

DISTRIBUTION OF SESSILE MARINE ORGANISMS ON THE WALL OF A LITTORAL LIMESTONE CAVE AT BARAFUNDLE BAY, SOUTH PEMBROKESHIRE

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ABSTRACT

A description is given of the distribution and abundance of sessile organisms on the wall of a littoral limestone cave at Barafundle Bay, Dyfed, South Wales. Species found include bryozoans, serpulid tubeworms, barnacles, ascidians and red algae. Distinct differences in distribution are observed between species with distance into the cave. The major environmental factors influencing these patterns are probably decreasing desiccation, temperature variation and light intensity, the availability of planktonic food supply and changing water movement patterns.

Observations made within atypical environments such as littoral caves could be used to supplement standard student investigations carried out on open, seaward facing rocks. There is also much scope for further individual research within this cave and in adjacent littoral caves and tunnels. Many of the species found are more typical of cryptic microhabitats or of the sublittoral zone and are hence often neglected despite their overall importance in rocky shore ecosystems

INTRODUCTION

Most research on the distribution patterns of rocky shore animal and plant species has been performed on open, seaward-facing rock (e.g. Southward, 1958; Moyse & Nelson-Smith, 1963; Underwood, 1979; for general description see also Lewis, 1964; Newell, 1970). The patterns that occur within other rocky shore environments, such as caves, rockpools (Pyefinch, 1943; Naylor & Slinn, 1958), crevices (Glynne-Williams & Hobart, 1952; Morton, 1954; Kensler, 1964, 1965, 1967; Todd & Turner, 1986, 1988; Arístegui, 1987) have been less extensively studied (see also Lewis, 1964; Newell, 1970).

There is, in particular, very little published research on the ecology of littoral cave ecosystems. Norton *et al.* (1971) investigated the effect of light on organisms in a sea cave on Bullock Island, C. Cork, Eire. Harmelin (1983, 1985, 1986) described the distribution of sessile fauna (in particular bryozoan assemblages) in sub-littoral caves in the Mediterranean and found that the abundance and distribution of bryozoan species changed with distance into the caves, largely because of decreased light levels and water movement which in turn affected food supply and the degree of interspecific competition for space.

This study describes the patterns of distribution and abundance of sessile organisms on the wall of a limestone cave in the littoral zone on the north side of Barafundle Bay, south Pembrokeshire, Dyfed.

Many of the species found in littoral caves are more usually found on the lower shore or in the sublittoral zone or are associated with cryptic habitats such as crevices,

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over-hangs or the under-sides of boulders. Common cave dwelling organisms include barnacles, ascidians (sea squirts), sponges, serpulid tubeworms and encrusting bryozoans. All these groups are sessile filter feeders. Because of low light levels, algae are not abundant. The only algae represented in this study are encrusting calcified reds of the 'Lithothamnion' type.

The abundance and distribution of sessile organisms in this cave might be affected by abiotic factors such as light intensity, humidity/desiccation and temperature variation all of which gradually change with distance into the cave. Wave action and current intensity also change and, in turn, affect the degree of scouring by sand particles, the availability of planktonic food and the ability of larvae and spores to settle.

Any changes in fauna and flora with vertical height up the cave wall will be related to increasing period of emersion, as on open rock faces. The effects of scouring by sand and stones close to the cave floor might also be important.

MATERIALS AND METHODS

A small limestone cave in the lower shore was selected for this study (Plates 1 & 2). It is part of a series of caves and tunnels on the north side of Barafundle Bay (Fig. 1), most of which are easily accessible at low tide, especially during spring tide periods.

The cave floor is 2.7 metres above ELWS and consists of bed rock and sand.

