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Monitoring rocky-shore communities: a critical look at spatial and temporal variation

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ABSTRACT: Increasingly programmes are being set up to monitor rocky-shore communities in order to provide baseline data which will indicate changes resulting from subsequent pollution. However, these efforts are complicated by several factors. Firstly, there are overall changes in the composition of communities both within and between years. Secondly, there is variation within certain communities due to a mosaic distribution of components, the mosaic format changing continuously with a cycle of several years. This paper reports on studies of a medium-exposed rocky shore in the Isle of Man (U. K.). It describes patterns of spatial and temporal variation, and looks at certain implications for monitoring programmes: (a) the frequency of sampling, and the duration of the sampling programme, in the light of seasonal and long-term variation; (b) the efficiency, in terms of the minimisation of variability, of sampling the same area by different strategies – belt transects, small random quadrats, single large quadrat; (c) the effect of the distribution patterns of some commoner species on the variation between samples.

INTRODUCTION

The constantly increasing risk of marine pollution has generated a need to assess its effects at the whole community or ecosystem level. It may be necessary to determine whether the insidious effects of chronic pollution are manifest in a given area, or to measure the gross effects of a clearcut case of acute pollution. In either event the basic strategy is the same: to measure selected components of the community structure under natural conditions, and then hopefully to discriminate the changes produced by man-induced environmental disruption. Rocky shores are a favoured medium for this type of study, because they are accessible, can be non-destructively sampled in fixed areas, and present lesser taxonomic problems than most alternative environments. Some of the problems inherent in monitoring are discussed in this paper with reference to rocky shores, but it is to be anticipated that the same strictures will apply in greater or lesser degree to other littoral and sublittoral communities.

If the rocky-shore communities were spatially homogeneous, and did not change with time, then it would be relatively simple to define the unpolluted condition, and to assess man-induced change. However, the very property which commends these communities for monitoring work, namely the ease of observation of the major species, ensures that the frequent departures from a constant state are particularly evident. Rocky shores exhibit a high level of spatial and temporal diversity, and this greatly complicates the detection of further variation superimposed by pollution.

Spatial pattern exists at two levels. On the larger scale there are changes due to the

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two major environmental gradients, a vertical gradient of emersion in air, and a horizontal gradient of intensity of wave action. At any point in this environmental matrix there will still be considerable heterogeneity on a smaller scale, as illustrated in Figure 1. This patchiness will be partly due to variation in microhabitat, and partly due to biological interaction between species. The former will promote a static patchiness, the latter a mobile one, a distinction which has important consequences.

Two forms of temporal variation occur. Firstly, there are changes in the overall composition of the community, which can properly be referred to as "community change". Secondly, there is redisposition of the community components without change in the overall composition, and this can be distinguished as "mosaic recycling". Community change may be seasonal, due to more or less regular annual changes as a result of mortality, recruitment, growth and behaviour patterns. It may be a long-term trend continuing over a period of years, often attributed to climatic trends. Or it may be quite irregular, sometimes clearly due to abnormal weather conditions, but often of obscure origin: in many cases the proximate cause is direct biological interaction. Mosaic recycling occurs in situations where patchiness is directly maintained by biological interactions, often prompted by changes in intensity of interaction due to the fluctuating environment.

Examples of spatial and temporal variation will be presented in the next section, after which their implications for monitoring procedures will be discussed.

EXAMPLES OF VARIATION

These examples are taken from a continuing study of a medium-exposed shore at Port St. Mary in the Isle of Man.

