# DIVERSITY MEASUREMENT OF INTERTIDAL MACROBENTHIC COMMUNITIES IN CULLERCOATS BAY, NORTH SEA, ENGLAND

## Pengukuran Keanekaragaman Komunitas Makrobenthik Intertidal di Teluk Cullercoats, North Sea, Inggris

*Aidah A. A. Husain*[1]

[1)] Jurusan Ilmu Kelautan, Fakultas Ilmu Kelautan dan Perikanan, Universitas Hasanuddin

**ABSTRACT**

Diversity assessment has become the focus in ecological studies, and hitherto the matter has been concerned. Methods used for measuring diversity may affect the result significantly. To estimate the effects of spatial scale on sampling for diversity assessment on intertidal rocky shores, a nested series of quadrate sizes were employed from 0.25 $m^2$ to 75 $m^2$ within a 300 $m^2$ plot at Cullercoats Bay in North Sea, England. Data were collected in the summer of 1994 and 1995. Four major patterns emerged from the results of this study. First, Cullercoats Bay consists of a mix of community types and stratified sampling would result in a lower overall estimate of species richness than was actually present. Second, however, stratifying is a useful way of reducing sampling error variance in diversity measures. Third, no simple relationships were apparent between substrate type and diversity. And finally, results were generally seen to be constant between years. Recommendations are also put forward for appropriate sampling methods in this environment.

*Key words: diversity assessment, rocky shores, Cullercoats Bay, stratified sampling*

## INTRODUCTION

Assessment of diversity has been a central theme of many modern ecological studies, and methods for assessing and explaining diversity have been continually improved for many years. Although there are myriad of methods to analyze and measure diversity, they are all interpreted as an n indicator of *ecological quality* (Magurran, 1988). In turn, these studies on diversity have led to a central theme in conservation management, that is, keeping as large a number of species in an area as possible and monitoring the change over space and time in order to assess the well-being of natural communities (Harper and Hawksworth, 1994).

The impression of diversity in a given area is more likely influenced by how the measurement behaves than how species abundances change (Lambshead *et al*, 1983). Also the methods used for measuring diversity may affect the result significantly. Since a wide variety

[1)] Contact person: Ir. Aidah A. A. Husain, MSc.
Fakultas Ilmu Kelautan dan Perikanan Unhas
Jl. Perintis Kemerdekaan Km 10 Tamalanrea, Makassar 90245
Telp. (0411) 587 000

of diversity measurements have been conducted with different quantitative and qualitative measures, according to the consideration of natural characteristics such as habitat, life motion, width of area, etc. (May, 1994) as well as objectives of the study and technical feasibility, it is difficult to make general comparisons between diversity values obtained in different studies.

Most diversity measurements in the marine environment are adopted from techniques used in terrestrial ecological surveys, and this is especially the case in rocky shore surveys. The rocky shore environment has similar conditions to the terrestrial landscape, that are they both form a secure surface for attachment of organisms, and the organisms themselves have many structural parallels such as modular growth-forms (Dayton, 1992).

Various factors, including sampling methodology, the index or measure of diversity used and the scale and pattern of the communities assessed will affect the result and interpretation of ecological studies (Thrush, 1991), and this challenges the idea that a univariate measure of diversity of an area might constitute an adequate description the overall pattern of diversity (Williams and Gaston, 1994). This study addresses the effects of sample unit size within different physical strata or habitats on species diversity measures of a rocky shore intertidal site.

## METHOD

The area of study was the intertidal rocky shore at Cullercoats Bay, North Sea, England (Fig. 1). Sampling was carried out during low tides throughout summer time in May – July 1994 and June – July 1995. The low tide normally presents twice a day for 2 – 3 hours.

The method of measurement used was a nested system of quadrate size. The largest possible size as a starting quadrate was 300 $m^2$, and then decreasing sub-quadrate sizes were employed along approximate lognormal scales which were from 75 $m^2$, 40 $m^2$, 20 $m^2$, 10 $m^2$, 5 $m^2$, 2 $m^2$, 1 $m^2$, 0.50 $m^2$ and the smallest 0.25 $m^2$. Each of smaller quadrates was nested in the next larger ones. The system was modified from Hendrick's method in Krebs (1989).

The data on abundances and species richness were transformed into common species diversity indices, i.e. Shannon diversity index (H'), evenness (E), Simpson index (D) and pseudo-value or Jack-knifing index (VP) adopted from Magurran (1988). All species were sub-divided into family level to assess percentage cover distributions.