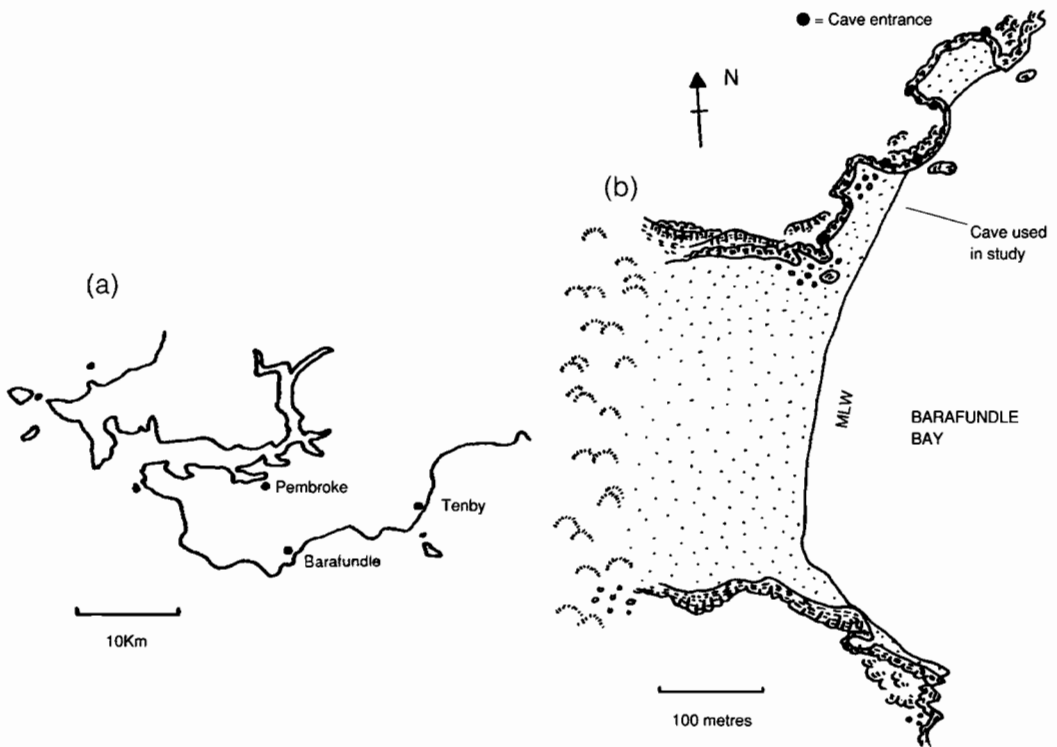


FIG. 1

(a) Map of South Pembrokeshire, Dyfed, Wales. (b) Map of Barafundle Bay (see OS map; Pembrokeshire sheet XLIII SW, 1: 10000 for more detail).

However, this height will change over a year as sand is deposited or removed from the beach by varying sea conditions. The cave is approximately 7 metres high from floor to roof and is 5.6 metres wide at its mouth. The main cave tapers back to a point 20 metres from the mouth. The main entrance faces in a south-easterly direction. There is a smaller entrance that enters the main cave about 15 metres from the mouth causing a fork. The left arm of this fork is a 1.5 metre wide tunnel that extends back another 25 metres (see Fig. 2).

The distribution and abundance of sessile organisms were studied on the right-hand wall of the main cave and on the left hand wall of the tunnel. Five basal stations were marked with non-toxic yellow marine enamel paint at three metre intervals back from the cave mouth. Each station was 3.3 metres above ELWST (measured using a 60 cm cross staff - see Quigley and Crump, 1985). Sampling sites were then marked at 30cm vertical intervals up the cave wall from each basal station. Depending on the ease of accessibility from the cave floor, between four and six sampling sites were marked vertically above each basal station. A total of 28 sampling sites were marked in the main cave. Four more basal stations (each with between five and seven 30cm vertical sampling sites) were then marked back into the tunnel (24 sampling sites in total). Station one in the tunnel and station five in the main cave were both 12 metres from the cave mouth.