Spatial pattern

The large-scale changes in community pattern in response to the emersion and wave-action gradients are phenomena so well documented (Southward, 1958; Lewis, 1964; Stephenson & Stephenson, 1972) as to need no further description here. In contrast the small-scale heterogeneity, although widely recognised (Connell, 1972), has received limited quantitative investigation (Dayton, 1973), and it is on this that attention will be concentrated. An almost horizontal area of 5 m by 4 m was selected, located in the *Fucus vesiculosus* zone, and within which the effects of the environmental gradients are hopefully negligible. This was surveyed using a grid of 0.5 m contiguous quadrats, recording either the number or percentage cover of selected organisms in each quadrat. The results for the three major components of the community are plotted in Figure 1. The degree of patchiness is conveniently assessed by the coefficient of variation ("V")- standard deviation × 100/mean. For the 80 half-metre quadrats this is highest for *Fucus vesiculosus*, less for *Patella vulgata*, and least for *Balanus balanoides.* The scale of patchiness can be investigated by looking again at the same data, but this time as twenty one-metre quadrats (Fig. 1). For *Fucus vesiculosus* the coefficient of variation is reduced, but still quite high, indicating that the basic patch size is greater than one square metre. For *Patella vulgata* the variation is reduced to a low level, suggesting a patch size of the order of a square metre. For *Balanus balanoides* there is little reduction in variation, so any patchiness must be at a scale of less than a quarter square metre, or else appreciably more than a square metre. Clearly there are major inter-specific differences in both the extent and scale of patchiness, and it is almost certain that these will also vary within a species both spatially and temporally. There is scope here for further investigation.

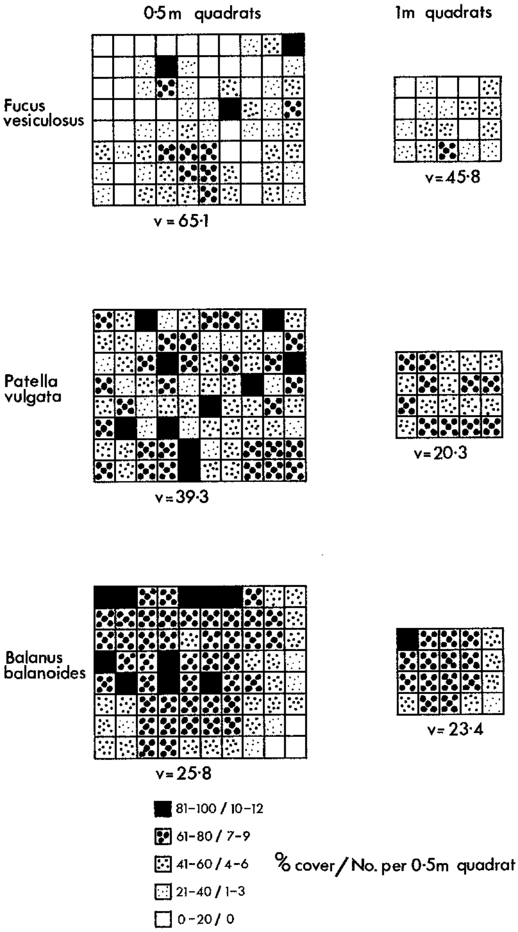

Fig. 1. Percentage cover of *Fucus vesiculosus* and *Balanus balanoides*, and number per quarter square metre of *Patella vulgata*. All diagrams of the same 5 m by 4 m area in the *Fucus vesiculosus* zone of a medium-exposed shore at Port St. Mary, Isle of Man

Temporal variation

Temporal changes have already been extensively documented, and good examples are presented by Jones et al. (1979a) and Lewis (1977). Some further instances of the three basic types of community change have been abstracted from our data, based upon the monitoring of 2 m by 1 m fixed quadrats at the shore levels detailed in the legends to the figures. Seasonal changes (Fig. 2) occur for a variety of reasons. In *Fucus serratus* there is the loss of fronds in winter, followed by regrowth from existing plants in late

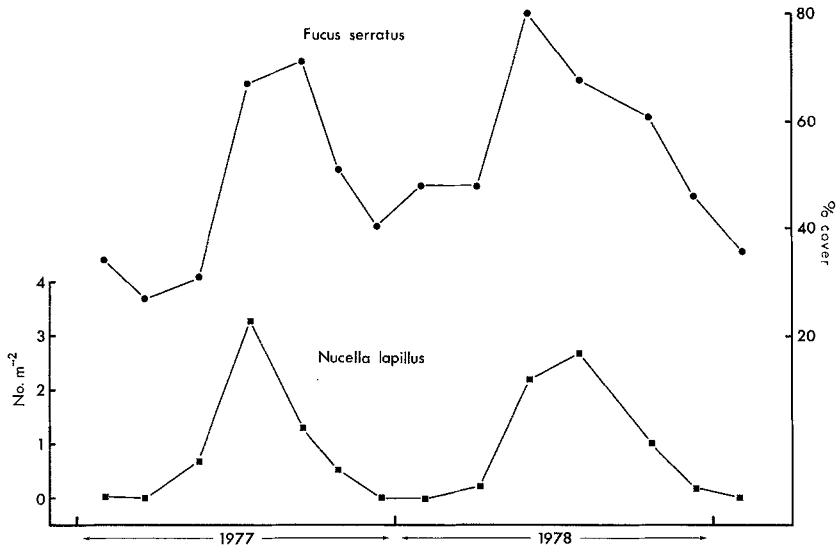

Fig. 2. Examples of seasonal variation: percentage cover of *Fucus serratus* on the low shore and number per square metre of *Nucella lapillus* on the mid-shore

