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STUDIES OF BARNACLES, LIMPETS AND TOPSHELLS IN MILFORD HAVEN

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ABSTRACT

Changes to the rocky shore communities of Milford Haven have been monitored by means of transect studies since the late 1950's. This paper describes detailed autoecological studies on selected species which have proved useful indicators of long-term change or pollution damage. They were proposed with the aim of complementing the original monitoring surveys and answering some of the questions raised about adequacy of methods and data. The species selected for study were *Semibalanus balanoides, Elminius modestus, Patella vulgata, Gibbula umbilicalis* and *Monodonta lineata*. The studies included estimations of population size, age structure, recruitment, mortality and migration, and the testing of alternative methods for monitoring, where the current approach has been inadequate. During the twelve months of fieldwork, comprising six bi-monthly surveys, the effect of physical, biological and temporal factors has been assessed. The resulting information is relevant to the design of shore projects as well as in the context for which the study was carried out; namely, improving the monitoring of rocky shores in Milford Haven.

INTRODUCTION

FIXED belt transects on the rocky shores of Milford Haven (Dyfed, South Wales) have been studied by Oil Pollution Research Unit staff over the past nine years as part of the Milford Haven Monitoring Scheme (Little, in prep.). Limited comparisons have also been made with data from earlier transect surveys at similar locations over the previous decade (Little, 1983; Woodman *et al.*, 1983). These, in turn, followed the pioneering work of Ballantine (1961), Moyse & Nelson-Smith (1963) and Nelson-Smith (1967) prior to industrialisation. The basic survey technique has remained unchanged over the years. A tape is laid across the shore between the mean low water level of spring tides (MLWS) and the lowest flowering plant. Stations are taken at fixed vertical intervals along this tape and the abundance of selected species is recorded at each station, using a modified version of the scales originally proposed by Crisp & Southward (1958). In the current programme the tape is relocated on each visit using permanent marks on the rock surface and photographs. As a result, a great deal of information has been obtained about the overall changes in the communities and population patterns of common shore organisms.

Although such transect studies at two- or three-yearly intervals provide a broad picture of changes in the state of a shore with time (and a valuable baseline against which damage from oil spills and recovery can be assessed), they cannot begin to elucidate the size and timescale of the (often-cyclical) short-term natural changes in populations. Neither can they explain other changes which occur over long periods of time, altering the entire biological character of the shore through the natural maturing, ageing and senescence of communities or of elements therein. For some species which are known to be sensitive indicators of contamination by, for example, refinery effluents, the "broad brush" belt transect approach has produced data showing considerable variability in abundances over both long and short timescales. So little work has been done on the population dynamics of species that make up shore communities that it is often not possible to separate the effects of pollution, from changes that are environmental, behaviour or inter-specific. We do not know the carrying capacity of a square metre of rock surface for any species; nor how interspecific relationships affect that capacity—except in the case of limpets and barnacles for which some studies have been carried out (Branch, 1981, review). Likewise, we know little of recruitment, mortality, immigration and emigration rates for shore organisms.

This paper describes detailed autecological studies on selected species which have proved useful indicators of long-term change or pollution damage. They were proposed with the aim of complementing the original monitoring surveys and answering some of the questions raised about adequacy of methods and data. The studies included estimations of population size, age structure, recruitment, mortality and migration, and the testing of alternative methods for monitoring, where the current approach has been inadequate. During the twelve months of fieldwork, comprising six bi-monthly surveys, the effect of physical, biological and temporal factors has been assessed. The resulting information is relevant to the design of shore projects (for any purpose) as well as in the context for which the study was carried out; namely, improving the monitoring of rocky shores in Milford Haven.

SELECTION OF SITES AND SPECIES AND SAMPLING PROTOCOLS

Three easily accessible sites in Milford Haven—West Angle Bay, East Blockhouse and Pwllcrochan Flats (Fig. 1)—were selected because they supported suitable populations for study across a small range of environmental conditions.

The list of organisms to be studied was selected during field trials carried out between March and July 1982. The species tested are either important components of the shore biota or are known (or suspected) from past studies to be vulnerable to pollution by oil or oil-related compounds.

They were:–

The acorn barnacles	*Semibalanus balanoides, Elminius modestus,*
The common limpet	*Patella vulgata*
The topshells	*Monodonta lineata, Gibbula umbilicalis*

During the trials a range of additional species (*Anemonia viridis, Lichina pygmaea, Chthamalus montagui, C. stellatus, Littorina saxatilis/L. arcana,* total lichen cover and fucoid sporelings) were investigated, but not studied in detail as suitable sites, populations, methods or time were not available. Full details of the trials can be found in Little (1985).

For each organism, study areas on the shore were chosen within the most abundant part of its vertical distribution, where one would expect conditions to be optimal for that organism at that site.

Field sampling was carried out as follows:

Pwllcrochan	East Blockhouse	West Angle
18–19/8/82	20/8/82	24–25/8/82
16–19/10/82	31/10/82–2/11/82	3–4/11/82
15–16/12/82	17–18/12/82	30/12/82
18–24/2/83	25–27/2/83	1/3/83
14–15/4/83	18–19/4/83	25–27/4/83
20/4/83	26–27/4/83	16/6/83
14–15/6/83	17–20/6/83	

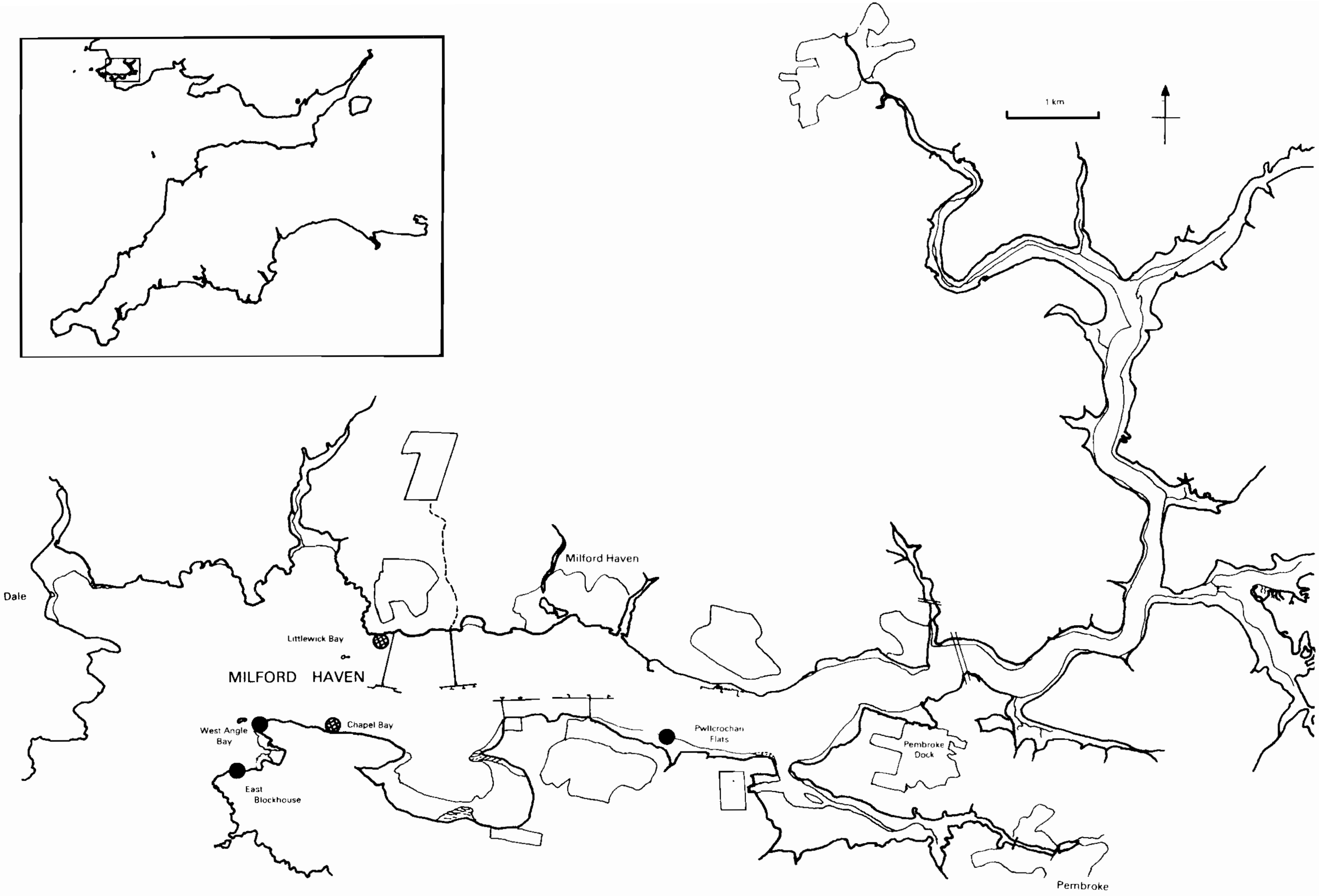


FIG. 1.
Map of Milford Haven showing the positions of the three primary survey sites (●) and the two secondary sites (⊗).

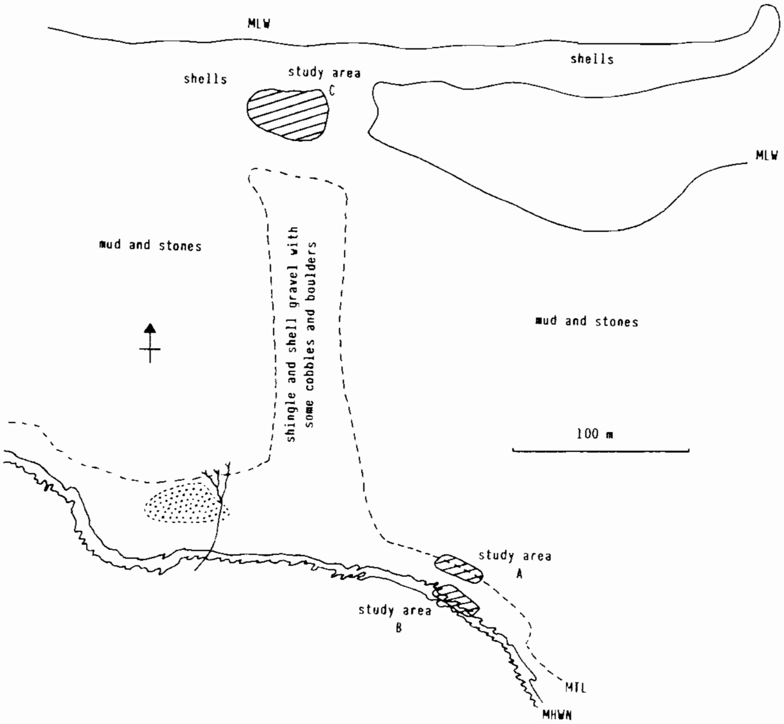


FIG. 2.
Pwllcrochan Flats, showing the survey areas (crosshatched). "Nursery" area for *Mondonta* shown by dots.

FIG. 3.
Pwllcrochan Flats, looking south-east from the shingle spit near study area C. Study areas A and B were on boulders and bedrock below the trees to the right of the photograph.

