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Detecting change in intertidal species richness on sandy beaches: calibrating across sampling designs

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A B S T R A C T

Detecting changes in the biodiversity of biotic communities is fundamental to evaluating ecological responses to anthropogenic and climatic drivers at multiple scales. Species richness, the simplest measure of biodiversity, can be strongly affected by sampling design, making comparisons among results of different studies challenging. We investigated the use of extrapolative species richness estimators to address these issues in comparing species richness results from two sampling designs that differed in area sampled for intertidal macroinvertebrates on exposed sandy beaches. The area sampled by the proportional area sampling design increased with beach width (0.4 m^2–3.0 m^2) across our sites. The area sampled by the fixed area sampling design (3.5 m^2) was independent of intertidal width. To obtain datasets for comparisons, we simultaneously used these sampling designs on nested intertidal grids at seven sandy beaches in central and southern California, USA. Observed species richness differed significantly ($p \leq 0.05$) between the two sampling designs and was consistently lower (3–10 species less) for the proportional area design compared to the fixed area design (8–35 vs. 12–38 species, respectively), except at the widest beach where sampling areas were most similar (3 m^2 vs. 3.5 m^2). All seven non-parametric species richness estimators provided higher estimates of richness for both designs (mean = 5.4 ± 3.8 species), but only four of the richness estimators reduced differences in richness obtained by the two designs to a non-significant level ($p \geq 0.05$) across the sites. The ratio of richness values (proportional area/fixed area) obtained by the two designs was strongly correlated with sampling area for observed richness and four of the seven estimators, suggesting these estimators did not uniformly correct for sampling area. When we used an extrapolation of sample-based rarefaction to adjust for sampling area, differences in species richness between sampling designs were reduced (mean difference = 0.9 ± 3.1 species) to within the 95% CI at every site and estimated species richness did not differ significantly among designs. Our results suggest that use of the extrapolative sample-based rarefaction approach could provide a means of calibrating species richness among sampling designs that differ in area sampled. This approach could allow more robust analyses and enable comparisons of species richness data collected across larger temporal and spatial scales. Such comparisons will provide needed opportunities to evaluate the responses of biodiversity to larger scale effects of human impacts and climate change in coastal ecosystems.

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1. Introduction

Biodiversity and its many components represent an underlying principle in many ecological models and conservation strategies (e.g. Gotelli and Colwell, 2001). Shifts in biodiversity may indicate climatic or anthropogenic environmental change or impacts on a variety of temporal and spatial scales (e.g. Vitousek, 1994; Pimm et al., 1995; Chapin III et al., 1997; Vitousek et al., 1997; Sagarin et al., 1999; Harley et al., 2006; Parmesan, 2006; Schlacher et al., 2008). Changes in biodiversity can affect ecosystem function (e.g. Chapin III et al., 2000; Hooper et al., 2005; Isbell et al., 2011), food web dynamics (e.g. Cardinale et al., 2002), and resilience to environmental change (e.g. Chapin III et al., 2000).

Evaluating the impacts of press drivers, such as climate change or anthropogenic disturbance, on the biodiversity of an ecosystem or community requires robust and accurate comparisons of datasets collected over time scales of appropriate length. One such press driver, climate change, has been studied less extensively in marine

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ecosystems (Hoegh-Guldberg and Bruno, 2010). Changes in temperature, UV exposure, sea-level, ocean circulation, and pH can influence biodiversity in marine ecosystems (Macpherson, 2002; Harley et al., 2006), but the paucity of data spanning sufficient time spans in marine ecosystems has made the identification of changes in marine biodiversity challenging (Richardson and Polocanska, 2008; Richardson et al., 2012). This data gap is particularly evident and critical for sandy beach ecosystems (Dugan et al., 2010; Richardson et al., 2012) which make up ~70% of the world's open-ocean coasts and have a high socioeconomic (e.g. Parsons and Powell, 2001; Klein et al., 2004) and ecological importance (e.g. Fairweather, 1990; Schlacher et al., 2007; Dugan et al., 2010).

The simplest and most commonly used way to describe biodiversity in terms of species is species richness, a measure of the total number of species observed in a given area or sample (Magurran, 1988). However, species richness can be strongly affected by sampling effort, area, and design, a major issue for estimating species richness in both marine and terrestrial ecosystems (Gotelli and Colwell, 2001; Colwell et al., 2012; Chase and Knight, 2013). These issues are particularly relevant for sandy beach ecosystems where biotic survey data are limited in many regions. To date, large scale evaluations of global patterns in intertidal biodiversity of beach ecosystems have usually relied on data from surveys that differ in sampling designs and effort, acknowledging that this could be a source of considerable uncertainty (Dexter, 1992; McLachlan and Dorvlo, 2005).