A one-way ANOVA was used on the Shannon index. The results of percentage of occurrence were analyzed through Bay-Curtis similarity to perform clustering of species rank of all quadrate units and then transformed into non-metric multi-dimensional scaling (MDS) plots. The MDS plots interpret some function of the (dis)similarity measure between each pair of sample as a distance in ordinary Euclidean space (Field *et al*, 1982). *K*-dominance plots are applied to distinguish the species-abundance distributions of different samples. If *k*-

dominance curves do intersect then diversity indices cannot be relied upon to give the same diversity ordering (Lambshead *et al*, 1983; Warwick and Clarke, 1993). The MDS plots and *k*-dominance tests were carried out through the PRIMER program.

Figure 1. Ordinance survey map of the intertidal rocky shore in Cullercoats Bay, North Sea, England. Note the distinction of sandy shore which is represented by dotted pattern illustration.

## RESULTS AND DISCUSSION

### *Species Inventory*

There were 49 different species of macro algae and macro fauna in total found for all quadrate sizes. Specifically, the species richness in 1994 was 40, whereas in 1995 it was 42. Replication sampling in temporal scale might differ even though observations were carried out at the same position. This is due to the common reason that some of the species 'gained' at a later time may have been present previously but not sampled; or the possibility that 'lost' species may still be present but rare. In 1995, there were 7 species undetected from the previous year, but correspondingly 9 'new' species were gained.

### *Diversity Indices*

The results in both years show that abundance does not appear to depend on quadrate size (Table 1). In contrast, species richness was significantly positively correlated with quadrate size ($F_{1994}$=1.04, p=0.37; $F_{1995}$=0.92, p=0.41). There is no clear indication from the

relationship that species number is leading to asymptote, indicating that the whole Cullercoats north bay site (300 m²) must be sampled in order to assess total diversity present.

Table 1. Species diversity and abundance indices from all quadrate sizes (S-94 = sample in 1994; R-94 = replicate in 1994; S-95 = sample in 1995; R-95 = replicate in 1995).

| Species Indices | ($m^2$) | 300 | 75 | 40 | 20 | 10 | 5 | 2 | 1 | 0.50 | 0.25 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Abundance | S-94 | 86 | 89 | 90 | 85 | 91 | 99 | 107 | 103 | 130 | 126 |
| | R-94 | | 58 | 105 | 127 | 98 | 111 | 86 | 138 | 102 | 120 |
| | S-95 | 92 | 117 | 117 | 119 | 106 | 111 | 93 | 106 | 86 | 60 |
| | R-95 | | 72 | 128 | 134 | 103 | 111 | 55 | 105 | 73 | 55 |
| Species Diversity | S-94 | 22 | 19 | 16 | 15 | 13 | 15 | 18 | 15 | 14 | 13 |
| | R-94 | | 13 | 18 | 16 | 14 | 13 | 14 | 13 | 9 | 9 |
| | S-95 | 25 | 22 | 21 | 21 | 20 | 16 | 17 | 17 | 13 | 6 |
| | R-95 | | 18 | 22 | 22 | 16 | 13 | 11 | 15 | 13 | 6 |
| Shannon Index (H') | S-94 | 2.61 | 2.05 | 2.13 | 1.99 | 1.99 | 2.04 | 1.89 | 1.57 | 1.66 | 1.45 |
| | R-94 | | 1.98 | 2.34 | 2.04 | 2.06 | 1.87 | 2.03 | 1.86 | 1.20 | 1.30 |
| | S-95 | 2.72 | 2.34 | 2.39 | 2.30 | 2.02 | 2.05 | 1.84 | 1.84 | 2.06 | 1.31 |
| | R-95 | | 2.26 | 2.40 | 2.42 | 2.03 | 1.94 | 1.49 | 2.12 | 1.67 | 1.08 |
| Evenness (E) | S-94 | 0.85 | 0.70 | 0.77 | 0.74 | 0.78 | 0.75 | 0.65 | 0.58 | 0.63 | 0.56 |
| | R-94 | | 0.77 | 0.81 | 0.73 | 0.78 | 0.73 | 0.77 | 0.73 | 0.55 | 0.59 |
| | S-95 | 0.84 | 0.76 | 0.79 | 0.76 | 0.67 | 0.74 | 0.65 | 0.65 | 0.80 | 0.73 |
| | R-95 | | 0.78 | 0.77 | 0.78 | 0.73 | 0.76 | 0.62 | 0.78 | 0.65 | 0.60 |
| Simpson Index (D) | S-94 | 0.10 | 0.20 | 0.18 | 0.21 | 0.20 | 0.20 | 0.25 | 0.32 | 0.29 | 0.34 |
| | R-94 | | 0.19 | 0.14 | 0.19 | 0.18 | 0.22 | 0.18 | 0.22 | 0.39 | 0.36 |
| | S-95 | 0.09 | 0.15 | 0.14 | 0.17 | 0.23 | 0.20 | 0.27 | 0.26 | 0.16 | 0.32 |
| | R-95 | | 0.15 | 0.15 | 0.14 | 0.21 | 0.21 | 0.35 | 0.16 | 0.28 | 0.42 |
| Pseudo-value (VP) | S-94 | 3.28 | 2.61 | 2.44 | 2.34 | 2.18 | 2.33 | 2.24 | 1.86 | 1.83 | 1.61 |
| | R-94 | | 2.34 | 2.79 | 2.32 | 2.28 | 2.08 | 2.30 | 1.97 | 0.24 | 1.38 |
| | S-95 | 3.66 | 2.85 | 2.90 | 2.76 | 2.52 | 2.32 | 2.24 | 2.15 | 2.33 | 1.34 |
| | R-95 | | 2.86 | 2.92 | 2.86 | 2.31 | 2.09 | 1.80 | 2.40 | 1.95 | 1.13 |