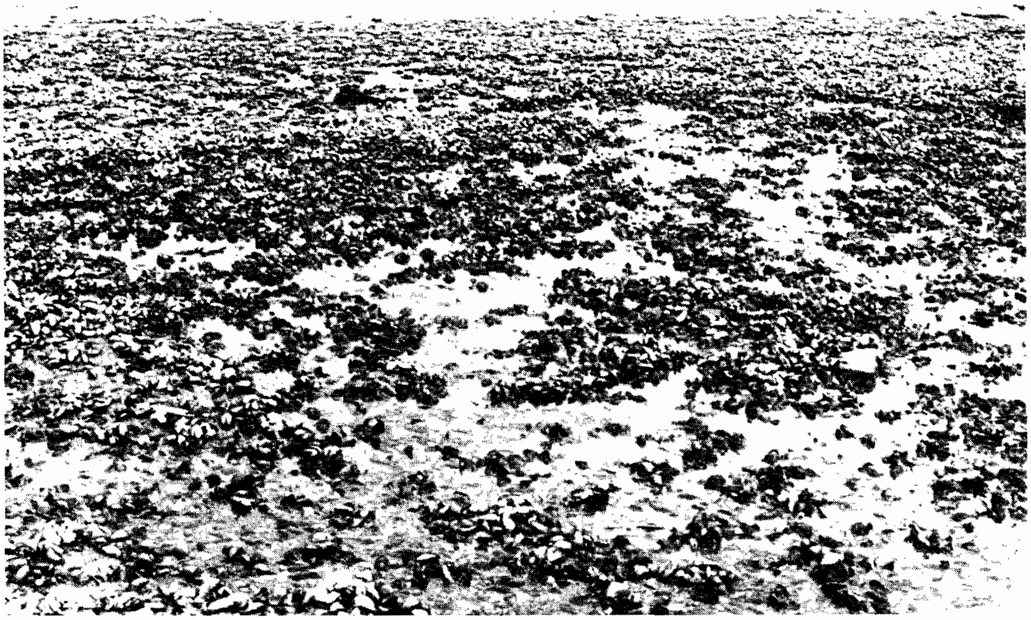


FIG. 4.
Mytilus communities on the shingle spit at Pwllcrochan.

SITE DESCRIPTIONS

Pwllcrochan

This site is just to the west of Martins Haven, at OS Grid Reference SM921034–6 (Figs 2, 3 and 4). The lower shore is an extensive spit made up of stony shingle, mussels and their empty shells, overlying a mudflat (Fig. 4). In places the mussels are heaped into low ridges that retain tidal pools. Three study areas were chosen; one near MTL (Mid-Tide Level) on a break in slope between the mudflat and a steeper section of shore with very eroded bedrock ridges, large boulders, stones and shingle (Area A in Figs 2 and 3). Another, near MHWN (Mean High Water level of Neap tides), was on steeper ridges of bedrock which rose up to a very low, often overhung, cliff, typical of many sheltered shores around Milford Haven (Area B in Figs 2 and 3). The third area, for topshells only, was at about MLWN (Mean Low Water Level of Neap tides (Area C in Figs 2 and 4).

West Angle Bay

This site was located in an old quarry area to the north of the amenity beach at SM852034 (Figs 5, 6, 7 and 8).

The two areas for topshell surveys were in gullies cut in soft rock between hard, near-vertical limestone beds, giving a substratum of bedrock, boulders and stones, with many pools (Areas A and B, Figs 5 and 6). There was much seawater run-off from higher-rock platforms on either side through the lower area, which had some shingle (Area B). The *Patella vulgata* survey was conducted near area A (Fig. 5), on a hard bedrock pinnacle surrounded by loose stones and shingle (Fig. 8). The rapidly eroding nature of some of the

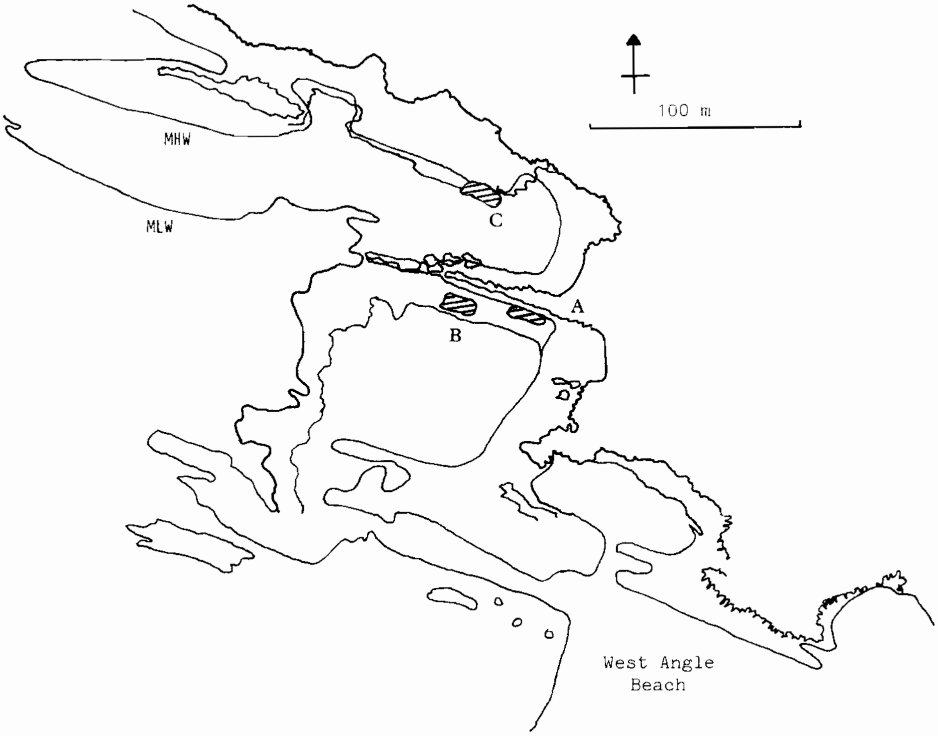


FIG. 5.
West Angle Bay (north side) survey areas (crosshatched).

FIG. 6.
Study areas A (right) and B (left) at West Angle Bay, looking west.

FIG. 7.

Study area C at West Angle Bay, looking west.

FIG. 8.

The rock pinnacle used for the limpet study near area A at West Angle Bay, looking west.

rocks in this area and the large quantities of occasionally mobile substrata have prevented the establishment of mature fucoid algal or barnacle populations on the midshore. The barnacle survey area was therefore sited further north, in a small adjacent bay where the bedrock was in the form of an uneven wave-cut platform beside a stony beach, with low east–west ridges of steeply sloping rock (area C, Fig. 5 and Fig. 7).

East Blockhouse

This site was close to the mouth of Milford Haven, at SM844029 (Figs 9 and 10). Large rock stacks are separated from the cliff at this site by a beach of mixed substrata ranging

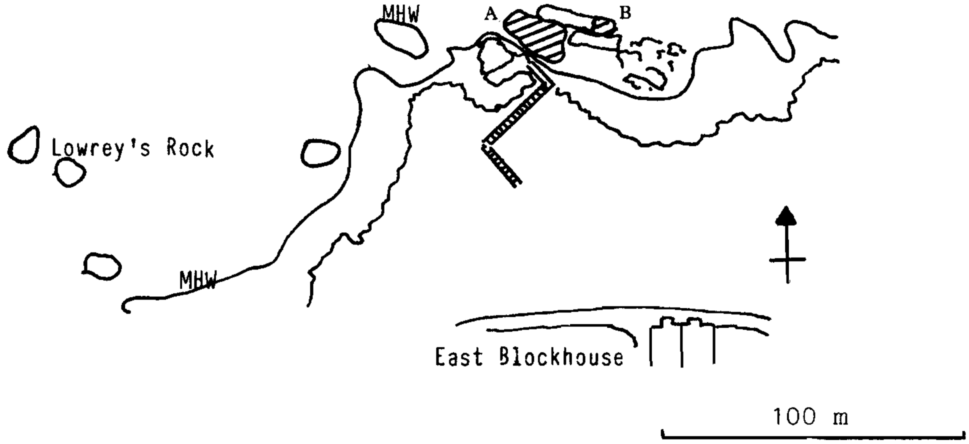


FIG. 9.
East Blockhouse survey areas (crosshatched).

FIG. 10.
East Blockhouse study area A, looking east. Area B is over the ridge in the centre of the photograph.

from massive boulders to small stones. This was the most exposed site surveyed in this study and, although protected from the largest swells by aspect and by the offshore stacks, much of the beach material was free of all encrusting organisms, suggesting that the stones and smaller boulders are mobile during rough weather. This was apparent during the study period, when much beach material was removed between the October and December visits. The *M. lineata* survey area lay between the base of the stack and cliff at about MTL (Area A, Fig. 9). The barnacle survey area was on the seaward-facing side of an adjacent stack on a north-facing, steeply sloping but broken rock face (Area B, Fig. 9).

Barnacles

Semibalanus balanoides (Linnaeus, 1758)
Elminius modestus Darwin (1854)
(Fig. 11)

The aim of this study was to monitor barnacle density, species composition, total recruitment and mortality. On all three chosen shores, the barnacle survey areas were located on steeply sloping bedrock faces within the area between MTL and MHWN. For a general account of barnacle biology see Rainbow (1984).

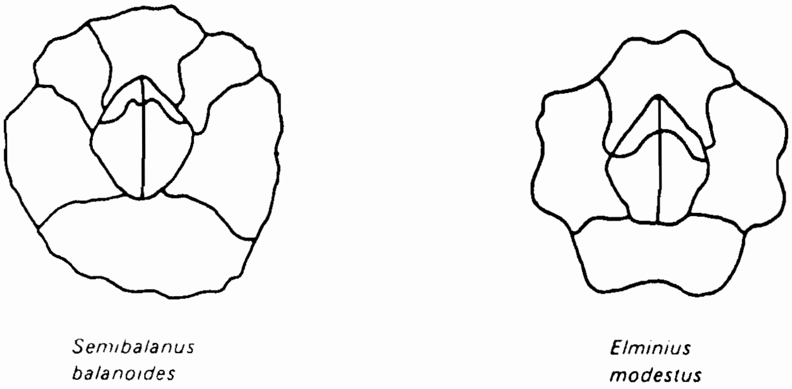


FIG. 11.
The two species of middle-shore barnacle studied in this survey. From Rainbow (1984).

Sampling Procedures

The number and size of the quadrats used were determined from a series of experiments in March 1982 (Crothers, unpublished data). 3.125 cm^2 quadrats provided statistically acceptable results using 16 replicates in each area. The total area studied at each site was thus 50 cm^2, within which all barnacles were identified and counted. The quadrats were located within a grid scored in a rigid polythene template, using a random number table to find the co-ordinates. The selected squares were then cut out with a hot knife. The same template was used throughout the survey, so once the positions of the quadrats had been selected, they were fixed (Fig. 12). At each site, the study area in the upper part of the limpet/barnacle dominated zone was marked with masonary nails along three sides so that the template, and thus each quadrat, could be relocated accurately.

Initially the agreement between workers was not good and problems of parallax at the edges meant that repeatability was also poor, especially where the rock surface was uneven.

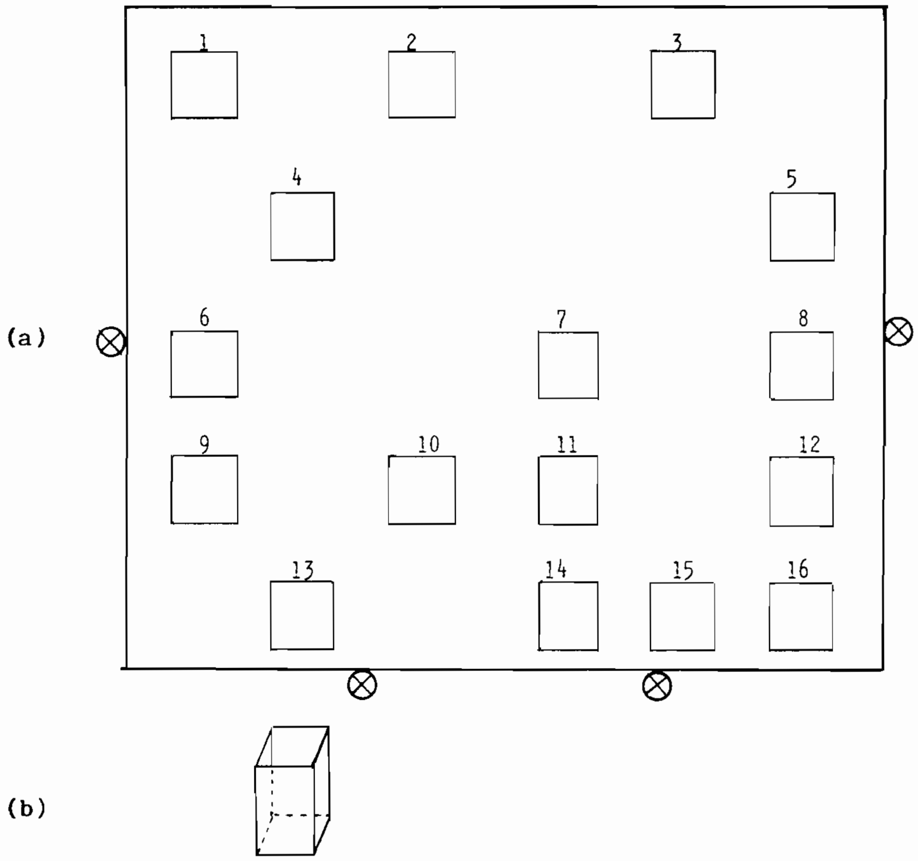


FIG. 12.