Comparisons of observed species richness or standardizations of observed species richness through the use of simple ratios of the number of species per unit area are unreliable and should never be used (Magurran and McGill, 2011). Instead, interpolative or extrapolative approaches to estimating species richness for the smallest or largest common sampling units (area), respectively, can be used to compare species richness on different spatial or temporal scales (Magurran and McGill, 2011).

Species-accumulation curves can be used to evaluate relationships between sampling effort and species richness, if applied properly (Chase and Knight, 2013). The appropriate level of sampling effort (area) needed to adequately determine species richness of intertidal infauna has been extensively considered for sandy beaches through the interpolation of rarefaction curves (Jaramillo et al., 1995; Brazeiro, 2001; Schoeman et al., 2003; Schlacher et al., 2008). The recommended sampling area for sandy beaches is ~4 m^2, which can be adjusted to scale with the diversity and width of a beach (Schlacher et al., 2008), was based on a balance between the accuracy, bias, and precision of an extrapolative approach to estimating true species richness through the use of non-parametric richness estimators (Schoeman et al., 2008). These extrapolative richness estimators provided more accurate estimates of species richness than observed values on sandy beaches (Foggo et al., 2003; Schoeman et al., 2003, 2008). Recent advances in estimates of richness allow the extrapolation of rarefaction (interpolation) curves to larger sampling effort with unconditional 95% confidence intervals (Colwell et al., 2012). This method yields species accumulation curves that are statistically very similar to interpolative results for a given dataset but has the advantage of allowing the use of all available data rather than a subset (Colwell et al., 2012). Importantly, species richness estimators and other extrapolative approaches to estimating richness could potentially be used to calibrate results between different sampling designs, including those that differ in sampling area (Basualdo, 2011).

Increased confidence in comparisons between samples taken with different methods decades apart could enable interesting and important inferences about change and stability in sandy beach and other coastal ecosystems. For example, in California, high-quality quantitative sampling of intertidal invertebrates on sandy beaches using a variety of sampling designs were initiated following the 1969 Santa Barbara oil spill continuing through the 1970s (Straughan, 1982). Decades later, intertidal surveys of California mainland beaches have primarily used a single sampling design (Dugan et al., 2003; Schooler et al., unpublished) that differs from those in earlier surveys.

Considering the number of different sampling designs used in intertidal surveys, the ability to calibrate results across designs is critical to identifying long-term and large-scale change in species richness for beaches and other ecosystems. In this study, we investigated the effect of sampling design on species richness by simultaneously employing two sampling designs over the same intertidal grid, effectively surveying an identical intertidal community at seven beaches. One design sampled an area that was proportional to intertidal width with randomly spaced sampling units (hereafter referred to as the proportional area sampling design). The second design sampled a fixed area of habitat that was independent of intertidal width using a consistent number of uniformly spaced sampling units (hereafter referred to as the fixed area sampling design). We compared observed species richness and evaluated the ability of several non-parametric species richness estimators to calibrate values of intertidal species richness across the two sampling designs. Lastly, we investigated the efficacy of estimating species richness using extrapolations of sample-based rarefaction curves to larger sampling areas as a calibration method.

2. Methods

2.1. Study sites

The central and southern California coast is characterized by microtidal modally intermediate beaches with mixed semidiurnal tides. In this study, the biodiversity of intertidal macrofauna was surveyed on seven sandy beaches ranging from Cayucos, California to San Diego, California (120°55′ W 35°25.986′ N – 118°15′ W 32°51.832′ N) (Fig. 1). Sites were chosen to represent a range of beach types that varied in richness, level of disturbance, and morphodynamic state across the geographic region and to include locations of intertidal surveys conducted several decades ago (Straughan, 1982).

2.2. Sampling design

We investigated the effect of sampling approach on values obtained for species richness of sandy beaches by comparing results of two stratified sampling designs, a proportional area sampling design and a fixed area sampling design, both previously used to survey intertidal macroinvertebrate biodiversity in California. At each site, we simultaneously employed the two designs (Straughan, 1982; Dugan et al., 2003) nested within the same intertidal grid, effectively sampling an identical intertidal community (Fig. 2). We conducted these surveys during spring low tides at seven beaches (Table 1) in daylight when invertebrate surface activity is minimal. All surveys were conducted in late summer and fall of 2009 when beaches are typically widest in the region except for the beach at Scripps (August 2011). Historic basepoints were identified for each site and a measuring tape was run from the basepoint to the low swash to act as a reference for the sampling grid. We used the same mesh size, core size, and core depth in all surveys.

The proportional area sampling design was adapted from methods used in sandy beach macrofaunal surveys in the 1970s by Patterson (1974) and Straughan (1982) in central and southern California. We used a stratified random quadrat sampling layout (Fig. 2) in which 3.0 m by 12.2 m (10 ft by 40 ft) strata were divided into four replicate contiguous 3.0 m by 3.0 m (10 ft by 10 ft) shore-