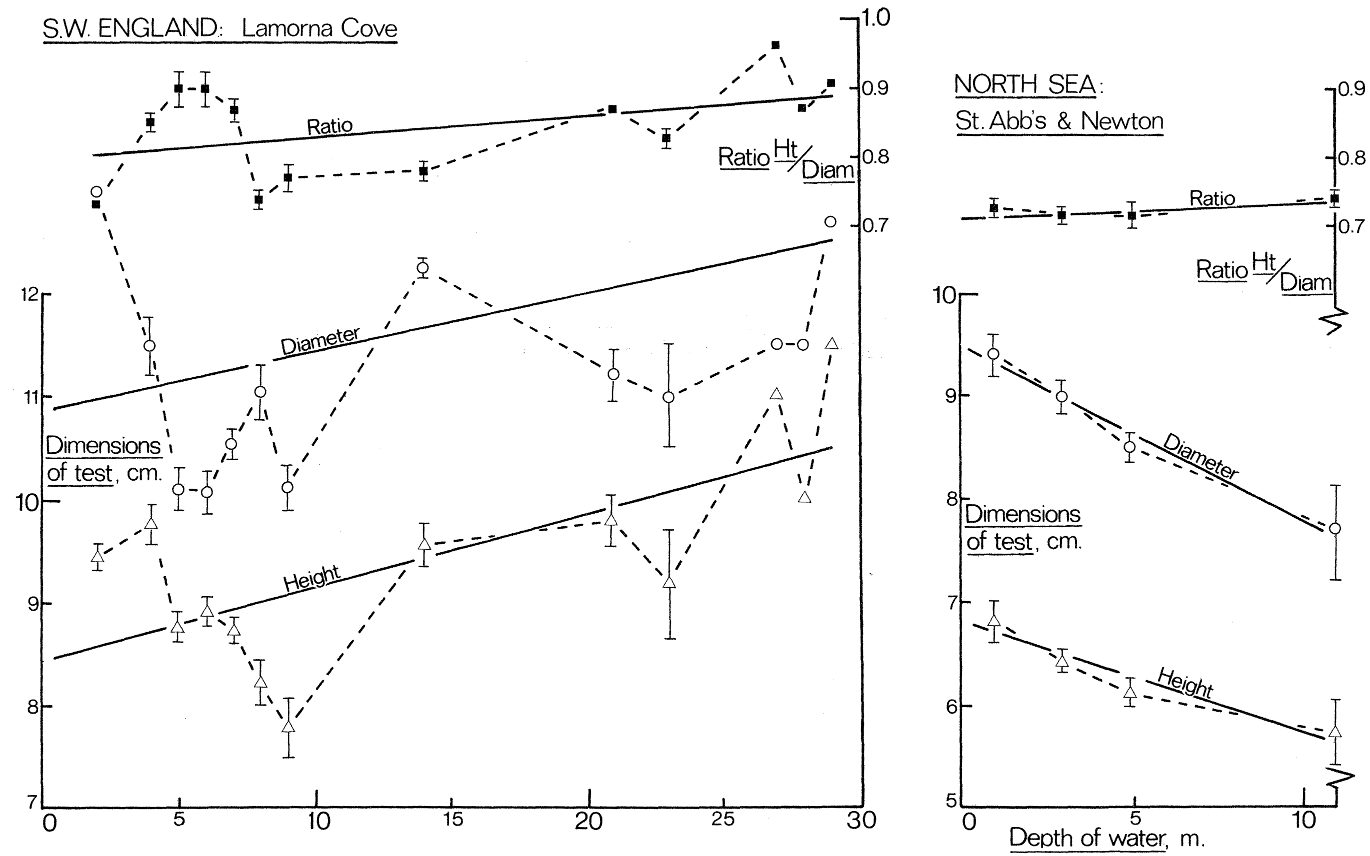

a. Carrigavaddra
Ratio Ht/Diam
1.0
0.9
0.8
0.7
Ratio
10
Dimensions of test, cm.
9
8
7
6
5
Diameter
Height
Depth of water, m.
0
5
10
15
20
25
30
b. Sheelane Island
0.9
0.8
Ratio Ht/Diam
0.7
Ratio
10
Dimensions of test, cm.
9
8
7
6
5
Diameter
Height
Depth of water, m.
0
5
10
15
20
25
30

Fig. 4. Graphs showing the relationship between mean values of diameter, height and ratio for specimens of *Echinus esculentus* from a. Lamorna Cove, South-West England, and, b. St. Abb's and Newton, on the North Sea coast of Britain. Conventions as for Figure 2.