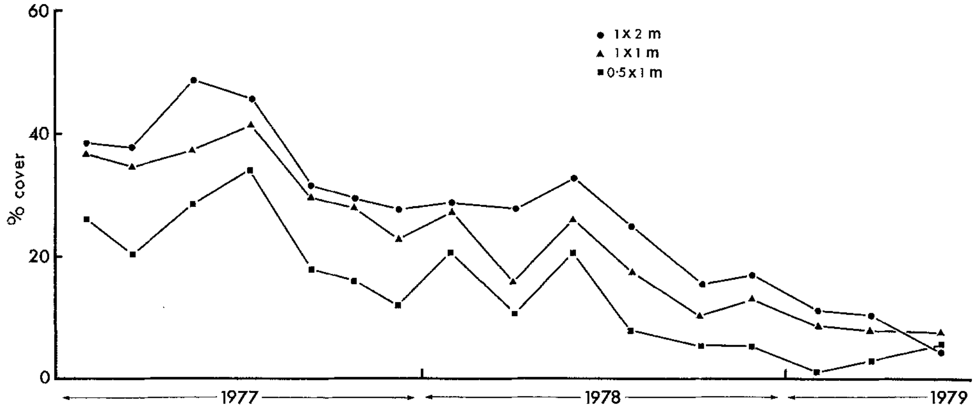

Fig. 3. Examples of long-term trends: percentage cover of *Fucus vesiculosus* on the mid-shore and *Balanus balanoides* on the low shore

spring and summer (Knight & Parke, 1950), so that the summer cover is about 250 % of the winter level. The changes in *Nucella* (Fig. 2) reflect its behaviour: in winter it shelters in crevices, only appearing on the open survey areas during the summer. Examples of trends extending over a period of two and a half years are given in Figure 3, and in *F. vesiculosus* the long-term decline is overlain by a pattern of seasonal fluctuation. The possible causes of these trends are obscure and complicated, and need not be discussed here. Irregular changes are illustrated in Figure 4, and these clearly demonstrate the major unpredictable variation which can occur under natural conditions. The fluctuation in the cover of ephemeral algae is particularly striking.

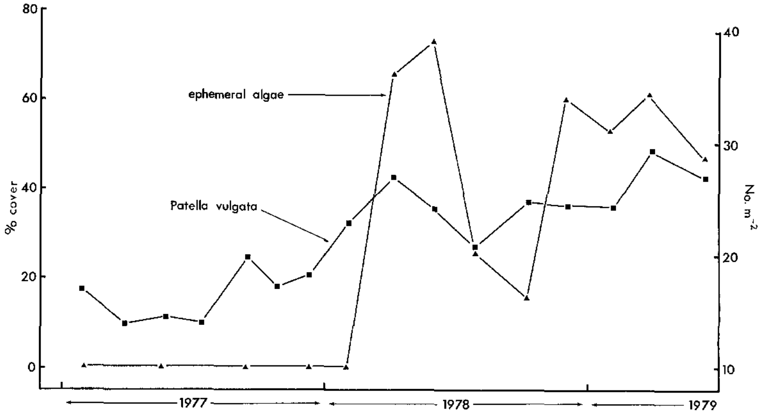

Fig. 4. Examples of irregular change: percentage cover of ephemeral algae within the *F. spiralis/F. vesiculosus* boundary zone and number per square metre of *Patella vulgata* on the low shore

The concept of mosaic recycling on medium-exposed rocky shores has been discussed by Burrows & Lodge (1950) and by Southward (1964), and the duration of the cycle appears to be several years. However, detailed studies under natural, as opposed to experimental conditions, are lacking. Our investigations of this phenomenon are not yet ready for presentation.