A point sampling technique was employed to record changes in the distribution and abundance of species within the cave and tunnel. A 15cm by 15cm sheet of flexible transparent plastic, marked with 100 equidistant points, was placed over the cave wall at each sampling site. The species under each of the 100 points was identified and recorded. Because of overgrowth of one organism by another, more than one species could be recorded at a single point. An estimation of percentage cover for each species was then made for each sampling site. Where possible,

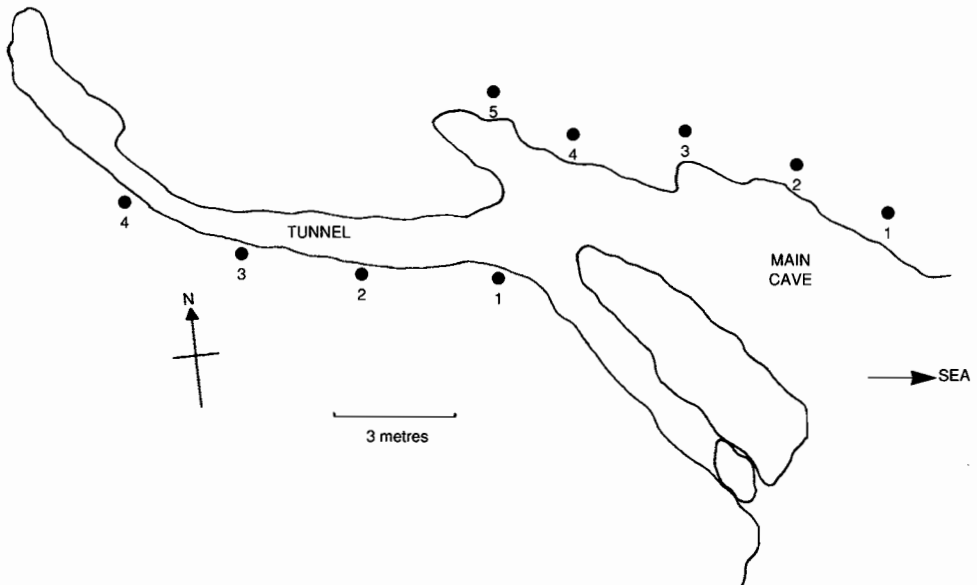


FIG. 2
Simplified ground plan of the cave system with numbered stations.

organisms were identified to species level, *in situ*, using a x10 hand lens. Samples of smaller species (e.g. bryozoans) were collected and identified in the laboratory using a stereo zoom microscope. This procedure was performed for all the sampling sites until the cave wall and tunnel wall had been mapped.

Species were identified using standard field guides (General: Barrett & Yonge, 1980; Fish and Fish, 1989. Barnacles: Rainbow, 1984. Bryozoans: Ryland & Hayward, 1977; Hayward & Ryland, 1979; Hayward, 1985. Serpulid tubeworms: Nelson-Smith and Gee, 1966; Knight-Jones & Knight-Jones, 1977. Ascidians: Millar, 1980). Because of taxonomic difficulties, no attempt was made to identify encrusting red algae to species level (see Hiscock, 1986). All colonies found have been recorded as 'Lithothamnion' type.

The floor of the cave gently slopes upwards so that although all the sampling sites for the first few stations fall within the middle shore (between the mean neap tide levels), some of the higher sampling sites in the tunnel are in the upper shore (above HWNT).

The cave was sampled on the 30th January, 1991, and the tunnel on the 14th February, 1991. Most of the organisms were assumed to be relatively permanent and long-lived. There were no major storms between the two sampling dates which might have altered the community structure.

It is recognised that some of the differences between sampling sites are caused by local differences in cave wall topography (e.g. aspect, gradient, number of crevices) or by freshwater seepage from the cave roof, rather than because of distance from the cave mouth or height above sea level. It is assumed that major distribution patterns will still be apparent despite these local differences.

RESULTS

The results of the survey are shown in Table 1 and Fig. 3. Table 1 shows the greatest percentage cover recorded for each species at each station. Fig. 3. shows changing patterns of distribution and abundance with distance into the cave system and with vertical height up the cave/tunnel walls for six of the commonest species. It can be seen that there are distinct changes in species composition with distance into the cave system.

The littoral barnacle, *Semibalanus balanoides* (L.), dominates at the mouth of the cave, as it does on open rock surfaces outside of the cave system.

At 3 to 6 metres from the cave mouth encrusting coralline red algae ('Lithothamnion' type) become abundant and *S. balanoides* becomes less common.

