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Effects of marine protected areas, environmental conditions, and biological interactions on the abundance of echinoderms on Georges Bank

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Summary

To assess the effects of marine protected areas (MPAs) it is necessary to analyze the natural variability within marine populations. We used video survey techniques to estimate the abundance of echinoderms on Georges Bank from 2005 to 2012. We evaluated multiple environmental factors, closed and open areas to fishing and predator/prey abundance, that could affect or determine the distribution of echinoderms. The most important explanatory factors for brittle stars *spp*. abundance and distribution were depth (90-110m) and abundance of American plaice (*Hippoglossoides platessoides*), their main predator. Sand dollars *spp*. were mainly associated with closed areas (highest densities found inside Closed Area I and Nantucket Lightship Closed Area), unstable substrates, and abundance of haddock (*Melanogrammus aeglefinus*) and ocean pout (*Macrozoarces americanus*), their main predators. Sea stars *spp*. appeared strongly related to closed areas (highest densities found in Nantucket Lightship Closed Area), stable sandy sediments, temperature (>15°C), and abundance of ocean pout. Sea urchins *spp*. were mainly associated with cobble and boulder stable sediments, temperature (10-15°C), and abundance of ocean pout. While MPAs appear to be a main driver for the distributions of sand dollars and sea stars, brittle stars and sea urchins seem to be confined to their preferred habitat conditions, regardless of fishing pressure.

Introduction

In 1994, three large areas on Georges Bank and southern New England (Closed Area I [CAI], Closed Area II [CAII], and Nantucket Lightship Closed Area [NLSA]), were closed year-round to all fishing activity (Murawski *et al*., 2000). Although these closures seem to have had a positive effect (increase in abundance) for some shallow and sedentary fishes and invertebrates (Murawski *et al.*, 2000; Stokesbury, 2002; Stokesbury *et al*., 2004), other studies indicate that the habitat is a much more important driver for changes in fish and invertebrate populations (Link *et al*., 2005). Therefore, the simultaneous examination of abiotic and biotic factors is pivotal in determining the effects of MPAs on species abundance and distribution, which was the main objective of this study. Echinoderms represent the majority of biomass on the benthos of Georges Bank, they are present in different habitats, can cause dramatic changes in other marine communities, and have several commercially important predators and prey (Brusca and Brusca, 1990).

Materials and methods

The SMAST video survey database (Stokesbury *et al*., 2004; Stokesbury, 2012) from 2005 to 2012 includes more than 14,331 images containing echinoderms. Mean density of echinoderms was estimated using the equations for a two-stage sampling design (Cochran, 1977) and was the dependent variable of this study. To examine relationships between echinoderm abundance and independent variables (depth, sediment stability, sediment type, and predator/prey abundance) in a spatially explicit manner, a grid composed of 5km^2 area cells was overlaid on the Georges Bank region. Each cell represented the average value of each explanatory factor by year. Canonical correspondence analysis (CCA) (Ter Braak, 1986) was then used to examine the importance of the independent variables, on the abundance and distribution of echinoderm populations.

Results and discussions

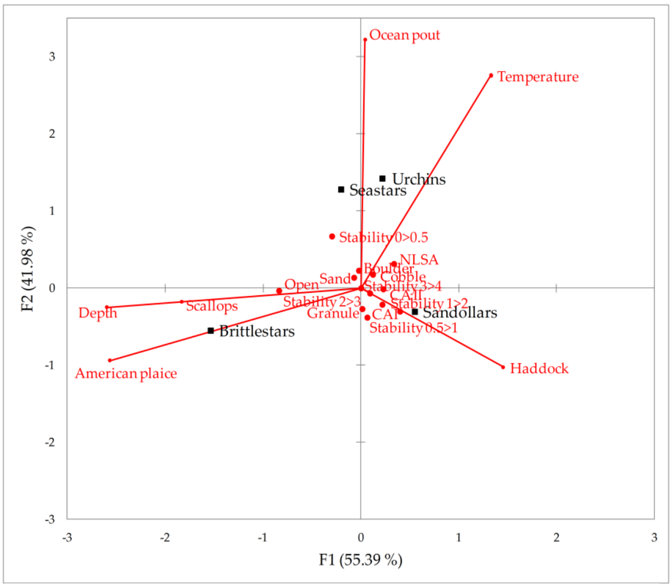

Figure 1. Ordination diagram of the first two axes of the canonical correspondence analysis for echinoderms abundance and explanatory factors.

The canonical relationship between matrices of independent and dependent variables was highly significant ($p<0.0001$, Monte Carlo permutation test, pseudo $F=0.153$, 1000 permutations). The first two canonical axes accounted for 97.4% of the constrained variance explained by the independent variables (Figure 1). Depth, temperature, and area (CAI, Open areas) were the variables with greater contribution to the first axis, while temperature, ocean pout abundance, depth, and American plaice abundance, were the variables with greater contribution to the second axis. An ordination diagram (biplot) (Figure 1) shows that brittle stars were associated mainly with depth and with American plaice abundance. Sand dollars were strongly associated with CAI, unstable sediments, and they seem to be negatively correlated with abundance of ocean pout and positively correlated with abundance of haddock. Sea stars were associated with areas of high stability, sandy substrates, and they were closely related to NLSA. Furthermore, they had a strong association with temperature, a positive correlation with ocean pout, and a negative correlation with haddock. Urchins seem to be more sensitive to temperature, sediment type, stability, and had a positive correlation with abundance of ocean pout. Population dynamics of echinoderms were most effectively assessed by examination of both biotic and abiotic factors, which was necessary to determine the effects of MPAs on species distribution. Our results suggest that predation is one of the most important factors in controlling echinoderm populations. Also, we found that sand dollars and sea star populations are being positively affected by fishing closures. