and between the stones is obviously desirable. Direct observation shows that a very high proportion of the individuals of many species are normally living below the stones where they are hidden from view. For *Potamopyrgus,* for example, about one per cent. of the individuals are visible at any one time; the rest are hidden beneath the stones. Even more extreme are the parnid larvae; not a single specimen of these has been seen under natural conditions during this work although areas containing in the aggregate several thousand specimens have been watched.

Another factor which may sometimes be of importance in the distribution of the fauna is the previous history of the area. Disturbance of the bed prior to the time of observation by floods and other causes may have greatly reduced the fauna. In June 1958 a sharp rise of about one foot in the Horokiwi stream disturbed much of the bed in the centre where the current was most rapid but had little effect near the banks. A series of samples was taken about a week later. In one subseries close to the bank in undisturbed conditions the total number of animals ranged from 1,374 to 2,115, but in the other subseries near midstream the range was from 31 to 105. Such marked variations are normally only temporary and, if stable conditions follow, a return to the more usual degree of variation soon takes place.

Finally, it should be noted that, the degree of variation among selected similar samples is much too great to be due purely to random effects and if it is not due to unidentified environmental factors the behaviour of the animals must be involved. A purely random distribution would tend to follow a Poisson series and its variance would be about equal to its mean. In the series so far studied the variance has always been very much greater, often 20 to 40 times the mean.

The Sampling Problem in Benthic Ecology

Alan R. Longhurst

The importance of the role of benthic invertebrates in the bionomics of demersal fisheries is very considerable for it is almost entirely through their agency that the demersal fish are able to utilise as food the organic material in the deposits of the continental shelves (Longhurst, 1958a). Yet quantitative ecology of the benthos lags far behind that of the plankton, in a ratio that seems disparate with the bionomic—and certainly with the economic—importance of the two subjects; it is fairly clear that the reason for this relative neglect lies in the nature of the material and the difficulties inherent in an assessment even of an instantaneous standing crop. The benthic fauna is buried in, or attached to, a substratum of varying consistency into which the gear must make uniform bites; the individual organisms are arranged patchily, both on a large and on a small scale; they may be extremely divergent in size and so sparsely distributed that much time will be expended in obtaining sufficient numbers for statistical treatment. The comparisons between this and a plankton sample with quantitative gear are so obvious as to need no enumeration.

To overcome these difficulties a great variety of grabs and dredges have been designed since Petersen (1911) introduced the first quantitative gear; none appears to be entirely satisfactory, but the later modifications of the Petersen grab, such as those designed by van Veen (Thamdrup, 1933) or Smith and MacIntyre (1954) are probably the best instruments available for quantitative work—in time they will doubtless be replaced by a corer of some sort, but a satisfactory type has yet to be designed and proved at sea. With proper design of the bucket and with adequate weight good results may be had with a grab provided its shortcomings are recognised and the validity of the samples analysed.

Unfortunately, the sampling characteristics of grabs are not yet satisfactorily understood, nor have there been adequate comparative trials at sea between one grab and another, though Ursin (1954), Thamdrup, Smith & MacIntyre, and Birkett (1958) have produced preliminary data; Holme (1953) and Jones (1957) have recorded data on the cumulative curves for recruitment of species to samples using scoop samplers and van Veen grabs respectively.

During a recent benthos survey on the West African shelf (Longhurst, 1958b) the sampling characteristics of van Veen and Smith grabs, each covering $0.1m^2$, were investigated to determine the number of hauls needed to obtain a valid sample of the population at each benthos station; the results of these trials appear to be of some interest and are discussed here in relation to what is already known of the characteristics of grab samples.

Three statistical stations were worked; these were:—

A. in shallow water of the Sierra Leone estuary, on soft muddy sand, van Veen x 10.

B. off Sierra Leone in six fathoms, on dark grey shelly mud, Smith x 20.

C. off Sierra Leone in 10 fathoms, on shell-sand, Smith x 20.

At the first two stations each sampling unit consisted of a full grab and the instrument bit to its full depth on each occasion; when it did not, the haul was discarded.

Quantitative grab sampling is, in principle, very similar to the quadrat method of plant or soil ecologists, but differs in two important aspects; firstly, complete enumeration of the organisms is scarcely possible, since not all are on the surface of the soil, and secondly, the problems of randomisation of the actual quadrat sites do not obtain at sea where the only difficulty is to keep them close to each other, and in a constant relationship with a marker buoy.

The variation between hauls (sampling units) at each station (sample) has two sources —the patchiness of the fauna on the deposits and the inefficient replication of the sampling technique. Ursin (op. cit.) has shown that the increasing skill of deckhands in working the van Veen sampler is reflected in the rising efficiency of the gear, which depends for its efficiency on the force with which it is dropped on to the deposits, its alignment in relation to the deposit surface, and the manner in which it is broken free. However, in the shallow water in which the grab was used in this survey this factor is not of importance, for elimination of it in the Smith sampler by the incorporation of twin trigger plates and the helical springs which alone drive the bucket into the deposits did not, in fact, produce greater replication between sampling units. The variation observed in the statistical stations may be considered, then, to be due only to the irregularities in the distribution of the fauna.

There is normally less variation between sampling units for the values of the gross faunal indices — biomass, numbers of species and individuals per unit area—than there is between the numbers of individuals of each species, since the distributional patterns of individual species do not necessarily coincide; this is illustrated by the values for the coefficient of variation $\left(V = \frac{100\ S.D.}{\overline{X}}\right)$ in the following table.

Stations		A	B	C
Sampling Units (N)		10	20	20
Species/sample	— $\overline{X}$	19.70	12.60	17.20
	— V	8.93	19.83	20.43
Individuals/m^2	— $\overline{X}$	140.60	32.60	40.60
	— V	34.42	27.85	14.60
Biomass (gm/m^2)	— $\overline{X}$	2.71	5.16	2.01
	— V	29.80	39.50	42.64
Mean Value of V for faunal indices	—	24.38	29.06	25.89
Mean Value of V for ind/m^2 of individual species	—	67.03	155.29	192.30

TABLE 1.—*Coefficient of variation for faunal indices and individual species*

There is an indication in these results that there may be value in the faunal indices as a quick overall measure of the density of the fauna on a particular ground, although it must be recognised that faunas with widely divergent ecology and constituent species may give similar values for biomass, or species and individuals per unit area.

From an analysis of the recruitment of species and individuals to the sample total at each successive sampling unit it is possible to derive some information both about the composition and distribution of the fauna and about the sampling characteristics of the gear being used. From the results of the statistical stations it is possible to take this analysis a little further than those of Holme and Jones.

The population structure at each station was composed—in accordance with expectation — of a very small number of exceedingly abundant species and a very much larger number of increasingly rare ones; the categories containing the greatest number of species were those with one, or at most two, occurrences per station (Fig. 1). The species are clearly arranged according to the principles investigated by Williams (1949) and others, forming a modified logarithmic series in relative abundance. In each case a very few species constitute a very high proportion of the total number of individuals in the sample:—