At the back of the main cave and into the tunnel encrusting bryozoans become the dominant fauna. Two species are abundant; *Cryptosula pallasiana* (Moll) and *Haplopoma graniferum* (Johnston). Both species are known to occur in cryptic habitats in the lower littoral zone (Hayward and Ryland, 1979). *C. pallasiana* is the most dominant bryozoan at the back of the main cave. In the tunnel, colonies of this species continue to be common but are mixed with the smaller more delicate colonies of *H. graniferum*, which becomes the dominant bryozoan at the deeper sampling sites in the tunnel. The encrusting bryozoan, *Flustrellidra hispida* (Fabricius), is also locally abundant toward the rear of the cave system. This species is usually found growing as an epiphyte on fucoid brown seaweeds in the lower littoral zone (Hayward, 1980, 1988).

Table 1. maximum percentage cover of each species for each station with distance into cave system.

Station no. Distance into cave (m)	MAIN CAVE					TUNNEL			
	1	2	3	4	5	1	2	3	4
Red algae; 'Lithothamnion'	0	52	77	5	0	15	0	0	0
Porifera; <i>Myxilla incrustans</i>	0	12	1	2	1	2	2	0	0
<i>Grantia</i>	0	0	0	0	0	0	0	0	1
Annelida, Polychaeta; <i>Pomatoceros lamarckii</i>	0	3	5	1	1	1	0	0	0
<i>Spirorbis rupestris</i>	0	2	1	10	0	0	0	0	0
<i>S. tridentatus</i>	0	0	0	1	84	13	51	49	52
<i>Circeis spirillum</i>	0	0	0	0	0	3	0	1	10
Mollusca, Gastropoda; <i>Patella vulgata</i>	4	4	1	0	0	0	0	0	0
Mollusca, Bivalvia; <i>Mytilus edulis</i>	0	0	1	0	0	0	0	0	0
Arthropoda, Crustacea; <i>Semibalanus balanoides</i>	96	81	68	74	2	80	37	2	0
<i>Chthamalus montagui</i>	4	0	0	0	0	0	0	0	0
<i>Elminius modestus</i>	0	0	5	6	0	0	2	0	0
<i>Balanus perforatus</i>	0	2	0	0	0	0	0	0	0
<i>Verruca stroemia</i>	0	0	0	0	35	48	31	5	3
Bryozoa, Gymnolaemata; <i>Cryptosula pallasiana</i>	0	0	0	56	100	6	29	0	12
<i>Haplopoma graniferum</i>	0	0	0	24	2	50	60	2	33
<i>Electra pilosa</i>	0	0	0	0	0	0	0	0	0
<i>Flustrellidra hispida</i>	0	1	0	6	1	11	6	1	0
<i>Alcyonidium mytilii</i>	0	0	0	0	0	0	0	0	3
Urochordata, Ascidia; <i>Dendrodoa grossularia</i>	0	0	0	0	22	11	1	0	3

Other less abundant but locally common species are also found in the middle regions of the cave/tunnel system. The barnacle *Verruca stroemia* (Muller) (see Barnes and Stone, 1973) is found toward the rear of the cave system. Elsewhere, this species is typical of the sublittoral zone. Some star barnacles, *Elminius modestus* (Darwin), are also found toward the rear of the main cave. This species is usually commonest on shores sheltered from wave action (Rainbow, 1984). The solitary ascidian *Dendrodoa grossularia* (van Beneden) (see Millar, 1954) is, also, locally very common. However, because of its very patchy and clumped distribution, its true importance might have been under-estimated in this survey.