The relationship of Shannon diversity with quadrate size shows the expected trend, where H' positively correlated with sampling scale ($R^2_{1994}$=0.35, P=0.09; $R^2_{1995}$=0.43, P=0.05). It has strong relationship with the species richness and it is influenced by underlying species abundance distribution (Magurran, 1988). Species evenness, however, appeared to be less dependent on quadrate size, and a possible trend in the 1994 survey was not repeated in 1995. This clearly suggest that the trend in H' was strongly dependent on species richness alone. Simpson index showed a negative relationship with sampling area. This suggest alternatively that degree of dominance shifted dependent on scale, i.e. that factors in addition to more presence of more species in a larger sampling area may have affected the measure of diversity.

Jack-knifing diversity measures allowed calculation of variance of diversity measures within each quadrate scale. The resulting Jack-knifed diversity index is believed to be a better indicator of diversity in non-randomly distributed samples. This was presumed to reduce the variance between replicates and showed a clear, near-linear trend in species diversity in

relation to sample area. The error variance and standard deviation of Shannon diversity H' determination from jack-knifed diversity measurement showed reduced variance in smaller sample units (quadrate sizes ≤ 2 $m^2$). In addition, the variance between years also decreased (consistency of estimates increased) at quadrate sizes ≤ 2 $m^2$.

*K*-dominance plots for 1994 and 1995 surveys showed a slightly increased diversity in 1995 vs. 1994 (Fig. 2). This appeared to be due to greater species evenness than to an increase in species richness. The lines do not intersect each other and mean that the given presence of species richness in 1994 is different to 1995, with the upper curve representing a less diverse sample (Bythell *et al*, 1993). MDS ordination showed distinct groupings of small (0.25 $m^2$ and 0.50 $m^2$) quadrates in 1994 and 1995 (Fig. 3). This was probably due mainly to the fact that small quadrates could not be accurately placed in exactly the same position in each year and were effectively different samples. However, each of the "small quadrate" groups was shifted away from the main group, suggesting that species abundance distributions were distinct within these "small quadrate" samples. Similarly, "large quadrate" groups (300 $m^2$ and 75 $m^2$) were apparently different to the main group, but were not distinct between years. The rest of the pattern on the MDS plot showed very little difference between quadrate size and years, with differences between replicates often being greater than between years or between quadrate sizes (1 $m^2$ – 40 $m^2$).

Figure 2. *K*-dominance curves for intertidal macrobenthic species diversity in assemblages of all quadrate sizes in 1994 and 1995. The species ranks represent the percentage of occurrence within all quadrate sizes.

Figure 3. MDS ordination of percentage diversity at 38 quadrate sizes. Polygons drawn around groups of points are presented to highlight specific quadrate groups (e.g. SMALL'94) rather than show distinct dissimilar groupings.

### *Class Level of Distribution Pattern*

Instead of giving a horrendous figure on species level distribution pattern, the simply way to exhibit was by compiling them into class level. Generally, the brown algae were the dominant in all quadrate sizes except in 75 $m^2$ replicate, which was dominated by Cirripedia or barnacles. Brown algae constitute an over dispersed pattern by occupying more than 50% cover of the given space (Kershaw and Looney, 1985). By virtue of their overall dominance on many rocky shores, brown algae are generally favorable. In particular, their large size, broad fronds, and massive holdfasts provide suitable habitats for diverse assemblages of sessile and mobile organisms. *Crustose corallines* algae were also found extensively dispersed as was the encrust red algae *Corallina officinalis*.

