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Can we estimate molluscan abundance and biomass on the continental shelf?

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ABSTRACT

Few empirical studies have focused on the effect of sample density on the estimate of abundance of the dominant carbonate-producing fauna of the continental shelf. Here, we present such a study and consider the implications of suboptimal sampling design on estimates of abundance and size-frequency distribution. We focus on a principal carbonate producer of the U.S. Atlantic continental shelf, the Atlantic surfclam, *Spisula solidissima*. To evaluate the degree to which the results are typical, we analyze a dataset for the principal carbonate producer of Mid-Atlantic estuaries, the Eastern oyster *Crassostrea virginica*, obtained from Delaware Bay. These two species occupy different habitats and display different lifestyles, yet demonstrate similar challenges to survey design and similar trends with sampling density. The median of a series of simulated survey mean abundances, the central tendency obtained over a large number of surveys of the same area, always underestimated true abundance at low sample densities. More dramatic were the trends in the probability of a biased outcome. As sample density declined, the probability of a survey availability event, defined as a survey yielding indices >125% or <75% of the true population abundance, increased and that increase was disproportionately biased towards underestimates. For these cases where a single sample accessed about 0.001–0.004% of the domain, 8–15 random samples were required to reduce the probability of a survey availability event below 40%. The problem of differential bias, in which the probabilities of a biased-high and a biased-low survey index were distinctly unequal, was resolved with fewer samples than the problem of overall bias. These trends suggest that the influence of sampling density on survey design comes with a series of incremental challenges. At woefully inadequate sampling density, the probability of a biased-low survey index will substantially exceed the probability of a biased-high index. The survey time series on the average will return an estimate of the stock that underestimates true stock abundance. If sampling intensity is increased, the frequency of biased indices balances between high and low values. Incrementing sample number from this point steadily reduces the likelihood of a biased survey; however, the number of samples necessary to drive the probability of survey availability events to a preferred level of infrequency may be daunting. Moreover, certain size classes will be disproportionately susceptible to such events and the impact on size frequency will be species specific, depending on the relative dispersion of the size classes.

1. Introduction

Molluscs, primarily bivalves, and echinoderms, primarily echinoids, are the dominant producers of carbonate in estuaries and on the continental shelf in temperate to arctic climes (Moore, 1972; Farrow et al., 1984; Lejart et al., 2012; Lebrato et al., 2010; Waldbusser et al., 2013). As the carbonate balance of the world's oceans becomes an increasing focal point (Cooley et al., 2009; Doney et al., 2009; Feely et al., 2009), determining carbonate production rates and the influence of climate change on these production rates becomes an expanding need (Gattuso et al., 1998;

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Kleypas and Yates, 2009; Wright and Burgess, 2005; Tomašových et al., 2006; Dorshel et al., 2007). Carbonate balance is a function of the rate of carbonate addition, the rate of taphonomic loss, and the rate of burial (Powell, 1992; Tomašových et al., 2006; Powell et al., 2012). The processes and rates of taphonomic loss and burial have received considerable attention, particularly in nearshore settings (Parsons-Hubbard, 2005; Best et al., 2007; Powell et al., 2006; Waldbusser et al., 2011), but also on the continental shelf (Parsons-Hubbard et al., 1999; Powell et al., 2002b, 2011a,b; Smith and Nelson, 2003). Carbonate production rates should also be readily acquired; however, few such estimates exist (e.g., Smith, 1971; Lebrato et al., 2010).

Estimates of carbonate production require effective estimation of population density and size frequency, as well as the implementation of population dynamics models or direct observations permitting estimation of recruitment, growth, and mortality rates (e.g., Powell et al., 2012). A number of population dynamics models have been described for carbonate-producing denizens of the continental shelf (Bradbury and Tagart, 2000; Munroe et al., 2013; NEFSC, 2013). These models require a reliable estimate of abundance; however, the adequacy of abundance estimates from benthic surveys has recently been questioned (Powell and Mann, 2016). The issue arises from the tendency of molluscs to contribute in larger measure to biomass than to abundance (Staff et al., 1985); that is, well represented among the infaunal biomass dominants are the filter-feeding bivalves and predatory gastropods that are among the larger of the continental shelf benthos and among the principal carbonate producers. Such species are present at relatively lower densities than the smaller infauna and tend to be patchy, thus estimates of their abundance and biomass are heavily dependent on sampling gear and sample density (Rago et al., 2006; Powell and Mann, 2016). The problem of sample density is well-considered in the literature (e.g., Findlay, 1982; Livingston, 1987; Kidwell et al., 2001; Battista, 2003; Bennington, 2003; Brown, 2003), but few empirical studies have focused directly on the effect of sample density on the estimation of abundance and biomass of carbonate-producing fauna, particularly the biomass-dominant molluscs of the continental shelf.