Regression equations are as follows:

a.	South-West England.	Diameter:	$y = 10.88 + 0.033x$
		Height:	$y = 8.433 + 0.071x$
		Ratio:	$y = 0.797 + 0.003x$
b.	North Sea.	Diameter:	$y = 9.49 - 0.168x$
		Height:	$y = 6.768 + 0.104x$
		Ratio:	$y = 0.712 + 0.0021x$


S.W. ENGLAND: Lamorna Cove
Ratio
Ratio Ht/Diam
Diameter
Height
Dimensions of test, cm.
NORTH SEA: St. Abb's & Newton
Depth of water, m.

towards the seaward end of a long, narrow inlet (Bantry Bay), while the other (Sheelane Island) was at a slightly more sheltered site further into the Bay. The results for Carrigavaddra (fig. 3a) are similar to the mean result from Western Scotland (fig. 2f), while those for Sheelane Island (fig. 3b) show that here the average diameters of the urchins measured decreased with depth of water, and the average heights increased. At both sites the ratios show a positive slope, that is, on average the urchins are becoming taller with depth.

In South-West England the site chosen was at Lamorna Cove, Cornwall, a fairly exposed site. The results (fig. 4a) show that here again diameter and height, and the tallness of the urchins, increase with depth of water.

The last area consisted of two sites near the English-Scottish border on the North Sea coast of the United Kingdom. This area yielded the least satisfactory set of results, because the North Sea between the British Isles and Scandinavia is more turbid than other waters from which surveys were taken, and few populations of the sea-urchin occur here. The two sites are about 30 km apart; the one at Newton-By-Sea, in the English county of Northumberland, has populations of urchins at depths of between 1 and 5 m, while the other, at St. Abb's, in the Scottish county of Berwickshire, has populations at 11 m depth. The results (fig. 4b) are combined, despite their slightly separated provenance. The graph shows that this area may be different from the others here described, in that both diameter and height decrease with depth of water; the tallness, however, increases. However, it must be noted that the sample size in this case is somewhat smaller than the others.

The calculated mean linear regressions for diameter, height and ratio for the four British Isles areas are summarised in figure 5. Where more than one site in each area has been surveyed, as in Western Scotland (5 sites) and South West Ireland (2 sites), the means of all sites in that area are plotted here, to show regional differences, if any. The lower part of the figures shows the diameters (upper line of each quadrilateral) and height (lower line) and the depth range for each of the surveyed areas; the upper part of the figure shows the mean ratios for the four areas. The figure shows that the urchin populations from South-West England are significantly different from those of the other areas, in that both the overall size at all depths is larger, and they have taller tests at all depths. Other differences that are revealed by this figure are that the rate of increase in size with depth and the increase in tallness with depth for urchins from Western Scotland are both greater than for other areas, and that the small and shallow sample from the North Sea shows that here the urchins decrease in size with depth of water.

Not all survey teams that contributed to this project were able to dive to the depths to which *Echinus* extends. Indeed, in some areas, such as the North Sea, the urchins themselves do not extend to any great depth, at least in the area surveyed. At some sites too, rather few specimens were encountered in deeper water, so the inclusion of the deepest results may be to some extent unjustified. To make a fairer comparison, the linear regressions for all sites down to a depth of 15 m only have been summarised in figure 6. In fact, the general statements above about the separation of the various areas hold true for these restricted results too. But there are minor differences. For instance, for populations in South-West England, omission of the deeper specimens shows that the regressions for both diameter and height (top and bottom lines for the 'South-West England' quadrilateral in figure 6) now show negative slopes, that is, the specimens become marginally smaller with depth. The ratio (tallness) for this area (upper part of the figure) also now shows a negative slope, though there is no significant difference between this line and a constant ratio (horizontal line) ($P>0.5$).

Larsson's (1968) paper included only diameters of the specimens he measured from the Koster Fjord, Sweden, in 1966. These results have been plotted on the same axes as the results here described from the British Isles (fig. 7). This graph shows that the Swedish population structure for this urchin is very different from that from all the British sites; in particular, the urchins in shallow water have a much smaller mean size, though the ranges overlap somewhat in deeper populations. It should be mentioned that Larsson's results and those reported here are separated by 11 years, but variation in individual sizes with time to the extent seen in these sets of results is unlikely, and in any case cannot be tested until the results from either country are repeated in the future.

