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A novel approach to measuring subtidal habitat complexity

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Abstract

Habitat complexity plays an important role in determining benthic community structure. A diverse range of methods for its measurement have been adopted but none are convenient for use underwater where access time is at a premium. We describe a novel, calibrated, tool for rapidly measuring scale-dependent habitat complexity developed, primarily, for use underwater. This tool is based on a distance-wheel with interchangeable wheels of different sizes to allow a scale-dependent measure of distance. This technique was calibrated against a profile of known complexity, at relevant scales, and then trialed on the Loch Linnhe Artificial Reef, a replicated artificial substratum offering two different scale-dependent habitat complexities. The distance-wheel was cost-effective, simple to fabricate and enabled the rapid and straightforward measurement of perceived distance over the step-length range of 133–1020 mm.

Keywords: Artificial reef; Fractal dimension; Habitat complexity

1. Introduction

One of the major goals of aquatic ecology is to understand the spatial scaling laws that influence benthic community structure and the way organisms use and exploit benthic space (Almany, 2004; Ritchie and Olff, 1999; Taniguchi and Tokeshi, 2004). Improving our understanding of the relationship between organisms and the benthic habitat requires methods of quantifying relevant habitat parameters, such as habitat complexity, that are crucial in determining benthic community structure (including size structure) and productivity in the subtidal environment (Gratwicke and Speight, 2005a; Navarrete and Menge, 1997; Ritchie and Olff, 1999; Woodward et al., 2005).

There are several definitions of habitat complexity and numerous methods have been developed for its measurement (McCoy and Bell, 1991). Sebens (1991) considers habitat complexity to consist of two parts: habitat heterogeneity (patchiness) and habitat structure including aspects of the physical and/or architectural components of complexity. This paper is concerned with the measurement of habitat structure with particular emphasis on complexity.

There are two broad categories for measuring and expressing habitat complexity, one being based on Euclidean metrics and the other based on the estimation of scale-dependent perceived distance (Frost et al., 2005). Euclidean methods are frequently limited to specific habitats or situations restricting their usefulness in

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comparative studies (Frost et al., 2005) and have included counts of specific features within a given habitat, such as coral or boulder density (Charton and Ruzafa, 1998), the sizes of holes available for colonisation (Friedlander and Parrish, 1998) or metrics such as the five and six point scores adopted by Gratwicke and Speight (2005b) and Polunin and Roberts (1993) respectively. Perceived distance methods are based on a comparison between the linear distance and various step-length-dependent measures between two points (Frost et al., 2005). Perceived distance methods allow a scale-dependent measure of habitat complexity and tend to be more useful than Euclidean methods as a common currency for expressing surface roughness or heterogeneity (Gee and Warwick, 1994a; Ritchie and Olff, 1999) and, where the change in perceived distance as a function of step-length is constant, be used to calculate the fractal dimension (Schmid, 2000) (discussed below).

The scale-dependent step-length approach to measuring habitat complexity can be approached using a variety of indirect and direct techniques. Indirect techniques seek to accurately reproduce the surface profile being assessed from which scale-dependent changes in complexity can be calculated using a variety of approaches including the Richardson Procedure and Kolmogorov or Box-counting method (Schmid, 2000). Some objects, for example leaves, can simply be photographed in silhouette but other, predominantly larger or awkward-to-move surfaces, need to be mapped using profile gauges (e.g. Devescovi et al., 2005; Frost et al., 2005), stereo-photographic methods (Frost et al., 2005) or by taking casts (Commito and Rusignuolo, 2000). Such approaches have the advantage that a permanent reproduction of the surface (of very high quality in the case of photographs and casts) is produced. Photographic methods could be used at any scale (provided adequate visibility) but profile gauges are limited by practical considerations, for example, Frost et al. (2005) used 300 mm profile gauges with a 1 mm resolution whilst McCormick (1994) describes the use of a 1000 mm profile gauge with a 100 mm resolution. Profile gauges and photographic methods are 'top–down' methods that cannot be used to measure the additional habitat spaces under overhangs and in recesses (Commito and Rusignuolo, 2000). This problem has been overcome, in part, by fixing a habitat using plaster-of-Paris, removing it to the laboratory and sectioning it to gain a view of the habitat complexity offered (Commito and Rusignuolo, 2000). However, casting methods, applied to 30 cm × 30 cm sections of mussel bed by Commito and Rusignuolo (2000), are likely to be limited by the practicalities of scale and the labour involved in sample preparation.

Direct methods of assessing the step-length dependent distance across a surface have been approached in a number of ways but all are based on a measurement of distances using different step-lengths (perceived distance). The 'step' can be formed by dividers (with an infinite number of steps available between their minima and maxima) or chain links of fixed lengths (Frost et al., 2005; McCormick, 1994; Willis et al., 2005). When the topographic complexity is at a smaller scale than the step-length then the 'observer' (or observing device) will effectively ignore (step over) such complexity and the total distance traveled between two points will more closely reflect the linear (straight-line or Euclidean) distance. On the other hand, when traversing a convoluted surface where the step-length is of a scale which enables the observer to closely follow the surface topography, the perceived distance will be greater than the linear distance. Plotting the perceived distance against the step-length gives a clear indication of the scale at which changes in habitat complexity are, or are not, occurring.

The chain and divider techniques have been widely used in terrestrial and intertidal systems (during low water) (Beck, 1998; Frost et al., 2005; Polunin and Roberts, 1993) but both suffer from the difficulties in surveying very convoluted environments as a consequence of the practicalities of handling lengths of chain or pairs of dividers, particularly in the case of the chain method where slippage has been reported as a problem (Frost et al., 2005). Such handling difficulties are exacerbated underwater and, as a consequence, direct underwater measurements of habitat complexity are frequently based on Euclidean metrics (visual counts of specific features and assessments of complexity) (e.g. Gratwicke and Speight, 2005b; Polunin and Roberts, 1993). Visual counts and assessments, commonly used in warm-water situations such as coral reefs, have considerable merit but are potentially subjective and prone to observer bias (Wilson et al., 2007).

Where the relationship between the distance separating two points and the step-length is constant (on a logarithmic scale), the surface complexity can be characterized by a single metric, termed the fractal dimension (D) (Schmid, 2000).

The shapes of many natural objects, ranging from plants to clouds, are fractal in nature at least over certain scales (Schmid, 2000). However, some natural (e.g. corals, Bradbury et al., 1984) and man-made benthic structures may offer varying degrees of complexity as a function of scale. The degree of complexity offered, and the scale at which changes in complexity are occurring, can be assessed by measuring step-length dependent differences in the perceived distance between two points.