Barnacle sampling area "device". (a) A rigid polythene template was re-located on each visit by permanently-fixed masonry nails (⊗). The positions of the quadrats, windows cut in the polythene, were 16 coordinates on a 6 × 5 grid taken from random number tables. (b) A clear plastic inner sleeve with basal diameter 1/16 × 50 cm^2 was used to reduce parallax problems at the edges.

These problems were reduced to an acceptable level by the innovation of fitting a sleeve of thin clear plastic inside each quadrat (Hannam, unpublished). This could be slid down inside the polythene template to contact the rock surface beneath, taking care to avoid damage to barnacles. To minimise edge effects, barnacles partly obscured by the edge were counted at the left and top sides but ignored along the right and bottom edges unless the entire opercular opening was visible.

Results and Discussion

The total counts in each sampling area are summarised in Table 1 and in Figs 13 and 14.

E. modestus produces larvae throughout the spring, summer and autumn and may even produce small numbers in winter. In contrast, *S. balanoides* larvae are all released in spring (see Rainbow, 1984). In the study areas, settlement of *S. balanoides* in 1982 varied from dense (more than 10^3 in 0.01 m^2) at East Blockhouse through fairly dense (around 5×10^2 in 0.01 m^{-2}) at West Angle Bay to sparse at Pwllcrochan (less than 10^2 in 0.01 m^{-2}). *E. modestus* settlement was most dense (around 6×10^2 in 0.01 m^{-2}) at Pwllcrochan and sparse on the other areas (less than 10^2 in 0.01 m^{-2}).

Table 1. *Summary of data for all barnacle species (number of individuals 0.005 m^{-2}), 1982–83*

	East Blockhouse	W. Angle Bay I	W. Angle Bay II	Pwllcrochan
a. *Semibalanus balanoides*				
August	711	343	341	57
October	656	250	352	54
December	560	221	266	75
February	392	125	238	62
April	248	65	141	42
June	278	323	317	45
b. *Elminius modestus*				
August	14	18	43	370
October	10	22	34	360
December	18	15	39	342
February	4	14	30	196
April	2	10	19	126
June	1	11	16	94
c. *Chthamalus montagui*				
August	35	44	21	—
October	39	48	22	—
December	42	53	24	—
February	34	53	22	—
April	44	53	20	—
June	30	47	21	—
d. *Chthamalus stellatus*				
August	—	3	6	—
October	—	2	5	—
December	—	6	6	—
February	—	5	8	—
April	—	2	7	—
June	1	1	2	
e. Spat and cyprids (undifferentiated)				
August	24	15	2	35
October	31	62	52	139
December	2	4	29	—
February	3	2	7	—
April	154	66	23	7
June	347	30	56	118
f. Empty and dead				
August	30	13	14	NR
October	61	12	19	17
December	164	20	32	22
February	228	26	38	22
April	248	11	33	36
June	57	7	17	36
g. Sheltering organisms				
August	42	NR	NR	NR
October	36	3	3	NR
December	25	8	8	6
February	14	8	2	16
April	32	7	3	2
June	12	1	3	4

NR = no record.

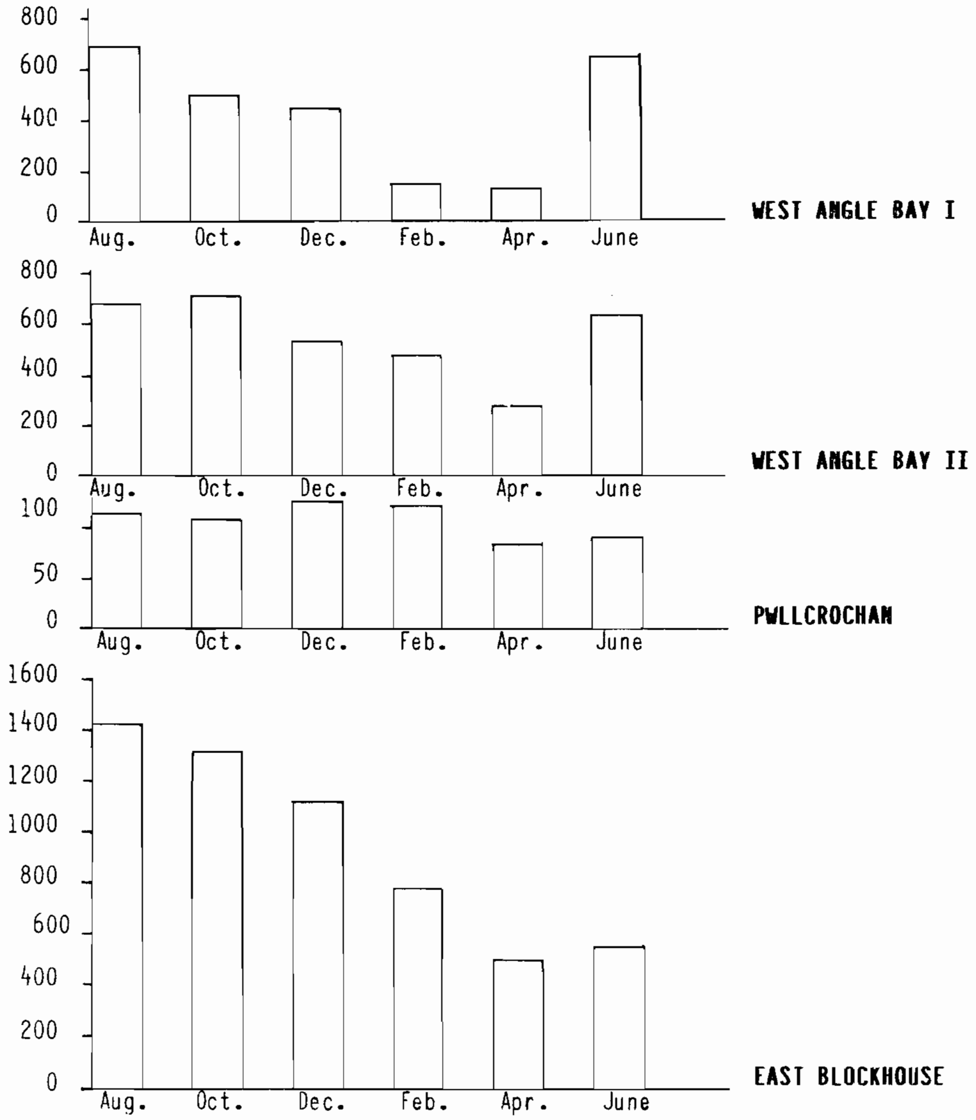


FIG. 13.
Density of *Semibalanus balanoides* in nos. 0.01 m^{-2} (1982–83). N.B. different vertical scales.

Numbers of both species fell overall at all three sites, the spatfall in 1983 not replacing those lost by predation and mortality during the study period. The decreases occurred at different times of year at different sites but the largest uniform drop was between February and April when about 20% of the original number of both species was lost from all sites.

There was heavy mortality of barnacles in their first winter of life. Many of them died with all the plates intact so predation was unlikely to have been the cause. Their major predator, the dog-whelk *Nucella lapillus*, feeds little at this season (Crothers, 1985). This observation is in agreement with those made during studies carried out in Northwest Scotland by Kendall *et al.* (1982), in which high initial settlement was often followed by high mortality.

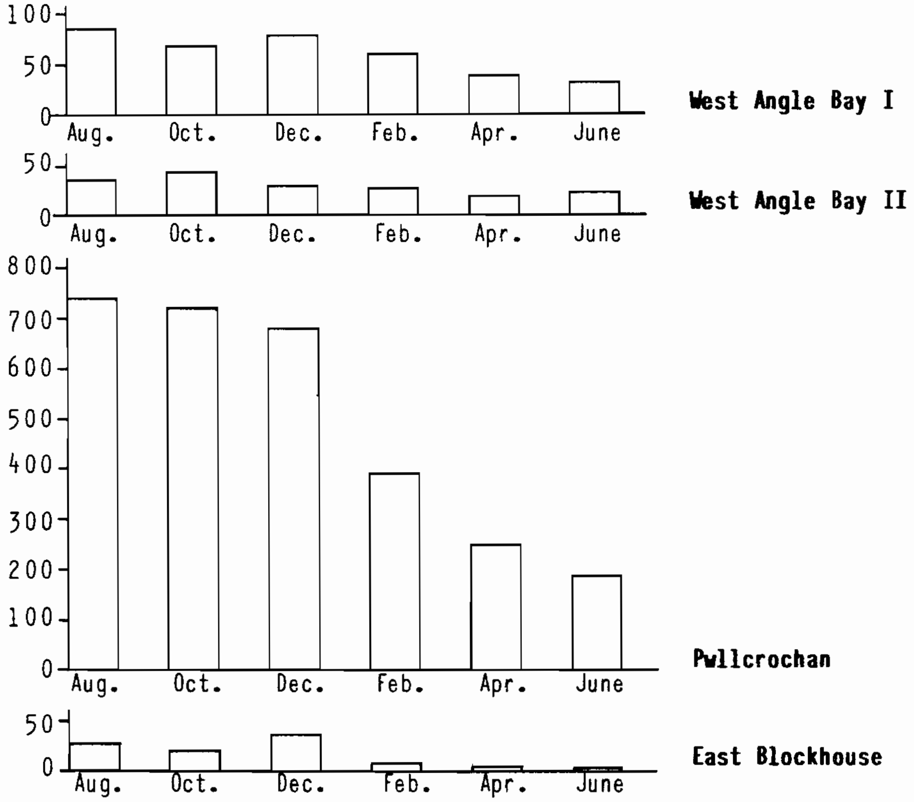


FIG. 14.
Density of *Elminius modestus* in nos. 0.01 m^{-2} (1982–83). N.B. different vertical scales.

At the selected tidal levels, *S. balanoides* was the dominant barnacle at both the West Angle Bay and East Blockhouse sites with densities generally in excess of 500 0.01 m^{-2} and was present at a fairly constant density of around 100 0.01 m^{-2} at the Pwllcrochan site. *E. modestus* was the dominant barnacle at the Pwllcrochan site with densities in excess of 500 0.01 m^{-2} until the February survey. At the West Angle Bay site densities of *E. modestus* were between 20 and 90 0.01 m^{-2} and at East Blockhouse less than 40 0.01 m^{-2}.

The *S. balanoides* counts at all sites were large enough to be analysed statistically for seasonal changes, although, for *E. modestus*, only the Pwllcrochan data were acceptable. The other data are included in the figure for completeness. Although the arrangement of quadrats within each area was randomised and a large number of quadrats were used, the quadrat size was not large enough to justify the assumption that the data conform to a normal distribution because of the patchiness of barnacle populations. Thus, the raw data could not be analysed using parametric statistical tests. Tests using distribution-free or non-parametric statistics were however appropriate.