IMPLICATIONS FOR MONITORING PROCEDURES

The various forms of variation which have been described have important implications for rocky-shore monitoring, in relation to both the frequency of sampling and the sampling format. This is clearly so not only where the aim is to determine a baseline against which pollution effects can be assessed, but equally so where the intent is a purely academic one of community description. Ecological surveys in general have tended to pay scant attention to the uncertainties inherent in the data, in contrast to the sometimes obsessive attention to confidence limits in experimental studies.

Implications of temporal change

The implications for sampling frequency will be discussed first, and quite briefly since they have already been thoroughly considered elsewhere (Lewis, 1976). Single surveys are clearly of very limited value, since they will provide no indication of the extent and nature of the background variation. Surveys need to be made a number of times during the year in order to reveal the pattern of seasonal variation – two-monthly intervals are perhaps sufficient. Currently there are monitoring programmes sampling as, or more, frequently than this (Jones et al., 1975; Myers et al., 1978). More frequent sampling runs the risk of counterproductivity, firstly in terms of reduced return for effort, and secondly because of the real danger that frequent sampling will itself modify the community structure. Fletcher and Jones (1976) and Jones et al. (in press) have noted damage due to trampling in areas sampled monthly, and we have noted severe effects in areas studied at frequent intervals to record barnacle settlement. Surveys also need to be made over a period of years, firstly to see whether seasonal cycles are consistent, and secondly to see if there are superimposed longer-term trends. Various studies indicate that these trends may have a period of ten to twenty years (Southward, 1967; Southward et al., 1975; Jones et al., 1979b). Even after a prolonged survey there is no certainty that the full range of natural variation has been recorded, and the imponderable risk remains that major unforeseen changes may occur due to such factors as freak weather conditions. As Lewis (1976) and others have pointed out, the extent and unpredictability of natural temporal variation means that subtle pollution effects are clearly going to be difficult to detect, and that the provenance of even gross effects may be subject to confusion. Bowman (1978) cites a salutory example of community changes coincident with a pollution incident, but which were in fact a response to unusually hot weather conditions. The sudden increase in ephemeral algae in Figure 4 has the hallmark of a pollution response (see Southward & Southward, 1978, for examples), but is a purely natural change probably related to the breakdown of the fucoid canopy, as *Patella* numbers remained stable during this period.

The degree of temporal variation differs between species and between communities, and it may be possible to increase the effectiveness of monitoring programmes by concentrating upon those which display least variation. Lewis (1977) points out that stability is higher on sheltered than exposed shores, and on exposed shores is higher with increasing level. This could argue for the use of the upper shore in exposed conditions, or for the use of sheltered rather than exposed shores. However, the dense algal canopy of sheltered shores makes accurate non-destructive survey difficult, and the canopy is itself prone to damage as a result of repeated handling. Thus there is not a case for concentration on sheltered shores, although the high pollution risk of many such areas means that they must nevertheless be monitored.

Implications of spatial pattern

Spatial variation, in particular patchiness, means that the sampling format adopted has an appreciable effect upon the accuracy of the results. There are a number of variables to consider: (a) Should subjective or objective survey methods be adopted? (b) Should the sample areas be fixed, or randomly relocated on each occasion? (c) What shape should the sample area have? Should it be contiguous or of discrete units? What size should the sample units be? (d) How large should the sample area be?

The first decision is between the subjective approach of the belt-transect/abundance-scale method, and more rigorous but more restricted quantitative approaches. The former involves assessing the abundance of selected species in a broad vertical band up the shore according to a scale of abundance with five to seven classes, as is detailed by Ballantine (1961), Moyse & Nelson-Smith (1963) and Nelson-Smith (1979). This has the advantage of counteracting small-scale spatial heterogeneity, but is highly affected by operator bias. In what are essentially long-term projects this subjectivity is an unacceptable restriction. It is necessary to turn to strictly defined quantitative approaches where operator bias is minimised, even though this introduces its own problems. The use of restricted sample areas involves the risk that they are not representative of the community, a matter considered below in some detail. The non-destructive sampling of some organisms has to be done in terms of percentage cover rather than number, and it is not simple to do this accurately (Jones et al., 1975).