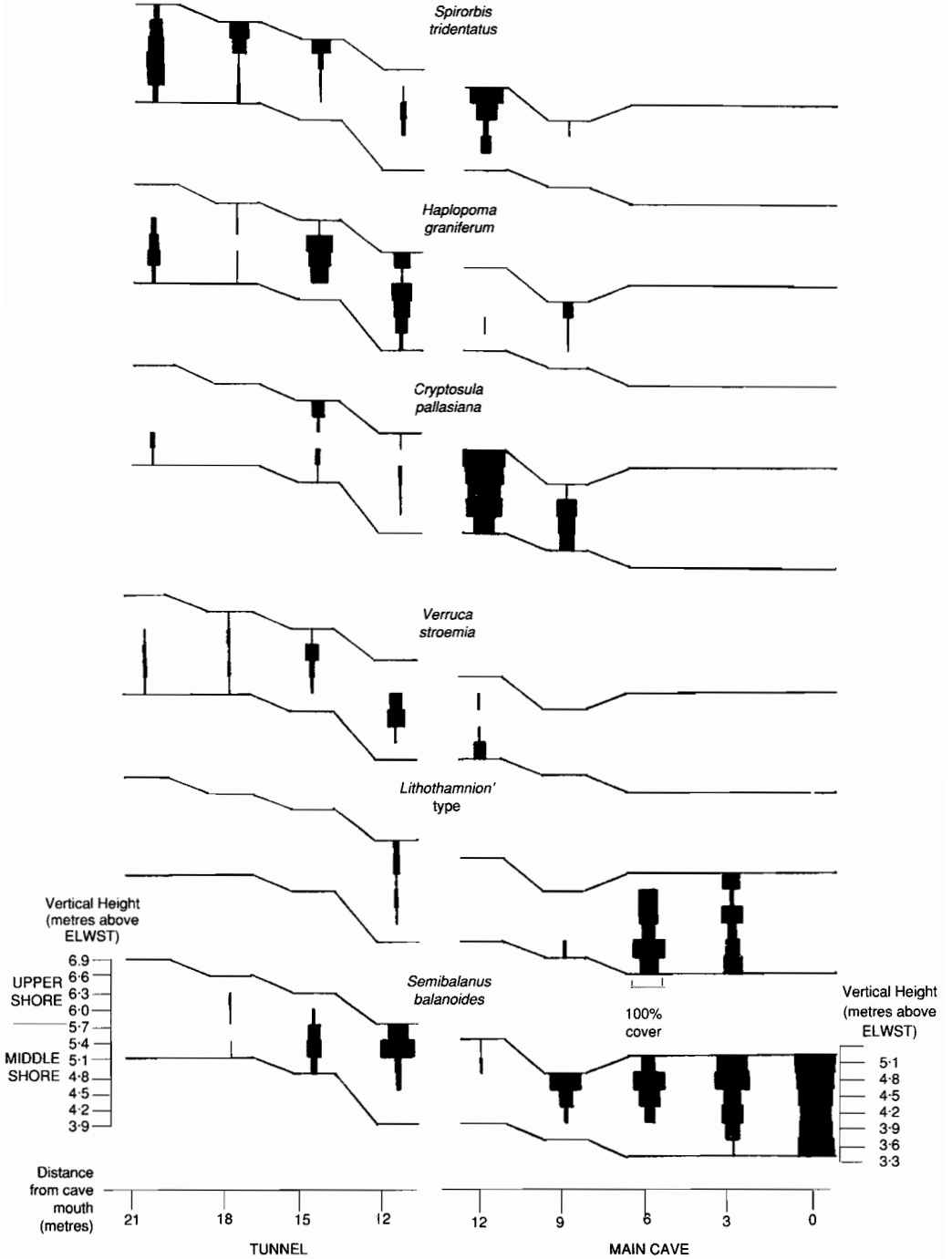


FIG. 3

Percentage cover of six common species at each sampling site with distance into the cave system and with vertical height up the cave/tunnel wall. At each station, the highest sampling site was determined by accessibility from the cave floor and the lowest sampling site by the height of the scour line.

Spirorbid tubeworms are also found in the middle regions of the cave/tunnel system and become the dominant fauna in the deepest part of the tunnel. Three species are found. Some *Spirorbis rupestris* Gee and Knight-Jones are found in the main cave. *Spirorbis tridentatus* Levinsen becomes abundant at the rear of the main cave and back into the tunnel. It is the dominant organism at the deepest sites (*i.e.* furthest from the mouth) sampled. Some individuals of the rarer *Circeis spirillum* (L.) are also found at the rear of the tunnel.