The data for *S. balanoides* were examined using Kendall's τ (tau) test to see whether the data for different areas were correlated when paired within sampling occasions or, in other words, to see whether there was any correlation between the trends observed or whether they could have been the result of chance factors. The correlation coefficients, τ, so obtained are summarised in Table 2.

Table 2. *Kendall's correlation coefficient* τ *(tau) to establish the level of correlation between temporal changes in the data on* Semibalanus balanoides *from all three sites. These correlation coefficients are mathematical descriptions of the degree of association between two variables. The probability (p) that the apparent association may be the result of random variations is calculated by a test of significance; the level of significance is given to the right of each value of* τ *(S = significant at 0.05 level. NS = not significant)*

	West Angle Bay		West Angle Bay II		Pwllcrochan	
	τ	P	τ	P	τ	P
East Blockhouse	0.6	0.068 (NS)	0.6	0.068 (NS)	0.47	0.14 (NS)
West Angle Bay I	—	—	0.73	0.028 (S)	0.07	0.14 (NS)
West Angle Bay II	—	—	—	—	0.07	0.4 (NS)

A significant correlation was only obtained between the two replicate sample areas at the West Angle Bay site. Pairing the data for each sampling period, the correlation coefficient between the West Angle Bay data sets is 0.73, which is significant at the 0.05 level (and very nearly so at the 0.01 level). In other words, there is less than 5$^{\circ}_{0}$ probability of the correlation occurring by chance.

It is thus very unlikely that the observations at West Angle Bay that (a) number of *S. balanoides* had decreased in both areas and that (b) the rate of decline was similar from October to April, could have arisen by chance.

The initial density of *S. balanoides* at East Blockhouse was extremely high, at over 14 cm^{-2}. Most of this was made up of "O" group-first year-animals that had settled during the spring of 1982. The *S. balanoides* at Pwllcrochan were generally older. At West Angle Bay, the majority was from the settlement of the year (1982), though the density of older individuals was generally higher than that at East Blockhouse. The 1983 recruitment did not restore the numbers to the August 1982 level at any site, and at East Blockhouse the settlement brought the density up to less than half the August 1982 figure.

Southward (1985) has found that counts on low-density species showed random "noise". In this study, the lower counts for *S. balanoides at* Pwllcrochan, *E. modestus* at West Angle Bay and East Blockhouse, and all records for *Chthamalus montagui* and *C. stellatus* could be expected to exhibit this property and no analyses of these results have been attempted.

Conclusions

The data gathered during this survey provide a valuable adjunct to transect studies as they demonstrate the great changes in barnacle density that can occur over just two months. Also, the different rates of mortality, at the duplicated sites at West Angle Bay, emphasise that even sites close together can show very different results. This demonstrates the need for large numbers of samples to detect true population changes.

When planning surveys, it is suggested that permanent monitoring areas for barnacles should be established within the optimum range for each species separately. The sampling effort needed (that is, the number and size of quadrats) will depend on the density of the species at each site. Monitoring once yearly (or less frequently) is unlikely to give adequate information on the changes in barnacle populations. Our data illustrate that numbers vary considerably in high density barnacle populations and that annual samples taken on set dates often show very different results from year to year because, for example, seasonal factors operate later or earlier in different years. Data collection should be made at least quarterly, with more frequent seasonal effort if the fate of the spatfall is to be followed.

Mention should also be made of the NERC Rocky Shore Surveillance Group technique (Wethey, 1984). This involves the use of black and white photographs taken with a focusing frame which slots into screw heads fixed in the rock to relocate permanent quadrats. The photographs are checked and stored but only analysed if they are needed. Crothers (1983), taking monthly photographs of permanent quadrats, found it a waste of time to attempt photography under wet conditions. The results were not comparable with those taken on dry days.

Limpets

Patella vulgata Linnaeus (1758)
(Fig. 15)

The aim of this part of the study was to monitor limpet density, recruitment and mortality. The separation of *Patella* species in the field is difficult (Fretter & Graham, 1976). All three British species (Gaffney, 1980) are present at East Blockhouse and no suitable area for a survey of *P. vulgata* alone could be found. At Pwllcrochan and at West Angle Bay, it was possible to select survey areas with relatively isolated populations of *P. vulgata* (although the possibility that some *P. depressa* were included in the West Angle Bay samples cannot be ruled out). In each case the sample site was a large boulder or boulders or an isolated finger of bedrock surrounded by shingle, loose stones or small boulders.

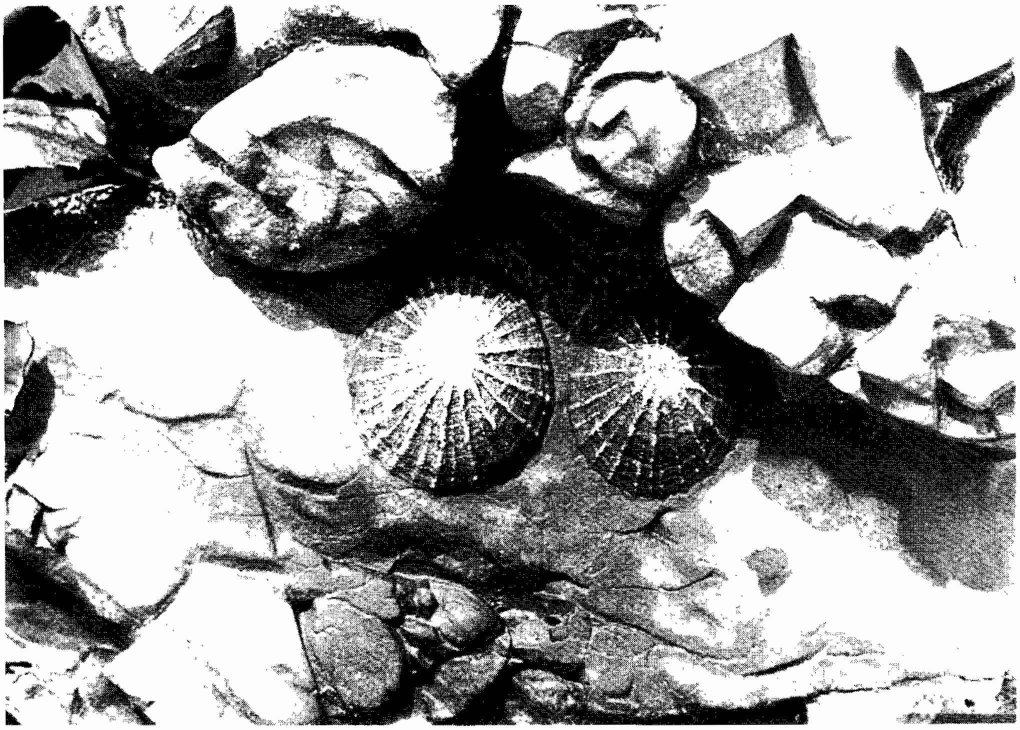


FIG. 15.
The common limpet, *Patella vulgata*.

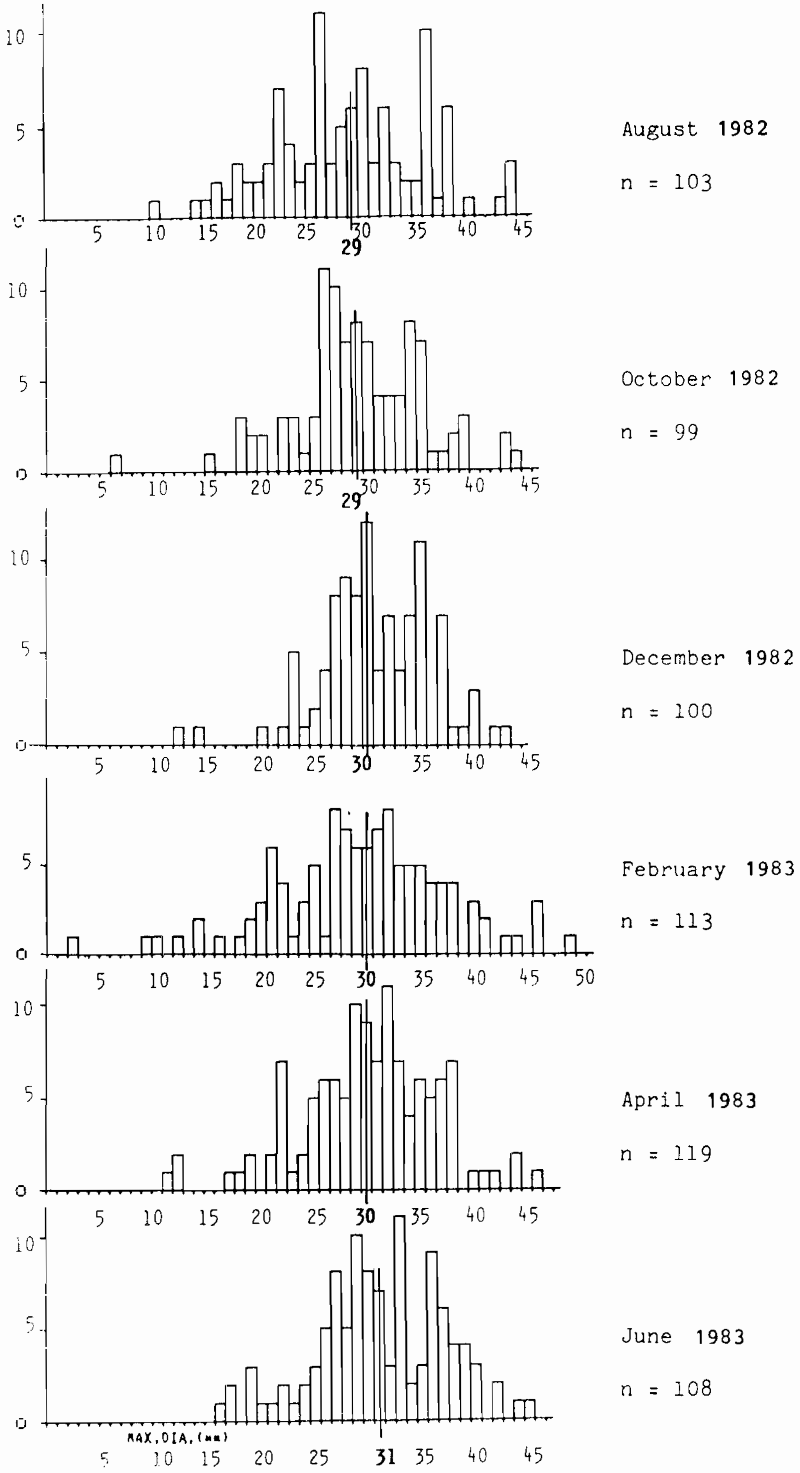


FIG. 16.

Limpet size-frequency histograms for Pwllcrochan.

(The vertical lines through the histograms denote the median diameter for each sample.)

