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A comparison of statistical approaches to analyzing community convergence between natural and constructed oyster reefs

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Abstract

Evaluating the success of habitat creation or restoration depends primarily on the selection of appropriate goals, relevant metrics and robust analytic approaches. For intertidal oyster reefs, the goal of restoring ecological function often is as important as the production of harvestable oysters, especially since oysters are the habitat. Assessing differences in resident faunal composition between created and natural reefs is one possible metric for evaluating ecological success. Yearly changes in the resident faunal composition on constructed and natural intertidal oyster reefs at one South Carolina restoration site were analyzed with a variety of statistical approaches to determine the most effective method(s) for documenting possible convergence in the similarity of reef assemblages over time. Two datasets were defined by the level of taxonomic identification, all taxa or a subset of common taxa, and the level of taxa reduction; all taxa, taxa >1% of total abundance, and taxa significantly contributing to variation. Data were analyzed using "classic" multivariate analysis of variance (MANOVA), null model analysis of co-occurrence (ECOSIM), nonparametric analysis of similarity (ANOSIM), and permutation tests for multivariate analysis of similarity (PERMANOVA). Taxa abundance was used to weight MANOVA and ECOSIM analyses, while the Bray–Curtis dissimilarity index was used to weight ANOSIM and PERMANOVA analyses. Initial constraints on the analytic design and data manipulations resulted in only one test where convergence of the constructed and natural reef assemblages was indicated. Prescribed reductions in the suite of taxa considered did not alter appreciably the results. The analytic approaches varied in suitability and effectiveness at discriminating among changes in compositional similarity, even when initial constraints were relaxed. MANOVA results indicated either no difference or a significant difference in resident faunal composition between reefs, but were compromised by the inability to transform the data sufficiently to test for multivariate homogeneity violations even in analyses with reduced taxa numbers. Interpretation of ECOSIM results suggested fewer taxa in common even on natural reefs and were affected by a lack of design alternatives and the possible inflation of Type I error that weighting by abundance may cause. ANOSIM results identified no significant reef treatment effects and also suffered from design constraints and an inability to generate enough permutations to test for significant differences in datasets with relatively small sample sizes. All test results from PERMANOVA analyses except one indicated unambiguously that resident faunal assemblages on constructed reefs generally were not yet similar to natural reefs even after 7 years. Convergence of constructed and natural reef resident assemblages was suggested by PERMANOVA tests only for the dataset with the fewest taxa. The negligible limitations of PERMANOVA, flexible design options, and ability to generate significance tests for small sample sizes make the approach powerful. The ongoing development of effective statistical approaches for testing the significance of taxonomic compositional changes among habitats makes the determination of whether restoration

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projects are successful less dependent on the choice of analytic technique. More critical, biological questions including whether convergence of taxa abundance and composition is a valid indicator of similar ecological function remain to be answered.

Keywords: ANOSIM; Bray–Curtis dissimilarity; Community composition; Convergence; ECOSIM; Habitat restoration; Intertidal; MANOVA; Oyster reefs; PCA; PERMANOVA; Resident fauna; Taxonomic similarity

1. Introduction

The creation or restoration of marine and estuarine habitats is viewed increasingly as a necessary and potentially sufficient response to anthropogenic effects (e.g., coastal development and related impacts, over-harvesting, introduced species). A number of different habitat types including seagrass beds (Fonseca et al., 2000; Bell et al., 2001; Sheridan, 2004), salt marshes (Levin et al., 1996; Craft et al., 1999; Desmond et al., 2002), offshore hard or live-bottom reefs (Beets, 1989; Edwardo et al., 2002; Relini et al., 2002), and intertidal and subtidal oyster reefs (Coen et al., 1999b; Lenihan et al., 2001; Peterson et al., 2003; Luckenbach et al., 2005) have been created and evaluated over the past decades. Although restoration efforts for some habitats date from the 1970s (e.g., Seneca et al., 1985; Broome et al., 1986), questions about the cost, value, and success of efforts remain widespread (Moy and Levin, 1991; Zedler, 1993; Weinstein et al., 1997; Craft et al., 1999; Block et al., 2001; Peterson and Lipcius, 2003; Luckenbach et al., 2005).

A major difficulty associated with evaluating the success of restoration efforts is the identification of appropriate goals and metrics (e.g., Coen and Luckenbach, 2000; Luckenbach et al., 2005). For example, if the goal of salt marsh restoration is to establish natural plant coverage then plant stem density probably is a reasonable assessment metric. Existing evidence based on stem density would indicate the near universal success of most marsh restoration projects (e.g., Broome et al., 1986). However, if the goal is to restore the numerous ecological functions of a natural marsh then stem density alone is insufficient. Suitable metrics for measuring marsh function can vary from breeding bird success (Zedler, 1993) to sediment biogeochemical cycling (Craft et al., 1999). The existence of multiple metrics suggests that evaluation of restoration success may be influenced by the metric selected (see Palmer et al., 1997; Thayer et al., 2003, 2005; Bernhardt et al., 2005; Luckenbach et al., 2005; Palmer et al., 2005).

Assessing the success of oyster reef restoration also is influenced by identification of goals and appropriate metrics. A consistent goal for reef restoration has been the production of harvestable (generally 75 mm) oysters, but reefs contribute many other ecological functions that are reasonable restoration goals (reviewed in Coen et al., 1999b; Lenihan, 1999; Coen and Luckenbach, 2000; Dame et al., 2001). Reefs can improve water quality (Nelson et al., 2004; Newell, 2004), stabilize shorelines (Meyer et al., 1997; Coen et al., submitted for publication), reduce predation (Grabowski, 2004), and provide habitat for both transient and resident fauna (Posey et al., 1999; Peterson et al., 2003; Luckenbach et al., 2005). An economic assessment of oyster reefs may suggest that restoration of ecological function may be as important as production of harvestable oysters (Coen et al., 1999b; Peterson and Lipcius, 2003; Peterson et al., 2003; Luckenbach et al., 2005).

Almost as critical as the choice of restoration goal and associated assessment metric(s) is the ability to evaluate the prescribed metric statistically to determine whether the restoration effort truly is successful. The statistical analysis of many relevant metrics (e.g., oyster density, benthic-pelagic coupling, associated community) presumably is a straightforward comparison between constructed and natural or reference habitats (Thayer et al., 2003, 2005 and references therein). However, evaluating other aspects of ecological function require more complex multivariate data and analyses. For example, assessing the temporal convergence of resident faunal similarity between constructed and natural reefs could provide a sensitive test of functional equivalency (Philippi et al., 1998). The variety of statistical approaches that exist to analyze community compositional change can be divided into analyses based on: (1) direct measures of abundance, percent cover and biomass for a ‘species’ or other ecological grouping (e.g., Navarrete et al., 2000; Lotze et al., 2001; Micheli et al., 2002; Chase, 2003; Allison, 2004) or (2) conversion of compositional data into a similarity index or other distance measure (e.g., Clarke, 1993; Legendre and Anderson, 1999; Langlois et al., 2005, Terlizzi et al., 2005; Wassenaar et al., 2005). Statistical models applied to one or the other types of compositional data include: (1) “classic” multivariate analyses (Johnson and Wichern, 1998; Rencher, 1998); (2) null models (Gotelli, 2000); (3) non-parametric analysis of among sample similarity (Clarke and Warwick, 2001); and (4) multivariate permutation analyses of distance