DISCUSSION

In this paper, trends in the size and shape of the components of the populations with changing depth of water are indicated by plotting linear regressions of the mean values of each depth for the two dimensions of diameter and height of the animal's body and also that of mean values at each depth of the ratio between these two dimensions for each individual. It is insufficient to rely solely on the regressions for diameter and height to express shape. For instance, in cases where the regressions for diameter and height lie approximately parallel to one another, as for Crowlin Island, Western Scotland (fig. 2b), this does not necessarily mean that the tallness of the animal remains constant throughout the depths surveyed; indeed, in this example the regression for the ratio of height to diameter has a markedly positive slope, showing that the average tallness of the animals at this site increases significantly with depth.

There is little substantial difference between results for the sites surveyed in Western Scotland, so far as the calculated linear regressions reveal the trends. Black Island, Crowlin Island, Eilean Ban and Eileanan Dubha (fig. 2, a to d) are all strikingly similar. The somewhat different results obtained from Tulm Island (fig. 2e) are more apparent than real, in that the regressions are skewed because of the inclusion of results from small samples (2 urchins only at each) from 17 and 18 m depth. In particular, the line for the ratio of height to diameter shows a negative slope. If results from these two small samples are omitted, the linear regressions show slopes that are similar to those for all the other Scottish sites.

The two sites surveyed in South-West Ireland differ from each other in that the one (Carrigavaddra) is nearer the open sea, and therefore more exposed, than the other (Sheelane Island), which is about half way up the elongated bay. This may account to some extent for the differences between the regressions for diameter and height, the urchins being relatively smaller inshore at Carrigavaddra, but larger inshore at Sheelane. Perhaps this reflects the exposure of the area in which they live, since a larger urchin is more likely to be displaced in the rougher waters of the exposed site.

The site in South-West England, Lamorna Cove (fig. 4a) is remarkable for a drop in the average size of urchins between about 5 and 10 m depth of water. This could be explained by some factor, such as the substratum, affecting the general success of the urchins at these depths, though nothing was reported by the diving team; or alternatively it could be a factor related to predation. It happens that this site is a favourite one for the collection of urchins by amateur divers for the curio trade (Nichols, 1978b). Such divers normally descend to between 5 and 10 m depth so that the dive can be recorded in their log-books, and it seems quite likely that the activities of these people have denuded the populations of the larger urchins at these depths.

The results from the North Sea sites, combined on one graph (fig. 4b), are the least satisfactory in this study; although they show an unequivocal trend towards a reduction in size in deeper water, this cannot be supported with confidence on these small and separated populations. The shape of the urchins from both sites appears to remain almost unchanged in the 10 m depth through which the animals occur.

A comparison of all four areas surveyed around the British Isles, as shown on the summary

Fig. 5. Summary graph of means of all results from each of the four areas of the British Isles surveyed in this investigation. In the lower part of the figure the top line of each quadrilateral is the regression for the mean values of the diameters of sea-urchins over the depth range surveyed, and the lower line is the regression for the mean values of the heights. In the upper part of the figure, the regressions for the mean values of the ratio of height to diameter against depth of water are plotted. Left-hand axis represents the dimensions and right-hand axis the ratios.

Regression equations are as follows:

South-West England.	Diameter:	$y = 10.88 + 0.033x$
	Height:	$y = 8.43 + 0.071x$
	Ratio:	$y = 0.797 + 0.0033x$
Western Scotland.	Diameter:	$y = 7.051 + 0.176x$
	Height:	$y = 4.91 + 0.182x$
	Ratio:	$y = 0.688 + 0.007x$
South-West Ireland.	Diameter:	$y = 8.23 + 0.009x$
	Height:	$y = 6.301 + 0.029x$
	Ratio:	$y = 0.769 + 0.0025x$
North Sea.	Diameter:	$y = 9.49 - 0.168x$
	Height:	$y = 6.768 - 0.104x$
	Ratio:	$y = 0.712 + 0.0021x$