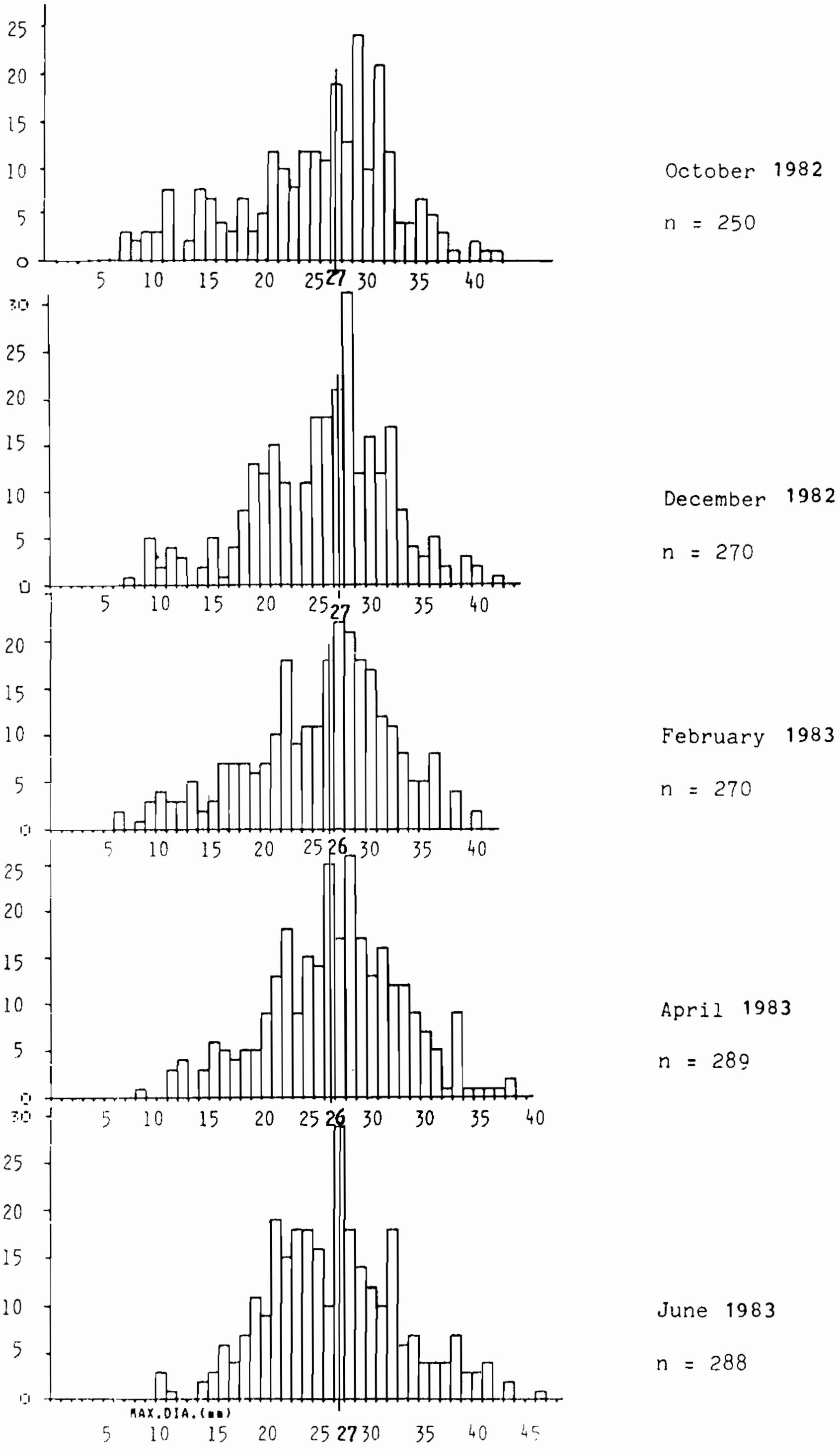


FIG. 17.

Limpet size-frequency histograms for West Angle Bay.

(The vertical lines through the histograms denote the median size class for each sample.)

Sampling Procedures

At each limpet site, every *P. vulgata* present within the defined area was counted and had its shell measured along its largest diameter (= length) without removing the animal from the rock. At the West Angle Bay site there was one deep crevice within which the limpets could not be measured.

Results and Discussion

Densities of *Patella vulgata* at both sites were higher than 100 m^{-2}. The frequency of occurrence of each size (= length) range was tabulated for each site and length frequency histograms produced (Figs 16 and 17). The sample sizes were not great enough to separate out the age groups in either population. Baxter (1982), working in Orkney, gave a figure of 900 + as an optimum sample size for this purpose.

Calculations of the median size class suggest that there was measurable limpet growth in the Pwllcrochan area during the period of the study. At West Angle Bay there was no overall growth (Fig. 16). The median size class increased from 29 mm in August 1982 to 31 mm in June 1983 at Pwllcrochan and varied between 26 and 27 mm at West Angle Bay. The increase in median size at Pwllcrochan continued despite a very low recruitment of small individuals into the sample area in February. An even smaller recruitment was observed at West Angle Bay. The differences between the histograms for each apparently identical area can only be explained by postulating migration of animals to and from the area, predation, differential mortality, growth of individuals or variations in the efficiency of search and accuracy of measurement by the workers involved.

At Pwllcrochan the number of limpets in the study area remained steady from August to December 1982, increased in the February and April 1983 samples but had fallen again by the June 1983 sample. The sampling areas were isolated and discrete. It was possible to mark every limpet to ensure a thorough search.

The counts at West Angle Bay were much larger. Numbers increased between October and December 1982 and again between February and April 1983. There were between 60 and 90 limpets inaccessible to measuring at this site.

Conclusions

At both the sites studied, *Patella vulgata* densities were greater than 100 m^{-2}, but were higher at West Angle Bay than at Pwllcrochan. Pwllcrochan limpets grew to a larger size than those at West Angle Bay. Differences between samples were not great enough to warrant frequent sampling throughout the year. Significant seasonal changes are confined to the youngest age classes which are poorly represented in our data—either through genuine absence or because, occupying small crevices, they were overlooked.

The Common or **Toothed Topshell**

Monodonta lineata (da Costa, 1778)

(Fig. 18)

The aim of this part of the study was to investigate the size and age distributions of *M. lineata* and to compare rates of growth between sites. At Pwllcrochan and at West Angle Bay two areas were selected for survey, one around MLWN and the other around MTL. At East Blockhouse there was only one suitable area, around and above MT. See Desai (1966), Fretter & Graham (1977) for information on the general biology of this species, and Garwood & Kendall (1985) for information on reproductive cycles.

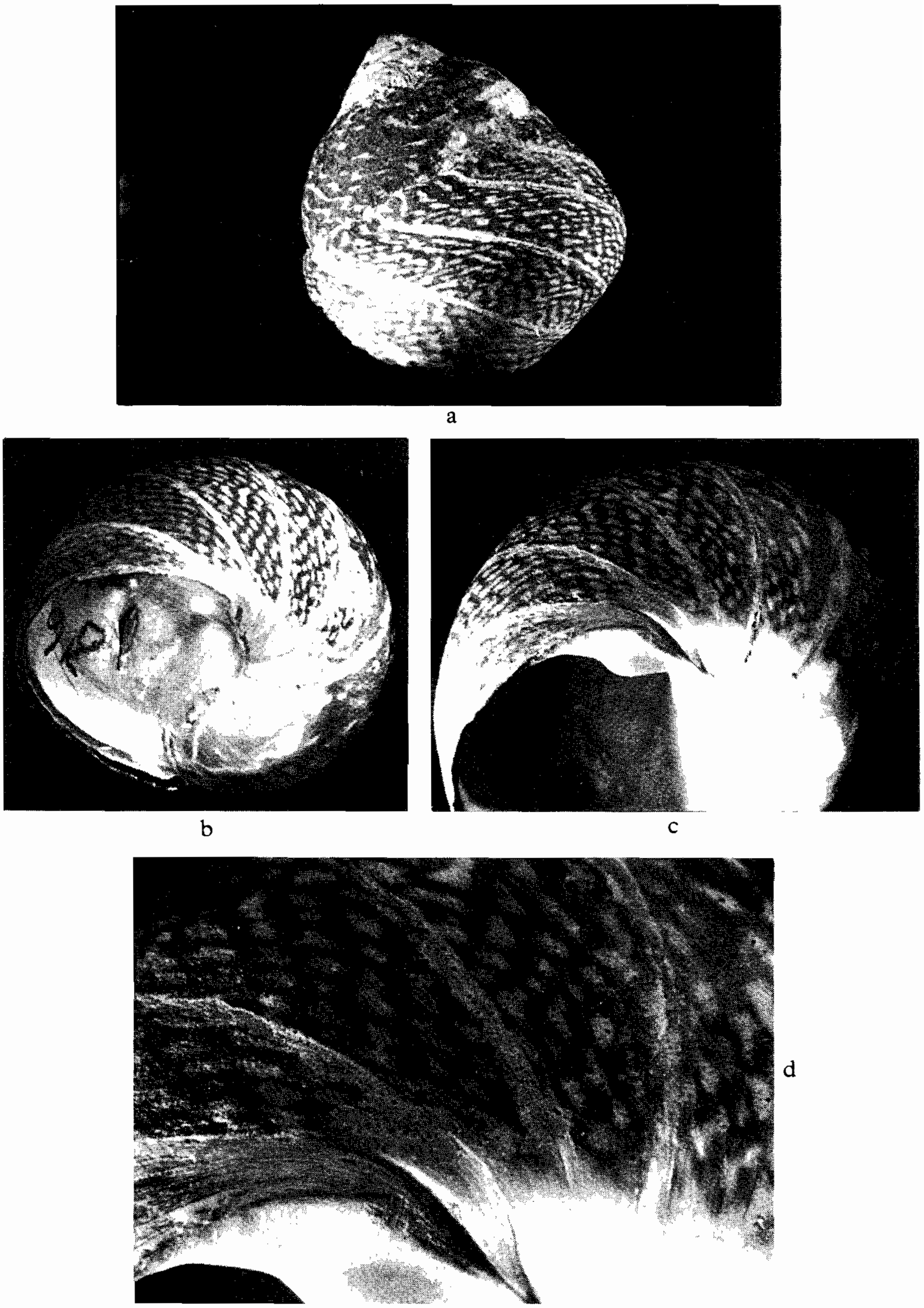


FIG. 18.

Shells of *Monodonta lineata* showing growth checks. (c) and (d) are photographs of the same shell at different magnifications. All these photographs were provided by Dr M. A. Kendall.

Sample Procedures

A timed-search technique was selected because of the substrate heterogeneity, typical of many shores in Milford Haven, and the mobility of the species. It is questionable whether an adequate assessment of such a mobile species can be drawn from belt transects alone. Similarly, counts within fixed areas may give very variable results, depending on environmental conditions. In the case of *M. lineata* the problems include:

1. The animals respond to weather conditions; moving away from positions exposed to strong winds.
2. The young, in particular, are usually cryptic in their behaviour; but under some conditions they may all come out from under the rocks when, an hour before, none was visible.
3. Boundaries between local populations are often impossible to define. Even when an isolated population is found, the area is often impossible to measure.
4. The planktonic young mix with those from other sites so recruitment is not dependent on any attribute of the local population.

The main disadvantage of a timed-search technique is that it is almost impossible to quantify except in terms of "catch per unit effort". However, if the searching procedure includes all possible microhabitats and the sample is large enough to be representative of the population, then the technique is very useful.

The sampling technique was to search areas of shore where *M. lineata* had been found on previous occasions, gradually working outwards for 15 minutes (or multiples of 15 minutes) until about 50 individuals had been found. Searches included the undersides of boulders and pools. Notes were made on the positions in which topshells were found. The numbers collected varied between 0 and 172 in 15 minutes. Each shell was measured along the largest diameter of its base and its age was determined by counting the growth checks (Fig. 18) in the shell. *M. lineata* grows throughout its life, and may reach an age of at least 12 years (Stanbury, 1974). As a complement to the studies described here, a mark-release-recapture exercise was carried out to further investigate the population size at two of the sites and the results enabled us to assess the effectiveness of sampling (Little & Dicks, in prep.).

Results and Discussion

Length and age frequency histograms have been plotted (Fig. 19). Scatter plots of size against age have been produced to investigate growth rates at each site (Fig. 20–22).

All three sites had relatively low-density populations compared with sites in Dorset, North Finisterre, Cornwall and Cardigan Bay (Kendall, unpublished data). However, they had larger than normal populations for Milford Haven.

At Pwllcrochan, the two sampling areas were remote from eath other and were much less than 1% of the area occupied by the whole population (see Fig. 2). Individuals smaller than *ca.* 20 mm (basal diameter) were almost always confined to the lower area (C). Individuals larger than *ca.* 22 mm were unusual in the lower area but comprised the bulk of those collected in the upper area (A). Not surprisingly, the population age structures of the two sample areas were different with, broadly speaking, 90% of those on the lower area four years old (4 group) or younger, with the bulk of them aged one or two years (1 and 2 groups). Most of those on the upper area were between four and seven years old (4–7 groups). There were no settlers (0 group) in the samples and relatively few aged two or three (2 and 3 groups). Searches at the time failed to reveal whether these were to be found elsewhere on the shore, or whether there had been low recruitment in those years.