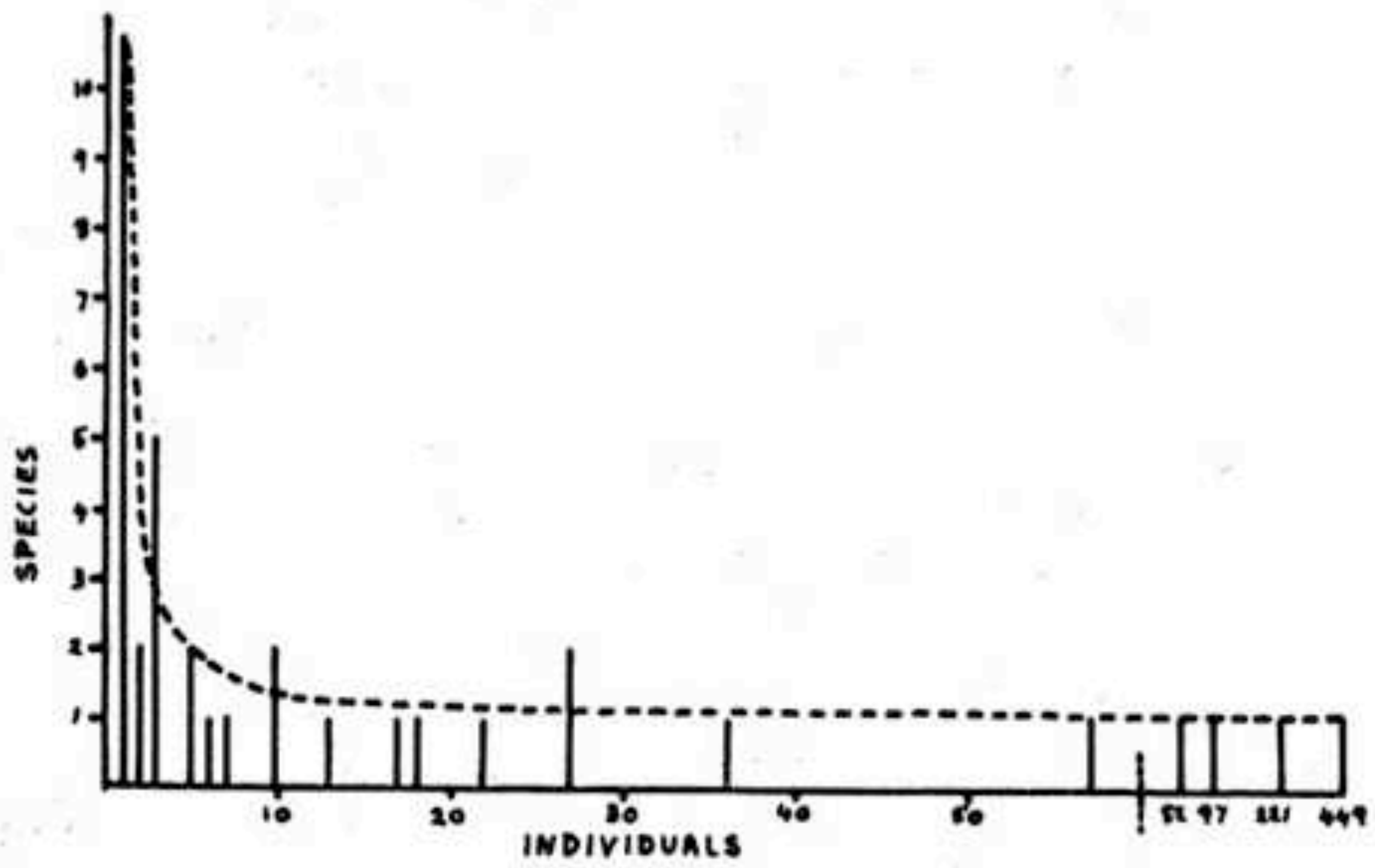

FIGURE 1.—*The relationship between the numbers of species and individuals at Station A.*

A — 4.3% (2) of the species included 64.6% of the individuals.

B — 6.4% (3) of the species included 58.0% of the individuals.

C — 11.0% (8) of the species included 50% of the individuals.

At each station the repetition of sampling units continued to recruit species to the total throughout the sample; this recruitment may be expressed as a cumulative curve which is exponential in form and is similar to those of Holme and Jones; the form of the curve is related in two ways to the total number of species in the sample.

(a) The number of sampling units at which the asymptote, for practical purposes, is reached is positively correlated with the number of species in the sample total.

(b) Similarly, the absolute value of the zero point of the curve is dependent on the mean number of species per sampling unit, and hence on the sample total.

Consequently, the percentage of the sample total which is attained by any given sampling unit is also dependent on the absolute total—

Percentage recruited by haul —	5	10	15	20
A (47 spp. 20 hauls) —	68%	81%	96%	100%
B (73 spp. 20 hauls) —	52%	72%	90%	100%

—and thus the validity of the samples after a given number of hauls depends upon the absolute sample total.

The species structure of the population and the relationship between abundant and rare species leads to two suppositions about the sampling technique. Firstly, that the abundant species may be adequately sampled well before the asymptote of the recruitment curve is reached, and secondly, that the sampling of the rarer species may not give a valid distribution per unit area even when the asymptote *is* reached. In other words, the value of the cumulative recruitment curve as used by Jones and Holme to define the minimal area for the sample is to be doubted.