Given that defined sample areas are to be used, they can either be permanent for the duration of the study, or randomly relocated on each survey. The use of permanent areas has several advantages: it speeds up the sampling process on occasions subsequent to the first, it eliminates the variation from clinal and microhabitat change, and provides a bonus in the form of records of sequences of change in defined areas. There are disadvantages, for as already mentioned repeated sampling might itself affect the areas, and if the areas are inadequate they may not represent the community as a whole. Either they may lie in unrepresentative microhabitats, or else they may falsely record changes in mosaic pattern as changes in the overall community composition. However, these last problems might equally arise from the use of non-permanent areas of inadequate extent. The benefits of non-permanent random areas are the avoidance of sampling damage, and the opportunity for more comprehensive statistical analysis: these are not sufficient to compensate for the increased labour and additional uncertainty introduced. Most current monitoring programmes do use permanent sampling areas.

Table 1. The coefficient of variation between samples of different format taken from the data in Figure 1. Each sample was randomly located, and consists of four half-metre quadrats. Twenty samples of each format were taken

Genus	Vertical column	Horizontal row	Square block	Discrete quadrats
Fucus	39.5	44.4	51.0	25.1
Patella	19.1	16.9	20.5	17.6
Balanus	16.6	16.0	21.6	10.8

The shape of the sample area may be influenced by the need to accumulate data for purposes other than monitoring, such as on community structure and interaction, and this may necessitate a sampling strategy which is less than optimal for monitoring. The question of shape can be examined by referring to Figure 1, which can be regarded as a community to be sampled, in that it is large enough to be representative of that position in the environmental matrix, but small enough to minimize clinal effects. The same area may be sampled as a vertical band (such as part of a vertical belt transect), a horizontal band, one large quadrat or a series of discrete smaller ones. The results of such a sampling exercise are seen in Table 1: twenty samples, each composed of four half-metre quadrats, were randomly selected according to each of the four formats. The coefficient of variation for the twenty samples of each format was calculated. The tendency is for the single large quadrat to display most variation, the samples composed of discrete smaller ones the least. This is an inevitable consequence of a patch size larger than the unit sample size. So the commonly adopted sampling format of a continuous vertical series of quadrats – a belt transect – is not the best from the aspect of sample variation. It offers some compensation in that it gives a clear indication of vertical species limits, although these may apply only to that transect, and not to the whole community. The other drawback of the vertical transect is that the quadrats are distributed along an environmental gradient. If that gradient is shallow, then it may be realistic to determine abundances from groups of contiguous quadrats, making the assumption that the gradient is ineffective over that distance. If the gradient is steep this becomes less acceptable, and an additional source of variation will be introduced. An optimal strategy might seem to be to work a series of stations at appropriate vertical intervals, at each station establishing a number of discrete randomly-selected permanent quadrats. However, practical considerations must be taken into account. The labour involved in marking discrete quadrats, and the problems in relocating them, are both higher than in contiguous sampling formats: for these reasons the increased variation inherent in the latter may be acceptable.

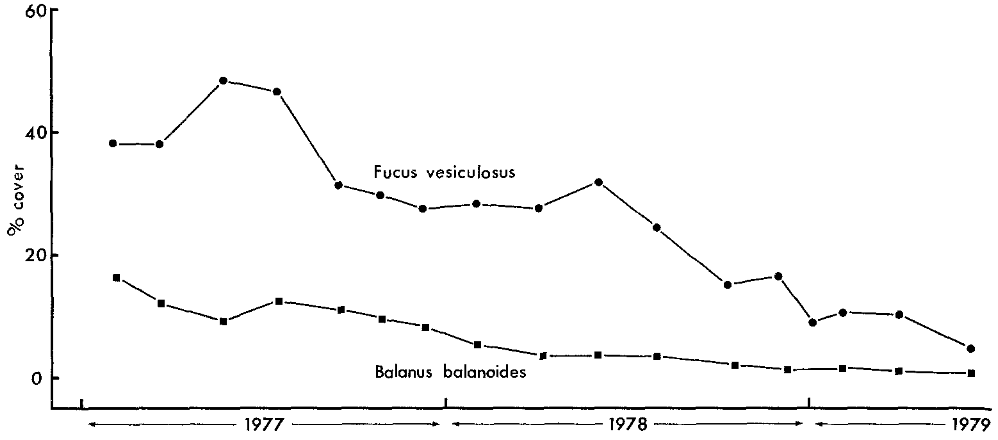

Fig. 5. Percentage cover of fucoids on the mid-shore plotted for increasingly larger components of the 2 m by 1 m quadrat