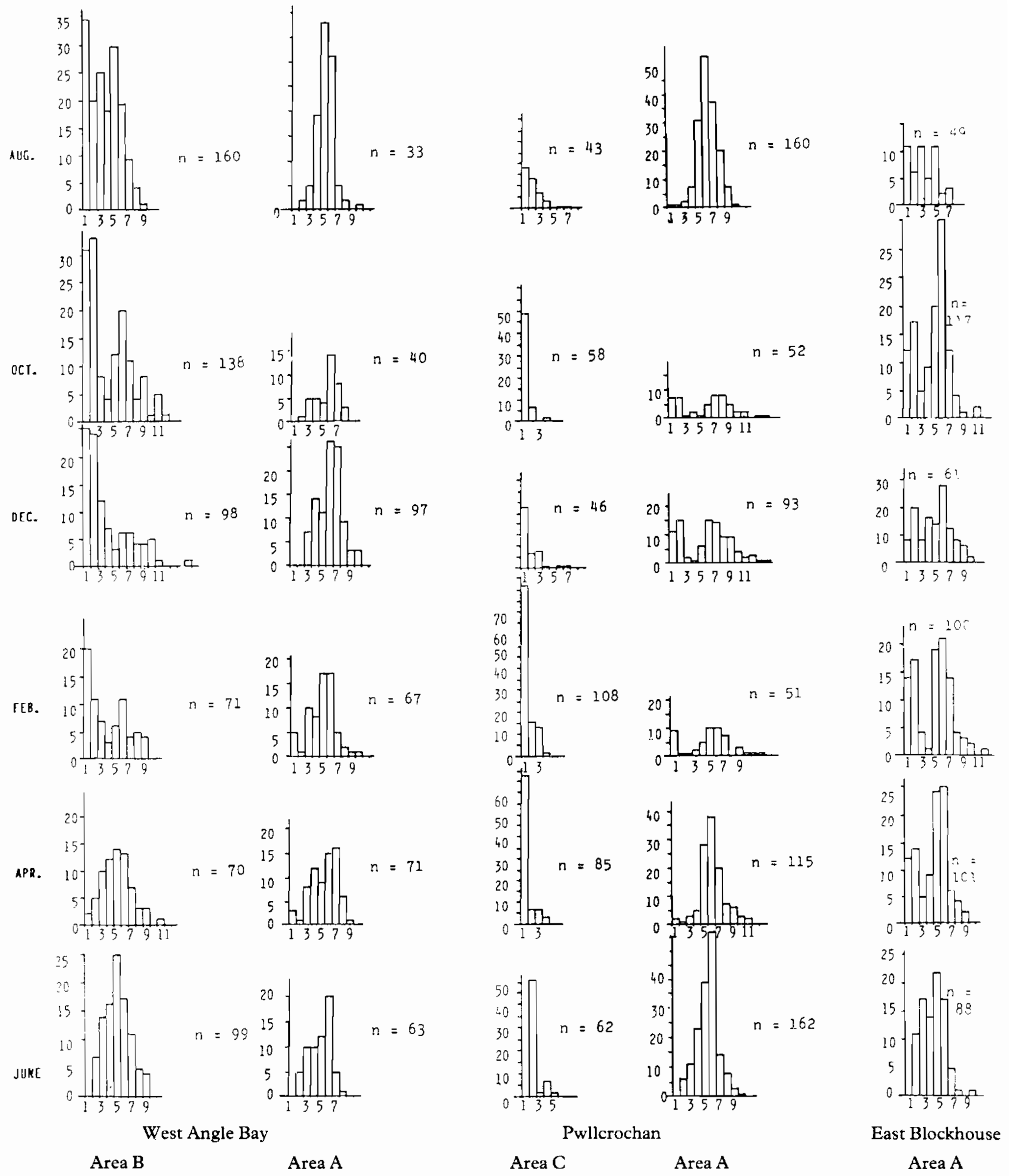


FIG. 19.
Age-frequency histograms for *Monodonta lineata* (1982–83). (NB. different vertical scales in each column)

Subsequent fieldwork (1984) confirmed the presence of a nursery area for *M. lineata,* intermediate in height on the shore and to the west of both sampling areas. New settlement of *M. lineata* (0 group) was discovered in well-drained stony ground on the upper mid-shore. Groups 2 and 3 animals were also found to be more common in this intermediate area—shown on Fig. 2 by dots—than on our sampling areas. Thus the whole population was not equally represented in the original samples.

Density varied enormously from sample to sample with 15 minute searches yielding between 0 and 41 individuals on the lower area and between 18 and 63 on the upper. The number of searches required to collect a sample of around 50 varied with the severity of the weather conditions and the season. It was hardest to find animals in December and February. Distribution on the shore was very patchy with large numbers congregating together in shelter during cold windy weather.

The mark, release and recapture exercise showed that the number of adults in the upper area was of the order of 500 (Little & Dicks, in prep.). In order to sample a representative proportion of the population, the sample size should have been in excess of 90 individuals. This is based on an accuracy of 0.5; that is "n" (true population size) in the range of 0.5 to 1.5 n (the estimated population size)—see Begon (1979), Robson & Regier (1964) and Seber (1973) for discussion of mark, release, recapture procedures. In this study, the samples were generally smaller than optimal; some of the variations between samples could, therefore, have been due to chance.

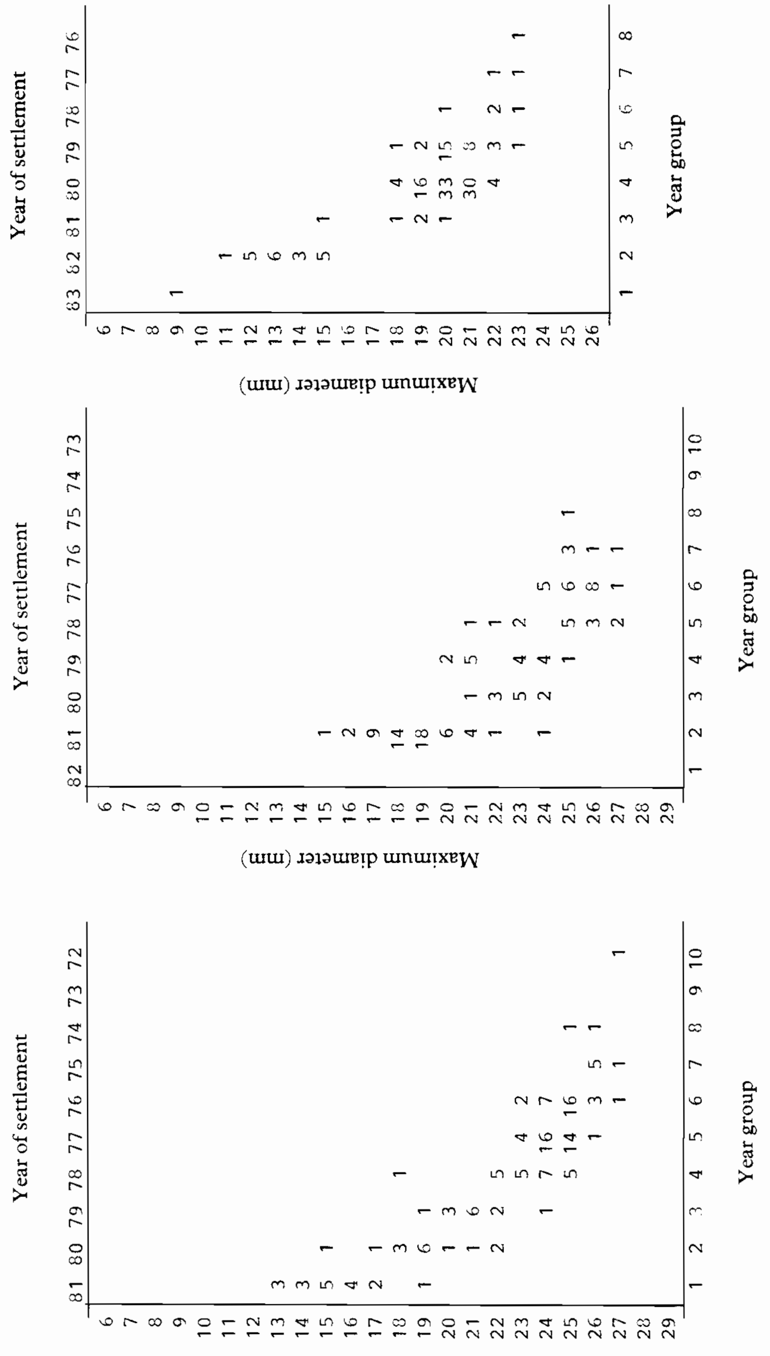
The population of *M. lineata* at Pwllcrochan was highly mobile. After their first winter in the nursery area, the young topshells move downshore onto the mussel bank. There they spend one or two years before migrating upshore again, leaving only very small numbers of ageing individuals behind. It may well be that there are high mortalities among the young animals on the mussel bank, both during winter storms and during the up-shore movement. In the former case, the banks of old mussel shells are turned over in rough weather, transforming the area. In the latter case the movement upshore can only occur along the neck connecting the offshore bar to the mainland (Fig. 2) as the surrounding areas are inhospitable in every other direction with mud on two sides and deep water on the third. Similarly, very few young animals reach the upper sampling area along the shoreline, the intervening mud preventing up- or downshore movement here. We did not detect any large scale seasonal migration of adults, as described by Williams (1966) at Craig yr Wylfa (near Borth) or by Underwood (1973) near Plymouth.

An examination of empty shells on this shore might show whether higher mortalities occur within any particular size or age class, and hence whether movement of elements of the population are accompanied by heavy casualties. It would be necessary to carry out some preliminary experiments with marked empty shells of different sizes to establish whether water movements are capable of mechanically sorting empty shells.

The migrations described above explain some of the peculiarities in Fig. 19; the disappearance and subsequent reappearance of year groups in the samples. This can be shown by examining the fate of, say, the 1977 settlement group through the age frequency histograms. These are the 5 group animals of the first five samples (August to April) and the 6 group of the June samples. The growth check for the 1982/83 winter showed up first in the June samples.

Examining the growth tables of size against age, the curves for the October, December and February samples are almost identical with that of the previous August, except that, by February, the 1981 settlers had grown by approximately 2.5 mm in diameter. The 1980 settlers had grown perceptibly but older animals were unchanged. By June the 1981 settlers had grown an additional 1 mm. The greatest new growth on marked individuals was recorded between the August and October samples. Perhaps metabolic effort until early summer goes into achieving gamete production and not growth.

From an examination of growth plots for samples taken in the summers of 1982, 1983 and 1984 (Fig. 20), it appears that the growth rates were not the same in each year; animals settling in 1980 and 1981 grew faster during the first two years than did those settling in 1982 and 1983.



18th August 1982

14th June 1983

31st July 1984

(Lower area only)

FIG. 20.

Plots of size against age in three successive summers for the *Monodonta lineata* population at Pwllcrochan.