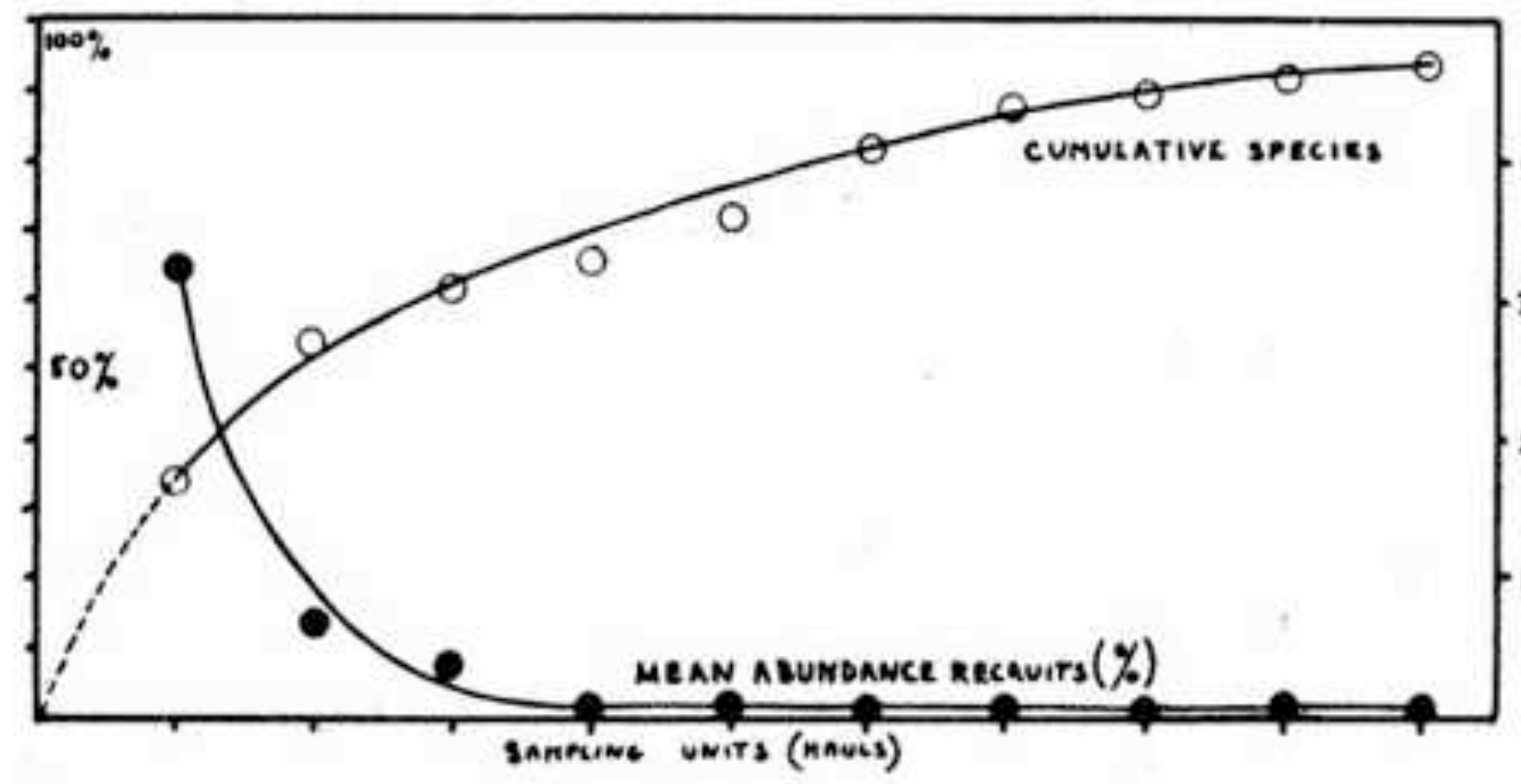

FIGURE 2.—*Decline in relative numbers of recruits during sampling at Station A.*

The first of the above suppositions is supported by the data presented in Fig. 2, which demonstrates for station A that the relative abundance of the recruits at each haul falls very steeply, and that the abundant animals are well represented in the first few hauls. That these are sampled adequately in the first five hauls is indicated by the lack of significant differences between the means (for individuals/unit area) for the whole sample and for the first five sampling units; nor is there any trend in the cumulative means for such species plotted over the whole range of the sample. The second supposition is sufficiently obviously true as to need no elaboration.

It should now be possible to assess the validity of a standard 5-haul station, covering $0.5m^2$, used in the subsequent faunistic survey; this area was chosen for practical reasons—the sea time of a research vessel being very costly—but proved, in fact, to be a fairly logical and satisfactory choice. From such a sample may be derived adequate information about the density and distribution of the abundant species and an enumeration of about 50–70% of the species which would be taken in a sample four times the size; included among these will be almost all the species which would occur more than once or twice in the larger samples. The faunal indices also appear to be adequately estimated by the 5-haul samples.

The criticism remains that the 5-haul sample, though valid in terms of larger samples with the same gear is not in fact truly representative of the fauna. As Birkett (1958) shows, a grab may miss deeply burrowing organisms entirely and—because of the semi-circular section of its bite—sample differentially organisms which are buried at different depths. Birkett suggests that a critical volume of soil in a sample is necessary before any particular organism can be considered to be sampled satisfactorily, the critical volume corresponding with a bite deep enough to sample effectively the complete stratum in which the organisms are buried. These criticisms were tested, to a limited extent, at stations B and C by taking a long haul in the sampling area with an efficient toothed dredge capable of digging more deeply than the grab; at B only two species occurred which had not previously been taken in the grab, and at C a further six. In the first case, the deposits being soft, the dredge dug deeply and the recruits were burrowing forms—a holothurian and a polychaete; in the second case the ground was harder, the dredge dragged more superficially, and with the exception of a single lamellibranch (*Psammobia*), the recruits were large, semi-mobile forms (*Ethusa, Natica, Strombus, Cymbium, Luidia*). It is evident, then, that a haul with a runner-dredge to sample the large epifaunal organisms at each station, would be of undoubted value in any faunistic survey; this does not, of course, dispose of the differential depth factor in grab sampling which can probably be solved partially by measurement of the soil volume in each haul and the application of factors to correct for the effect of different depth of bite in full or part-full grabs. It is this error which affords the greatest support for the replacement of grabs with some form of coring device to take a parallel-sided bite.