It can also be seen from the results that, although Station 5 in the main cave and Station 1 in the tunnel are at the same distance from the main cave entrance (approximately 12m), their species composition and abundance are notably different. At the rear of the main cave, the wall is dominated by *C. pallasiana* and *S. tridentatus*, whereas, at the tunnel entrance, these two species are rare and *S. balanoides* becomes relatively abundant again.

Differences in distribution also occur with vertical height up the cave wall, although these patterns are less obvious than the changes with distance into the cave. In the outer region of the cave 'Lithothamnion' type red algae are found close to the cave floor and *S. balanoides* at higher levels. In the middle region of the system *V. stroemia* is found near the floor and encrusting bryozoans at the higher sampling sites. In the depths of the tunnel bryozoans are found at the lower sites and spirorbids at the higher.

DISCUSSION

Many of the factors that cause zonation patterns in animal and plants on open, seaward-facing rock (*e.g.* desiccation, temperature variation, light levels, wave action, competition and predation) are also undoubtedly important in explaining patterns of distribution and abundance found within littoral caves. Their relative effects may differ, however, and other factors such as water movement patterns, scouring of the cave walls and lack of food supply might also be equally or more important.

On open rock, the stresses imposed on marine organisms by abiotic factors such as desiccation and temperature variations increase with vertical height up the shore. These factors are said to define the upper limits of the zones of many species. With distance into a cave, however, both these factors become more stable. Conditions become increasingly moist and cool. Therefore, many of the organisms that are dominant at the rear of the cave and tunnel, such as bryozoans, ascidians and spirorbids, are those more typically found in cryptic habitats on the lower shore or sub-littorally. The forward limit of these species might reflect their relative tolerance levels to desiccation and temperature variations (and possibly also to direct wave action).

The backward limit of species into the cave, conversely, might be linked to their relative abilities to survive low light intensity (*e.g.* algae), low food supply (*e.g.* filter feeders) and unusual water movement and currents, especially if associated with scouring effects. Because of these differing tolerances the growth rate and competitive ability of each species might peak at different distances into the cave system, hence causing the observed changes in dominance.

At the mouth of the cave the barnacle, *Semibalanus balanoides*, is dominant. It is well adapted to dry, exposed conditions (Rainbow, 1984) and colonises most of the

available free space. Although it does also penetrate some distance back into the cave, other species, such as the encrusting coralline red alga 'Lithothamnion' and encrusting bryozoans, soon become more abundant. These species might only be able to outcompete *S. balanoides* for space and/or food when conditions become cooler and wetter.

'Lithothamnion' for instance, is usually found on the lower shore, sub-littorally or in wave exposed rock pools (Fish and Fish, 1989). It is well adapted to low light levels, but cannot survive high levels of desiccation. Although it is too dry for it at the cave mouth, several metres into the cave it is able to survive and grows well on any surfaces not colonised by barnacles. Further back, light levels and hence 'Lithothamnion' growth rate decrease. Any colonies that do establish would probably be overgrown by encrusting bryozoans.

Such differences in distribution could be further enhanced by differential larval/sporeling settlement abilities. Many cryptic or sublittoral organisms, such as bryozoans, have larvae that show strongly negative phototaxis just before metamorphosis (e.g. see Ryland, 1976), which may cause them to settle further from the cave entrance.

Most of the fauna in the cave system are filter feeders. It might be that less planktonic food is available further from the cave mouth, either because it is depleted by barnacles at the cave mouth (Buss and Jackson, 1981) or because much of the plankton displays positive phototaxis. Because bryozoans, ascidians and spirorbids are all passive filter feeders, they might need less planktonic food than more active filter feeders, such as barnacles, and hence can survive further back into the cave.

Toward the rear of the cave system, there is a difference in distribution between the two common encrusting bryozoan species, *C. pallasiana* and *H. graniferum*. There is no detailed information on the ecology of these two species, but again differences in larval behaviour, desiccation/temperature tolerances and feeding abilities are probably important in causing the different patterns of distribution.

Spirorbids might be even more tolerant to low food levels and more negatively phototactic than the bryozoans, which would explain their dominance at the rear of the tunnel. *C. spirillum*, for instance, is usually found sublittorally at depths of 10 metres or below (Knight-Jones & Knight-Jones, 1977).