Maximum diameter (mm) / Year of settlement	81	80	79	78	77	76	75	74	73	72
6										
7	1									
8	1									
9	3									
10	3									
11	3									
12	1	2								
13										
14		1								
15										
16		1								
17		2	1							
18			1							
19										
20		1	1							
21			3	1						
22			5	3	1					
23			1	4	8	1	1			
24				2	24	15	1			
25				1	8	16	8	2		
26					3	15	16	4		
27						5	13	4	1	1
28						1	2	10	4	
29									2	
Year group	1	2	3	4	5	6	7	8	9	10

20th August 1982
(lower and upper areas)

Maximum diameter (mm) / Year of settlement	82	81	80	79	78	77	76	75	74	73	72
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20		7									
21		7	5	1							
22		2	12	3							
23		1	10	15	15	4		1			
24			1	14	26	12	3				
25				1	23	37	6	3	1		
26				1		16	6	1			
27						2	5	3		1	
28						1		1	2		
29										1	
Year group	1	2	3	4	5	6	7	8	9	10	

20th June 1983

Maximum diameter (mm) / Year of settlement	83	82	81	80	79	78	77	76	75	74	?
6	4										
7	4										
8	2										
9	1										
10	1										
11											
12											
13		1									
14		3									
15		2									
16		3	1								
17		2	3								
18			9	3							
19			24	6	1						
20			17	22	2						
21			1	24	7	2	1				
22				6	6	4	1	2			
23				1	5	2	4	4	6		
24					2	1	6	4	9	2	3
25						1	1	–	5	1	3
26										4	1
Year group	1	2	3	4	5	6	7	8	9	10	11+

31st July 1984
(lower area only)

FIG. 21.

Plots of size against age in three successive summers for the *Monodonta lineata* population at West Angle.

Year of settlement

Maximum diameter (mm)	82	81	80	79	78	77	76	75	74	73	72	71
6												
7												
8												
9												
10												
11		1										
12		1	1									
13		8	1									
14		6	3									
15		7	3									
16		2	3									
17		2	1									
18		2	2									
19		2	4	1								
20			8	1								
21			5	1								
22			2	3	1	1						
23			2	2	2	3	2					
24					1	4	10	4				
25						3	7	3	2	2		
26						1	1	3	2	2	1	1
27								1		2		2
28										2		2
29												1
30												
Year group	0	1	2	3	4	5	6	7	8	9	10	11+

3rd November 1982

Year of settlement

Maximum diameter (mm)	83	82	81	80	79	78	77	76	75	74	73	72	71
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16			1										
17			1										
18			2										
19			2	2									
20				6									
21				1									
22			1	2	6		1						
23				1	7	6							
24				2	3	7	4	1					
25						8	4	4	3				
26						2	6	5	1	1			
27						2	1	1		1			
28							1		1	2			
29													
Year group	0	1	2	3	4	5	6	7	8	9			

16th June 1983

FIG. 22.

Plots of size against age for the *Monodonta lineata* population at East Blockhouse.

At West Angle Bay the population was restricted to an area 10 to 20 times the size of the search areas. Samples from the two areas (one around MLWN and one above MTL) were proved to belong to the sample population during the mark-recapture exercise (Little & Dicks, in prep.). Once again, the lower area had more small individuals than the higher, although the larger individuals were more evenly distributed between the areas that at Pwllcrochan. This was not surprising as the two areas at West Angle Bay are physically close to each other and on similar terrain, unlike those at Pwllcrochan.

There was an increase in the number of large specimens in the lower area samples in October and February compared with the other samples. Marked individuals from the upper area turned up in the lower one in October, December, February and April. Treating the two areas together, there was a large increase in the number of 20–23 mm sized specimens in the April sample (cf. Pwllcrochan) but, unlike Pwllcrochan, these were largely confined to the lower area. It seems likely that this subgroup of the population was concealed in some refuge during the surveys up to April 1983, and not sampled.

Looking at the age structure (Fig. 19), the bulk of animals in the upper area were in the four to seven year-old age range (4–7 group) whilst the lower area had large number of *M. lineata* aged one to three years (1–3 group) as well as a peak in the four to seven age range (4–7 group). The total number of individuals younger than 3 group was less than that in the 5 group and above, suggesting that, unless there were large numbers of juveniles which were missed by the searches, the age structure was that of an ageing population at this time. Recruitment was characterised by one or two strong years with four or five weak years. The mark, release, recapture exercise showed that the total population was in the range 2000 to 5000 (Little & Dicks, in prep.). The sample size that would be required for an accuracy of 0.5 (that is, true "n" in the range 0.5 to 1.5) would be 200–300. In this study the sample sizes collected were between 70 and 200. For any longer-term study at this site, a minimum sample size of 250 would be required.

Examination of the growth tables of size against age (Fig. 21) showed a similar pattern to that observed at Pwllcrochan, although there were larger numbers of 2 and 3 group animals in most samples. Growth of large, marked individuals was most pronounced between the August and October samples, but was less than at Pwllcrochan. This contrasted with the growth of young *M. lineata* which grew faster at West Angle Bay, (from *ca.* 12 mm to *ca.* 18 mm in one year); faster than at any other site. It would appear that very localised factors affect growth rate and recruitment so that no overall pattern of good and bad years for *M. lineata* has emerged.

At East Blockhouse the area occupied by *M. lineata* was a boulder-strewn shore with outcrops of bedrock surrounded by larger outcrops on three sides, confining the population to an area less than ten times that used during sampling. No mark, release, recapture exercise was conducted here. Despite the northwesterly aspect of the bay, the boulders were moved around during winter storms.

Recruitment over the two years 1980 and 1981 was intermediate between that at Pwllcrochan and West Angle Bay. The population age structure was normally distributed around 5–6 year groups suggesting that this was also an ageing population at this time. The density was slightly less than at West Angle Bay, but was greater than at Pwllcrochan.

Examining the growth histograms of size against age (Fig. 22), in November 1982 there was a very large spread of sizes in the 1 and 2 group animals. Many *M. lineata* sampled here had suffered damage to the edge of the shell at some stage of their lives, possibly resulting in the deposition of false growth checks but, even excluding all those that were difficult to age, the 1 group animals varied from 11 to 19 mm in diameter. In the Pwllcrochan sample for

October there was one individual 6 mm smaller than all the rest which may possibly have been an 0 group animal. If that were the case the large number of 1 and 2 group animals here, may represent more than two years and could possibly include some fast growing O group animals.

An examination of two samples of *M. lineata* from Pwllcrochan and West Angle Bay was made by Kendall, who confirmed that our ageing technique was comparable to that used by the NERC Rocky Shore Surveillance Group, provided that an extra year was added to our estimates for the microscopic growth check assumed to be present for the first winter. The histograms and growth tables here presented have been corrected in this manner. There is still doubt over the amount of growth possible on different shores before the first growth check is laid down.

Two more shores have been studied briefly to assess their populations of *M. lineata*. These were Littlewick Bay on the North side of Milford Haven and Chapel Bay on the south (Fig. 1). The populations were very different.

At Littlewick Bay in October 1982, the area within about 100 m west of the refinery effluent discharge pipe (see Petpiroon & Dicks, 1982: Iball & Crump, 1982) was devoid of *M. lineata* despite the apparently suitable habitat. The first area within which they were sufficiently common to yield a reasonable sample was 190 m west of the effluent. Most of those in the sample had settled in 1975 or 1976 and were then in the 6 and 7 year groups and between 24 and 26 mm in diameter (Fig. 23).

At Chapel Bay, the population of *M. lineata* in March 1984 was the most dense encountered in this study. The growth histograms of size against age (Fig. 24) show a very

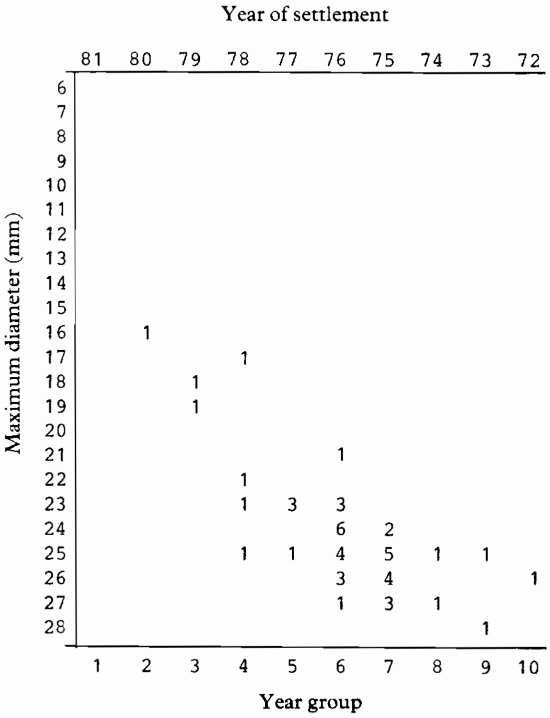


FIG. 23.

Plot of size against age for the *Monodonta lineata* population in Littlewick Bay, sampled on 18th October 1982.

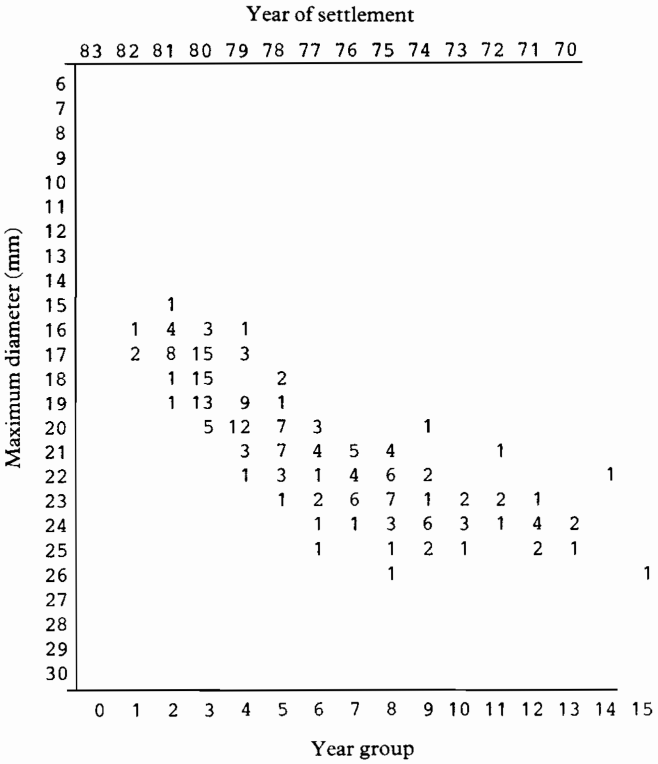


FIG. 24.

Plot of size against age for the *Monodonta lineata* population in Chapel Bay, sampled on 30th March 1984.

great spread of ages amongst animals of much the same size. There was also more variety in shell shape than elsewhere, with some animals being taller for a given diameter, whilst others had shells with much more square whorls than is usual. Comparing the sizes achieved for a given age at this site with the same information from Littlewick Bay, the settlers of 1975 and 1976 had only grown to between 21 and 23 mm compared with 24 and 26 mm at Littlewick eighteen months before. This would lend support to the tentative suggestion (Williamson & Kendall, 1981) that differences in growth rates may result from density-dependent factors operating on the population.

In general the maximum sizes of Milford Haven specimens were much greater than those reported by Williamson & Kendall (1981) from mid Wales, north Cornwall and Dorset, or by Underwood (1973) at Plymouth, but were similar to those found by Stanbury (1974) on Skokholm. However, it should be noted that Williamson & Kendall were concentrating on the areas of shores where the new recruits were found and they may have underestimated the older elements of their populations. Their "size for age" results are comparable.

Conclusions

Most rocky shore surveys in Milford Haven have included *M. lineata* as one of the species investigated, and in general the numbers recorded have declined at almost all sites between the 1961, 1962–63, 1968–70 and 1979 surveys, with a slight increase between the 1979 and 1982 surveys (Moyse & Nelson-Smith, 1963; Nelson-Smith, 1967; Crapp, 1970; Little

1983; Woodman *et al.*, 1983). This was one of the reasons for looking in detail at this species. Also, Nelson-Smith (1968) reported that in this geographical area (towards its northern limit), the species is susceptible to oil pollution and to extremes of cold. Intermittent oil spills and infrequent cold spells could together act to eradicate this species from the area.