The faunal indices are frequently employed in geographical comparisons of the benthic standing crop (e.g. Sparck, 1935) but there has been little uniformity in the way in which the indices have been derived from the results of grab samples. Both unit area and unit volume have been used, with emphasis on the former; Birkett, in view of the depth-differential effect of grab sampling has recommended the use of unit volume, but this appears to pose at least as many difficulties as it solves. A percentage of the species to be sampled will be found very superficially in the deposits and their numbers/unit volume will apparently decrease with increased depth of bite—the converse of the situation for deeply burrowing organisms which will apparently increase in numbers/unit area with increasing depth of bite; if the emphasis of interest is on an organism which occupies a stratum only just within the sampling power of the grab, as in the case of deeply burrowing fish-food lamellibranchs, then the unit volume method of presentation has much to recommend it, but in general survey work it should be used only with care and in such work the unit area method is still to be preferred.

In order to express densities/unit area from a sample which is generally smaller than the chosen unit the sample results are usually multiplied up to the standard; this appears to be valid except in the case of species/unit area and this index can only with difficulty be standardised. By extending recruitment curves, or plotting them logarithmically (Williams, 1950) it is possible to calculate the number of species in a larger unit area—but this is not possible if the hauls at each station are bulked. The most satisfactory expression of this index is in terms of species per standard $0.5m^2$ sample.

There is a very considerable divergence of opinion as to how the biomass of a sample should be expressed. Some express their results in terms of the total organic nitrogen in the benthos and determine this by direct ashing, or the application of factors to convert alcohol weight to dry weight. Others, less concerned with absolute than comparative values, have expressed biomas as wet, or fresh weight, or as alcohol weight, with or without a factor for the alcohol-soluble solids. Expressions of the standing crop of plankton have proved to be of great utility in regional comparisons; the values given by settled volume or by the Harvey phytoplankton pigment units are no less significant because of the complexity of converting them to absolute values; and it is clear that if such standardised techniques had been introduced early in benthos studies the many geographical surveys now published could usefully be compared with each other. As it is, such comparison is almost valueless, and there is no indication in recently published work in this field of any attempt at standardisation of methods.

It is thought that the alcohol-weight technique adopted for the West African survey could be useful under a diversity of conditions and might afford the basis for a standard method; it has the practical advantage that the specimens are not destroyed and are available for systematic study—an important consideration in an unexplored area; as only comparative figures were required, conversion factors for gut contents, calcareous skeleton, and alcohol solutes were not applied; it seems unlikely that these are of great precision, and it is clear that if the absolute values of organic material are required for productivity studies then a technique which involves ashing, after decalcification if necessary, must be used.

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The Northern Blue Penguin *(Eudyptula minor Novaehollandiae)* in Wellington Harbour

F. C. Kinsky

The following is a summary of observations made on the northern blue penguin in the Wellington Harbour area during the 1954-55 nesting season and continuously from August 1956 to March 1958.

Somes Island, situated in the middle of the Wellington Harbour, was chosen for this study mainly because of its comparative isolation and its closeness to Wellington, and the fact that it was known to have a large penguin population. The island is used as a quarantine station, is closed to the public, no predatory mammals occur, and so the birds are virtually undisturbed throughout the year.

METHOD OF WORK

During the 1954-55 nesting season fairly regular day visits were made to the island and only burrows occupied for nesting were observed at each visit. Notes were taken on incubation time, growth of chicks, and the time the chicks stayed in the burrows.

As insufficient data only could be assembled during that year, observations were repeated during the 1956-57 nesting period, by regular weekly day visits (interspersed with more visits if considered necessary). It was soon realised that because of the nocturnal habits of the birds no movement could be observed during day visits and therefore three nights were spent on the island during this nesting season. During the same season ringing of birds was started to facilitate recognition of individual adult birds, and all accessible chicks (21) were ringed. Adult birds and chicks were weighed as regularly as possible by means of spring balances and a cloth