### *Substrate Type*

Substrate types were divided into 7 categories, i.e. hard rock, semi hard rock, soft shale, small boulder, cobbles and pebbles, and sand. This categorization was not a fixed one, considering that more than one category might be found together in one point. Generally, the most cover of substrate which accommodate the area was expectedly hard rock type (Fig. 4).

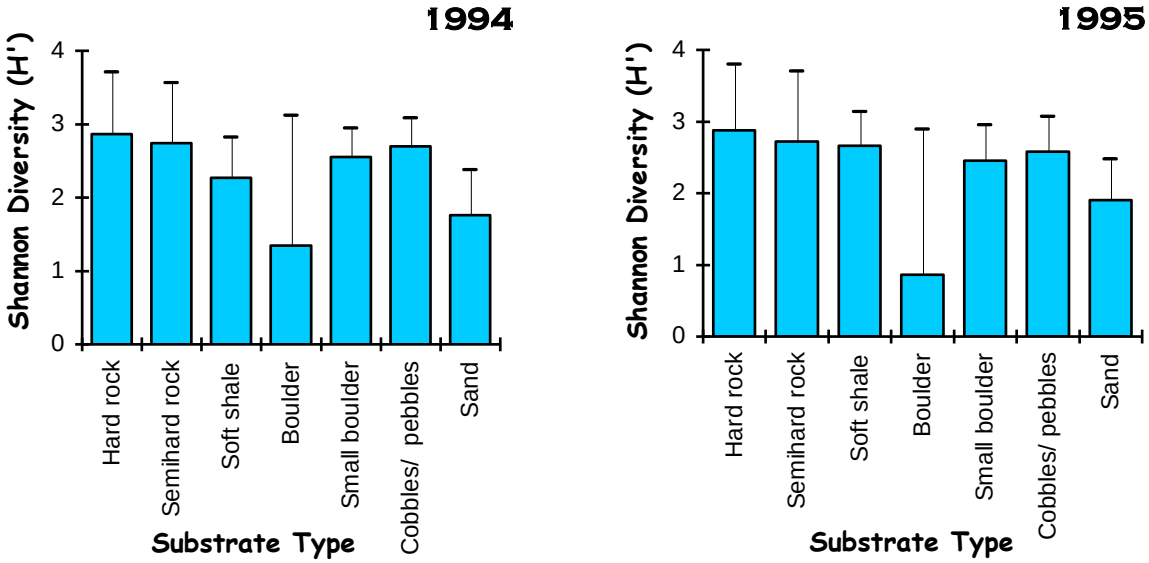


Figure 4. Shannon diversity by substrate type in 1994 and 1995. Data shown are means ± SE for n=10.

Results for the relationship of diversity (H') and substrate types were consistent between years. While H' for boulders was lower than other substrate types, the variance was higher and a one-way ANOVA showed no significant differences between bottom types (F=3.66, p=0.46). These data appear to suggest that differences (above) in diversity were more a function directly of sample area than differences in specific bottom type (habitat) present in each of the stratified quadrate sizes.

*Annual Changes*

In general, there was a consistency of trends seen in 1994 and 1995. For example, variance in diversity indicates was reduced below 2 $m^2$ in both years, and diversity of different substrate types was consistent between years. Conversely, the actual variance recorded for specific quadrate sizes larger than 2 $m^2$ varied considerably between years, showing that this was not generalized pattern for Cullercoats Bay. The nested hierarchical techniques suggested by Green (1979) cannot therefore be applied between sites or in the same site over time. It is questionable, in fact whether the specific variance pattern over quadrate scale represents a real 'signature' of variance at different scale, or itself brought about by random errors.

## CONCLUSION

Cullercoats Bay provides a complex mix of habitat types, and any sub-divisions of the whole show lower species richness and overall diversity than the whole site. MDS analysis showed that, both large and small quadrates produced different species-abundance

distributions to intermediate sized quadrates. Consistent result should however be produced with any quadrates size between 1 $m^2$ and 40$m^2$. Stratifying appears to be useful in reducing the error variance of diversity measurement, with a quadrate area of 2 $m^2$ or less being most appropriate at the current study site; it would seem that applying 1 $m^2$ or 2 $m^2$ quadrates over the whole area would be beneficial to both maximize species encountered and potentially reduce errors. No simple relationship between diversity and substrate type was apparent, except that boulders and sand appeared lower in diversity than other substrate categories. Result appear to be generally consistent between years, e.g. reduction in variance by quadrate size in consistent, diversity vs. quadrate size is consistent, etc.

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