The need to accurately estimate the abundance of larger benthic species on the continental shelf goes well beyond carbonate production, and arises from manifold survey needs, including stock assessments to manage commercial species (e.g., NEFSC, 2009; NEFSC, 2013), identification of impacts of fossil fuel exploration and production (e.g., Peterson et al., 1996; Currie and Isaacs, 2005; Parr et al., 2007), documentation of multifarious anthropogenic stresses (e.g., Kidwell, 2007; Carroll et al., 2009), baseline studies documenting community structure and function (e.g., Davis and VanBlaricom, 1978; Aller et al., 2002; Dubois et al., 2009; Buhl-Mortensen et al., 2012), and elucidation of the influence of climate change (e.g., Weinberg, 2005; Lucey and Nye, 2010; Powell et al., 2017). Although many such surveys have been carried out, rarely have their designs taken into account the potential biases imposed by a mismatch of sampling density and species patchiness. Here, we report the results of such an empirical study and consider the implications of suboptimal sampling design on the estimates of abundance and size-frequency distribution as they may affect characterization of biomass dominants on the continental shelf.

We focus on the Atlantic surfclam, *Spisula solidissima*, a principal carbonate producer and biomass dominant found on the continental shelf of the U.S. East coast from the Chesapeake Bay to Georges Bank (Weinberg et al., 2005; NEFSC, 2013), where it supports a major commercial fishery (NEFSC, 2013). The species is particularly sensitive to warming of the bottom waters of the Mid-Atlantic Bight, with well-documented changes in mortality rate and geographic range (Weinberg, 2005; Narváez et al. 2015; Munroe et al., 2016; Hofmann et al., in press), such that substantial spatial and temporal variations in community structure and carbonate production and deposition can be anticipated. The species is extremely patchy (Flowers, 1973; Weinberg et al., 2002; Powell et al., 2017), creating a challenge for accurate estimation of abundance and biomass.

2. Methods

2.1. Data collection

Sampling Design: The option of fixed versus random sampling designs has received considerable attention (e.g., van der Meer, 1997; Morehead et al., 2008). With certain exceptions (e.g., Sammarco and Andrews, 1989; Kennicutt et al., 1996; King and Powell, 2007), benthic surveys employ random sampling (e.g., Gavaris and Smith, 1987; Smith and Gavaris, 1993; Kimura and Somerton, 2006). The purpose of the sampling program undertaken for this study was to provide a uniform array of sampled sites that could be used as potential random locations for evaluating a random sampling scheme. To the extent possible, sites were distributed equivalently in space within a region of 33.5 km^2; depth constraints modified this design in a few cases. In total, 21 stations were sampled in a 33.5-km^2 region of the continental shelf offshore southern New Jersey (Fig. 1). These stations were separated by approximately 6 min of longitude and 2.4 min of latitude.

Sampling Gear: A hydraulic dredge was used. Hydraulic dredges are fitted with a water pump on the vessel that pumps water through a hose to a manifold at the front of the dredge. Nipples affixed across the manifold direct water downward, liquefying the sediment. The dredge is towed through this liquefied sediment, capturing the larger benthic animals (Meyer et al., 1981; Smolowitz and Nulk, 1982). These dredges are used throughout the surfclam and other clam fisheries (e.g., Fogarty, 1981; Ragnarsson and Thórarinsdóttir, 2002; Gilkinson et al., 2005; Hennen et al., 2012)

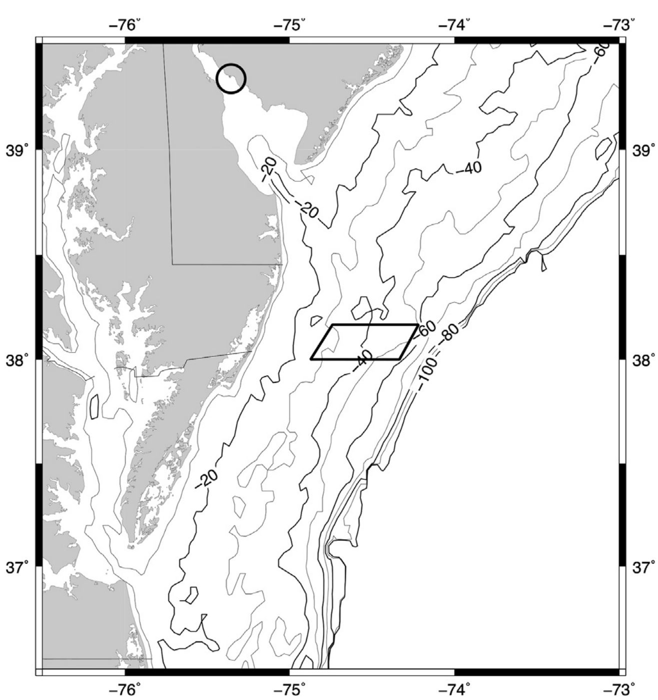

Fig. 1. The study region for the surfclam survey, marked as a quadrilateral, within the Mid-Atlantic region spanning Virginia to southern New Jersey. The circle marks the region in Delaware Bay wherein Cohansey Reef lies. Depths in m.