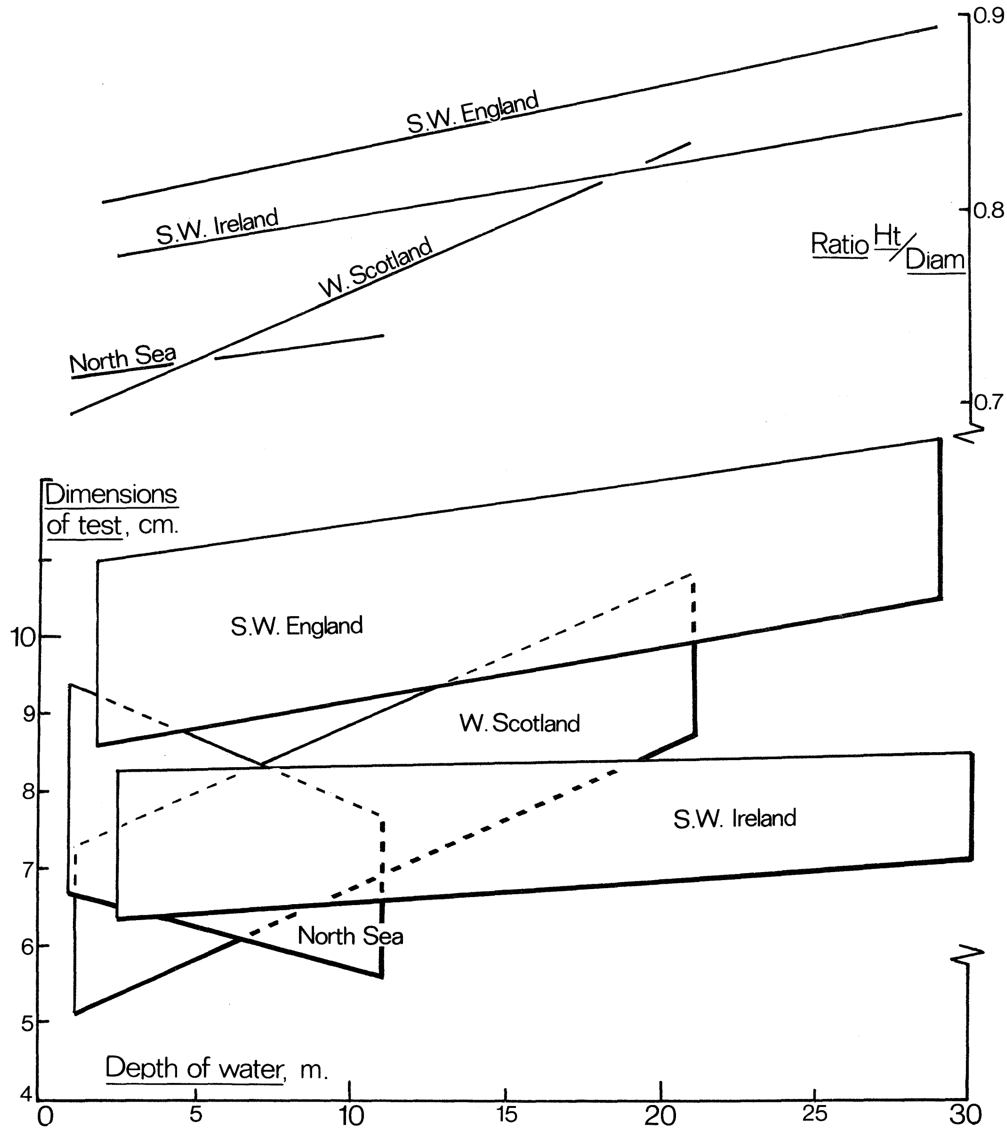
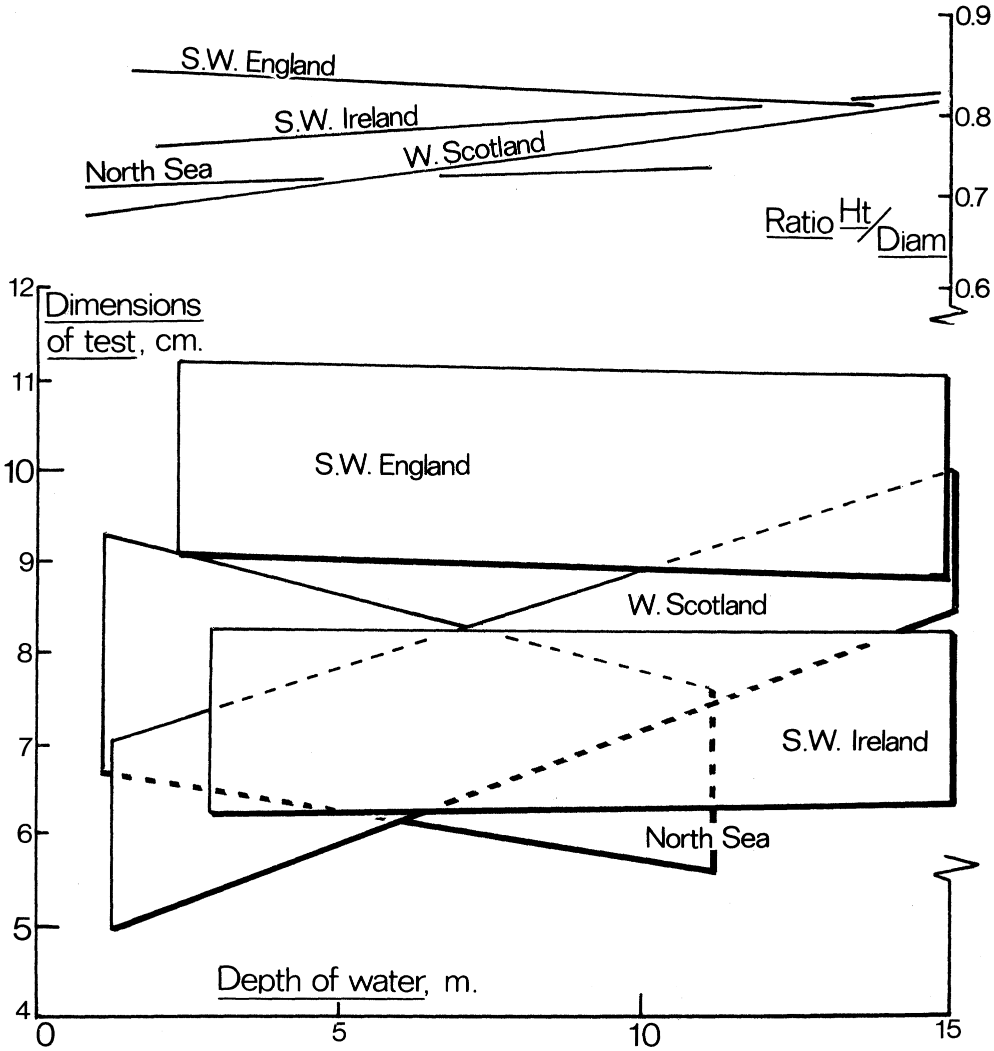