The areas searched in transect studies were small compared with the present one and so there is a possibility that reductions at all shores could be due to chance factors, considering the mobility of the organism and the small numbers recorded. Thus it would seem appropriate to search for mobile organisms such as *M. lineata* in suitable habitats in the vicinity of the transect sites rather than including them on a transect checklist. The search area should cover the whole of the midshore from MLWN to MHWN. An important point to bear in mind is that data from timed searches should not be translated into densities. The sites surveyed in this study had low density *M. lineata* populations compared with other sites in Southwest Britain and Brittany, although they supported some of the highest densities found on shores in Milford Haven. In Milford Haven, *M. lineata* is within 100 miles of both its northern and eastern limit in Wales (see Lewis, 1964).

M. lineata was observed to respond within minutes or hours to changes in weather conditions as they occurred. This greatly affects the ease with which they can be located and studied and must be a major source of data variation in the standard rocky shore monitoring technique. In addition, distribution on the shores was very patchy and different size and age groups were found at different levels and in different microhabitats. In monitoring *M. lineata* on shores like this, it is evident that the normal transect technique with abundance scale estimates or counts per unit area (however large the area) are not useful methods. To obtain an accurate record it would be necessary to work over the whole shore from MLWN–MHWN, sampling from every likely habitat to pick up each element of the population. Timed searches of large areas which contain most shore micro-habitats are more appropriate. Although not strictly quantitative, this technique produced good comparative estimates of actual population size. Alternatively, the work could concentrate on nursery areas and sampling could be carried out once-yearly to establish the timing and level of recruitment (see Williamson & Kendall, 1981).

Ageing by the counting of growth checks was found to be a useful technique. Information on the different growth rates achieved during different years and at different sites was obtained. Maximum size was achieved where densities were lowest. In most cases distinct year classes could be demonstrated. Recruitment in this species was characterised by intermittent strong years with several poor years in between. The ageing technique allowed inferences to be made about recruitment success, the general condition of the population and population growth performance over the immediately preceding years. The benefits of this in retrospective pollution studies are obvious, particularly where no previous baseline data are available for comparison. It should be feasible to detect effects on this species some years after the event.

In long-term monitoring schemes, a once-yearly sampling of this organism provides a large amount of information on the strengths and survival rates of the various year classes and on their relative strengths from shore to shore, giving an indication of local conditions during that most vulnerable of periods, during and just after settlement. It is relatively easy to collect samples at different times of year and in different weather conditions, but winter and very windy days should be avoided. In summer, the collection of large samples should be simple. The ideal time is late summer (end of September) when the new recruits should be present.

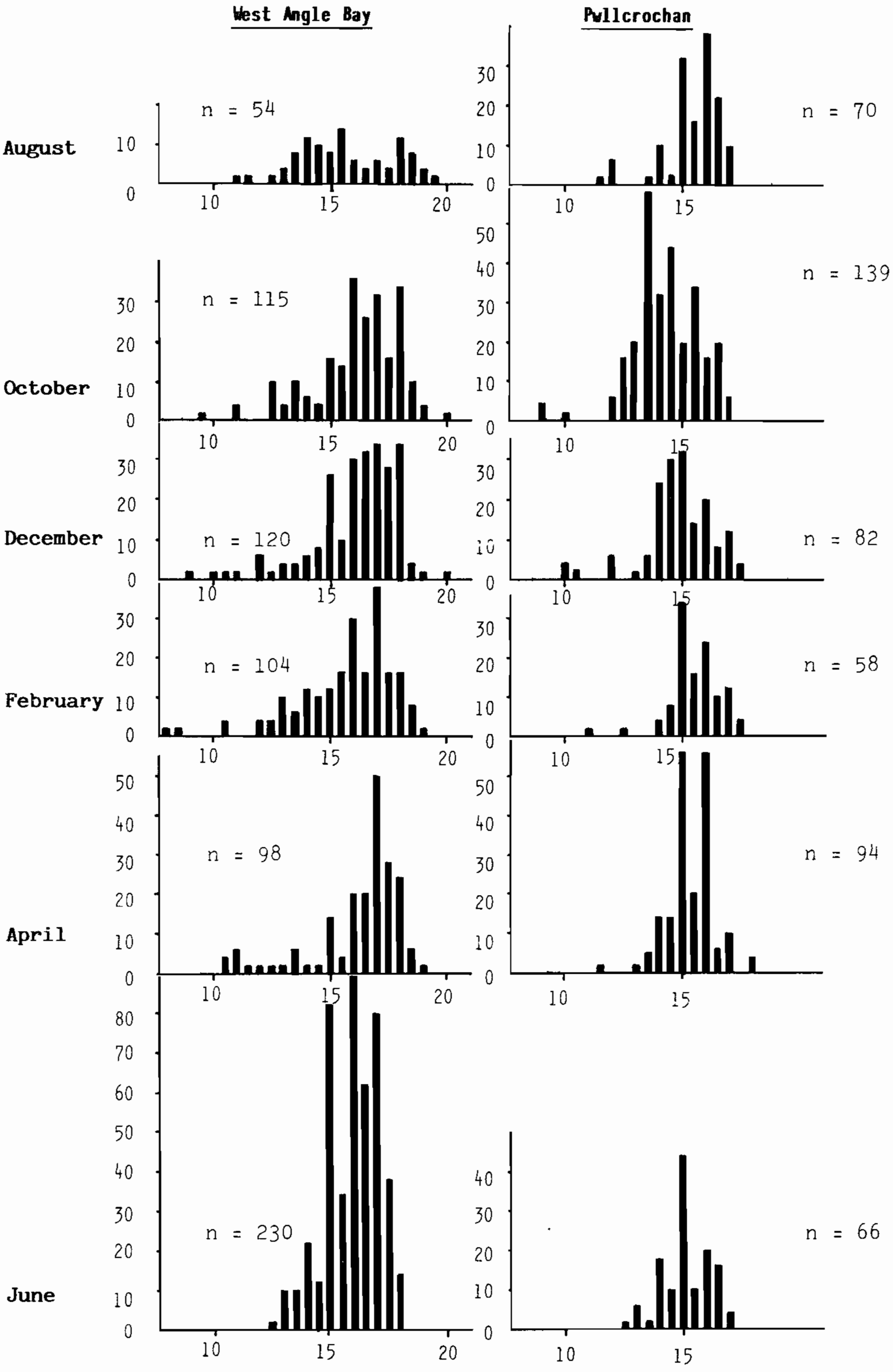


FIG. 25.
Size-frequency histograms for *Gibbula umbilicalis* (1982–83). (The size referred to is the basal diameter in mm.)

The Purple Topshell

Gibbula umbilicalis (da Costa, 1778)

The aim of this part of the study was to investigate the population size distribution of *G. umbilicalis*. See Fretter & Graham (1977) for information on the general biology of this species, and Garwood & Kendall (1985) for information on reproductive cycles.

Sampling Procedures

G. umbilicalis was studied in West Angle Bay, at around MTL, and at Pwllcrochan around MLWN. Timed searches of 15 minutes' duration produced collections of from 54 to 140 individuals. Each specimen was measured across the largest basal diameter of its shell, to investigate the size distribution within the populations.

Results and Discussion

Size-frequency histograms were plotted for each site (Fig. 25). The West Angle Bay sample contained more large individuals (median diameter 17.5 mm) than were collected at Pwllcrochan (16 mm).

Clear year groups could not be identified from the histograms as numbers of younger *G. umbilicalis* were low and the differences in size between subsequent year groups were too small to be resolved by measurement to the nearest 0.5 mm. Also, the existence of two growth forms, one low and broad and the other tall and thin (depending on degree of overlap as whorls are laid down), confuses any attempt at age separation by size. *G. umbilicalis* does not show clear annual growth checks, so ageing was not possible in the field.

The density of *G. umbilicalis* was higher at both sites that that recorded for *M. lineata*, and finding sufficient specimens for a sample was never difficult even during the very worst weather conditions (cold with strong winds). At such times *G. umbilicalis* was generally found under standing water rather than amongst boulders.

Conclusions

It would require a lot more effort to collect adequate population information for this species, which is, in any case, more adequately surveyed by standard transect methods than is *M. lineata*. Consequently, collection of size-frequency data is not recommended as part of a monitoring programme, and it may not yield useful information in student projects. Because this topshell is generally common in pools and crevices, transect surveys should include the searching of such habitats.

General Discussion on the Implications of this Study for Future Monitoring and other Survey Programmes

The object of the work described in this paper was to find appropriate methods for the examination of populations of a few rocky shore animal species, chosen for their suspected or proven sensitivity to pollution (or natural change) and hence their importance in monitoring schemes.

There has long been a need for studies on the population dynamics of important organisms in shore communities and, in the field of applied research, of those known to be susceptible to pollution. The value of such studies is well illustrated by the study of age structure in populations displaying annual growth checks (e.g. *M. lineata*) which can provide information on recruitment and subsequent performance over the last few years.

Much has been said (e.g. Lewis, 1976) on the virtues of examining species within their optimum range. However, *M. lineata* is susceptible to oil pollution within Milford Haven, whereas further south, where temperature conditions are more favourable for it, this is not the case (Nelson-Smith, 1968). Therefore, it could be argued that it is the species which are already under stress which are most likely to show the effects of chronic pollution, provided that information on their current status in nearby localities is available.

The barnacle survey techniques were very useful in following the fate of the animals in the sampling area and monitoring recruitment success, and it is clear that monitoring should be carried out quarterly. Four samplings per year provided greatly increased yields of information on the performance of the species compared with the annual (or less frequent) surveys employed in many monitoring programmes, and there are indications that further gains could be made by using a larger sampling area. Recording would then be very time-consuming. Depending on whether time or money is the limiting factor, photographic techniques might be more appropriate, and have the added advantage that "samples" can be stored until needed.

When studying limpet populations by belt-transect/abundance techniques, if counts are reduced to an abundance category information about population density is lost. However, counting and measuring an adequate sample (900+) is time-consuming and, in many cases, perhaps inappropriate. Nevertheless, considerable increases in the information yield of belt-transect monitoring could be gained by modifying the procedure used at present. It was observed that, on these shores, individuals up to about 15 mm in length tend not to establish "homes", and it would be advisable to separate them, in counts, from the larger, settled limpets. On selected shores fixed areas on the mid-tidal (say 4×0.5 m^2) should be examined annually in autumn to give counts of limpets greater than and less than 15 mm to assess the effect of each year's recruitment on the population. The juveniles are then of a size suitable for easy detection and counting.

To study limpet populations adequately on the more exposed sites in southwest Britain, the field worker must be able to separate *Patella* species (at all ages) on shell characters alone. Since limpets are susceptible to the effects of oil pollution and are important organisms in the shore communities, it may be that such an effort should be made. On the other side of the argument, exposed shores are mechanically cleaned very rapidly by the sea, or indeed are protected from oiling by wave reflection and consequently may sustain only limited damage to biota. Additionally, recovery may be relatively rapid after damage and undue concentration of effort on their communities in post oil spill studies would seem inappropriate.

The use of timed searches combined with sizing and ageing was found to be a very useful and effective monitoring scheme for *M. lineata*. The same methods (without ageing) were used with *Gibbula umbilicalis* but were less effective, and more time-consuming and more accurate measurements would be needed to separate the cohorts. *G. umbilicalis* is generally adequately sampled, except for the younger elements of the population, by the usual searches in unit areas. As this species prefers crevices and pools, these habitats should be included in all shore monitoring.

The methods tested in this pilot study varied somewhat in their applicability and usefulness, but all have resulted in suggestions for improving the information gained from rocky shore studies. Although much has been learned, it must be noted that we cannot pretend to have sampled through the full range of natural variation in one year. We can say with reasonable confidence which of the species investigated show large-scale changes over two months or less, and thus need careful attention if they are to be included in a sampling programme. The gains must be weighed against the penalties of time and cost where increased effort has been recommended and decisions must ultimately depend upon the aims and objectives of the monitoring or other research programme envisaged.

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We are indebted to our families for their support and understanding.

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