Whatever the sampling format, it must consist of sample units of a particular size. This must be small enough to allow examination without trampling it, or the immediately adjoining area, yet large enough to make its marking and relocation practicable. The half-metre quadrat has been a favoured size (Jones et al., 1975; Myers et al., 1978) and it is generally an excellent compromise. However, it has drawbacks for algae once the frond length becomes of the same order as the quadrat size, since the direction in which the algae are lying can determine to a large extent the proportion of the quadrat covered. In Figure 5 the percentage cover of fucoids in a fixed quadrat of 1 m by 0.5 m is recorded over 2½ years, as is the cover when the area is enlarged by the inclusion of contiguous quadrats: the irregular fluctuation for the small area is due to this frond effect. For large algae a quadrat size larger than a half-metre is indicated.

The total area (i. e. number of quadrats) sampled at each station in order to estimate overall abundance will to a large extent be governed by practical limitations, but it is instructive to have some idea of the confidence which can be placed in the results. This is not easily done, for there are considerable problems when calculating confidence limits for contiguous distributions, and strictly speaking appropriate transformations should be applied before doing this. Techniques for handling data in terms of number per sample are comprehensively discussed by Elliott (1977), but there is not a clear concensus as to the best methods for data expressed as biomass or percentage cover. Various North

American workers (e. g. Menge, 1976) have used the arcsine transformation as recommended by Sokal & Rohlf (1969) for proportional or percentage data. However, since percentage cover can be regarded as a direct measure of abundance rather than a proportion, this transformation may not be necessary. The whole problem of the statistical treatment of samples from patchy communities requires further attention, and would be an important aid to sound ecological practice. In view of this uncertainty attention here has been limited to a brief analysis of the untransformed data in Figure 1. The arcsine transformation has greatest effect on values over 70 %, so even if used its effect on this data, mostly in the range 30–70 %, would be limited. A sample format of discrete half-metre quadrats has been assumed: a contiguous format would increase the uncertainty. Quadrats were randomly selected, and the mean and standard error of the mean calculated for cumulative numbers of quadrats up to twenty (Table 2), which provides an indication of the precision of the sample (Elliott, 1977). The species differ, and obviously to provide the same degree of precision many more samples of some would be required than of others. From this a case might be argued for sampling more quadrats for some species than for others, but this rests upon the dangerous assumption that the degree of patchiness remains fairly constant for each species. This is certainly not the case: as an example, the area in Figure 1 was virtually free of *Fucus* two years prior to this survey, and exhibited minimal patchiness.

Table 2. The mean, standard error (SE) of the mean, and standard error as a percentage of the mean, for cumulative numbers of randomly selected half-metre quadrats from the area in Figure 1

	Fucus cover			*Patella* number			*Balanus* cover		
No. of quadrats	Mean	SE	*SE × 100* mean	Mean	SE	*SE × 100* mean	Mean	SE	*SE × 100* mean
2	56	27.5	49	5.5	1.49	27	73	7.5	10
4	43	13.4	31	6.5	0.87	13	69	4.3	6
6	37	9.5	32	6.3	0.96	15	70	4.3	6
8	30	8.4	28	5.6	0.88	16	71	3.5	5
10	31	6.8	22	6.3	0.83	13	73	3.4	5
12	32	5.6	18	6.4	0.69	11	74	2.9	4
14	28	5.3	19	6.3	0.60	10	75	2.6	4
16	30	5.0	17	6.3	0.59	9	74	2.3	3
18	34	5.4	16	6.4	0.60	9	71	3.5	5
20	33	5.1	15	6.3	0.59	9	69	3.4	5

CONCLUSION

It has not been our aim to define the way in which monitoring programmes should be carried out – that would be presumptuous in the extreme. The precise aims of a programme, and practical limitations, must be taken into account and may well be paramount. What we have tried to do is to highlight some of the sources of uncertainty inherent in any monitoring exercise, and suggest ways in which some of these might be reduced. Where resources are limited, the concentration of effort by sampling larger areas at a reduced number of stations is strongly indicated. The rocky intertidal clearly has great inbuilt spatial and temporal variation: whether pollution effects other than the most gross can be detected against this background noise remains to be seen.

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