0.9
S.W. England
S.W. Ireland
0.8
Ratio Ht/Diam
W. Scotland
North Sea
0.7
Dimensions of test, cm.
S.W. England
10
9
W. Scotland
8
S.W. Ireland
7
6
North Sea
5
Depth of water, m.
4
0
5
10
15
20
25
30

Fig. 6. Summary graph of means of results from each of the four areas of the British Isles surveyed in this investigation, but ignoring all results from below 15 m depth of water. Conventions as for Figure 5.

Regression equations are as follows:

South-West England.	Diameter:	$y = 11.21 - 0.019x$
	Height:	$y = 9.159 - 0.038x$
	Ratio:	$y = 0.843 - 0.004x$
Western Scotland.	Diameter:	$y = 6.75 + 0.219x$
	Height:	$y = 5.64 + 0.227x$
	Ratio:	$y = 0.673 + 0.0095x$
South-West Ireland.	Diameter:	$y = 8.33 - 0.005x$
	Height:	$y = 6.20 + 0.04x$
	Ratio:	$y = 0.748 + 0.0051x$
North Sea.	Diameter:	$y = 9.49 - 0.168x$
	Height:	$y = 6.768 - 0.104x$
	Ratio:	$y = 0.712 + 0.0021x$


S.W. England
S.W. Ireland
North Sea
W. Scotland
Ratio Ht/Diam
0.9
0.8
0.7
0.6
Dimensions of test, cm.
12
11
10
9
8
7
6
5
4
S.W. England
W. Scotland
S.W. Ireland
North Sea
Depth of water, m.
0
5
10
15