A further complicating factor, toward the rear of the cave/tunnel, is freshwater run off from faults in the roof. It was observed that the, usually epiphytic, encrusting bryozoan *F. hispida* seems to be particularly successful on regions of rock with freshwater seepage on them. This species is apparently tolerant to some degree of salinity reduction, as colonies living on middle shore fucoids on the open shore will be affected by rainfall at low tides.

Spirorbids might also be tolerant of low salinity. The *Spirorbis* spp. recorded in this study have both been found living high up estuaries (Nelson-Smith & Gee, 1966).

One major discrepancy observed in the results occurs between the last station in the main cave and the first in the tunnel, despite these both being equidistant from the main cave entrance (see Fig. 2). This disparity might be a result of different hydrological patterns on the two sides of the cave system. The tunnel entrance is probably affected by the proximity of the smaller cave entrance which may increase the availability of larvae, spores and planktonic food, hence explaining the abundance of *S. balanoides*. Light levels also appear to be slightly higher than at the rear of the

main cave hence allowing '*Lithothamnion*' to re-establish. Such discrepancies emphasise how important local differences in abiotic conditions can be in determining species distribution and abundance.

Vertical changes in species composition up the cave/tunnel walls will partly result from increasing periods of emersion with height above low water, as on open rock. Within a cave, the effects of desiccation and temperature variation are much reduced, however, and the degree of scouring, especially in bad weather, could, therefore, be an equally important influence on vertical zonation patterns. Sand, stones and boulders will abrade and scour the cave walls, especially at the lower sampling stations '*Lithothamnion*', the large serpulid tubeworm, *Pomatoceros lamarckii* (Quatrefrages), and the barnacle, *V. stroemia*, all tend to colonise the lower sampling sites. Possibly, all of these species are well adapted to either surviving abrasion or coverage by sediment and/or they tend to be early colonisers of space created by abrasion (Nelson-Smith and Gee, 1966; Adey and Adey, 1973).

The effects of scouring may also lead to the differences in distribution observed between encrusting bryozoans and spirorbids with distance into the tunnel. Water will be channelled into the restricted and gradually narrowing tunnel, especially during storms, causing extensive scouring of its walls. Some spirorbids are able to survive scouring and abrasion. *S. tridentatus*, for example, is known to be abundant in sand-scoured habitats (Knight-Jones & Knight-Jones, 1977). Conversely the more delicate bryozoans might easily be destroyed by this process.

CONCLUSION

The explanations proposed for the patterns of distribution and abundance found in this cave system are only tentative. Greater knowledge is needed of temperature/desiccation survival abilities, larval dispersal, larval settlement abilities and minimum feeding times of all the species. Measurements should also be taken of decreasing light levels, increasing humidity, decreasing temperature and changing water movement patterns with distance back into the cave system. The study could be repeated at Barafundle (and elsewhere) in other caves and tunnels of different depths, sizes, aspects and shapes and at different heights on the shore.

The patterns described in this study are important as a teaching resource, especially as a comparison with patterns that occur on open rock and in other environments within the littoral zone. An investigation of cave fauna is also useful, because many of the phyla present are usually only found in inaccessible cryptic and sublittoral habitats. They are, therefore, often neglected despite their overall importance in the rocky shore ecosystem.

At an undergraduate/postgraduate level, the caves at Barafundle offer a wealth of opportunities for further studies and individual projects. As well as descriptive work similar to that performed here, the distribution of the common cave species in relation to their niche requirements could be investigated. Because sessile marine species are often very small, they respond to fine grain differences in a heterogeneous environment. For example, a species may thrive equally as well at 15 metres depth on a kelp holdfast as it does at the back of a cave in the upper shore (e.g. *C. pallasiana*). The existence of such a diversity of microhabitats (all fulfilling the species niche requirements) is especially important when considering interspecific competition. Often, a single population is in apparent competition with completely different

assemblages of species in different parts of its range (Ward, 1988, 1989). This has important implications when considering the effect of interspecific competition on the evolutionary ecology and niche partitioning of species.

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