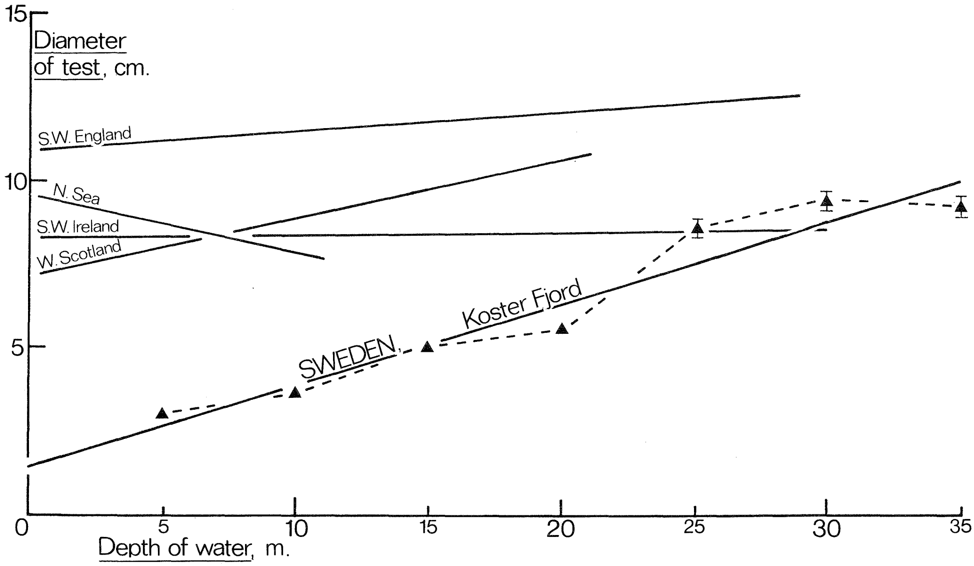


Fig. 7. Graph showing the relationship between mean values for test diameter and depth of water in which they occur (closed triangles) for the sea-urchin *Echinus esculentus* in the Koster Fjord, Sweden. Data extracted from Larsson (1968). Other conventions as in Figure 2. Regressions for the mean values for test diameters of urchins from the four British areas investigated in the present work are also included within the same axes for comparison.

Regression equations are as follows:

Koster Fjord.	$y = 1.433 + 0.242x$
South-West England.	$y = 10.88 + 0.035x$
North Sea.	$y = 9.49 - 0.168x$
South-West Ireland.	$y = 8.234 + 0.009x$
Western Scotland.	$y = 7.051 + 0.176x$

graph (fig. 5), reveals the following features: first, South-West England has populations of urchins that are significantly larger at all depths than elsewhere; secondly, in Western Scotland the size of urchins increases to a greater extent with increasing depth than in the other localities; thirdly, the North Sea urchins alone, so far as meaningful conclusions can be drawn from these results, decrease in size with increasing depth of water; and, fourthly, the populations in South-West England and South-West Ireland show little significant change in size with increasing depth. That these general conclusions are not merely a factor of the different depths to which the various diving teams surveyed is borne out by the similarity in appearance of the graph if the results are recalculated down to only 15 m depth of water (fig. 6). This depth was chosen principally because it is within that to which all the separate sites were surveyed, except those in the North Sea, and also because it roughly corresponds to the depth to which algae, a principal food of *Echinus,* penetrate.

Insufficient data are available on the physical conditions in the areas and sites surveyed to suggest reasons for the features that have emerged. However, the following suggestions are made: perhaps the slightly warmer waters in South-West England induce a larger overall size of urchins in that area; perhaps a difference in the availability of food in shallow waters helps explain the small size of urchins in the shallowest populations of Western Scotland; perhaps there is a more rapid fall-off in the density of algae with depth in the turbid water of the North Sea causing a reduction in mean size of urchins with increasing depth in that area. The study underlines the need for detailed physical, faunistic and floristic information to be considered alongside the biometrical data when surveys like this are undertaken if the biological significance of the trends uncovered is to be suggested.

Without similar additional information from the Swedish waters surveyed by Larsson in 1966 (fig. 7), it is just as difficult to suggest reasons for the marked differences between populations there and from the British Isles. The average size of the Swedish urchins is small in shallow waters, but increases at a greater rate with depth of water than those from any of the British areas, coming to overlap the British size ranges in deeper waters. Although the time of year of Larsson's survey is not known, it is unlikely that this, or a possible difference in the time of spawning of the Swedish population, could account for the difference between the Swedish and British populations.

For all the shortcomings in interpretation of these results, owing to the lack of ecological data taken with the initial measurements, the survey conducted by separate groups of divers, many of them amateurs, during Underwater Conservation Year in the United Kingdom, took the study of the population structure of *Echinus esculentus* much further than had previously been possible. It has underlined that there are regional differences in the overall size of individuals, a fact that could be significant to the curio industry now based on the dried test of the animal, and to any proposed industry based on its roe; it has shown that the population structure apparently can be affected by the exposure of the area; and it has suggested that the effects of human predation can be detected by surveys of this sort. More than this, however, it has demonstrated that the collection of scientific data can be aided by the activities of amateur divers, suitably briefed, and hopefully the experience gained by such people in taking part in such a programme will help them encourage others to conserve species like *Echinus* that are now under threat.

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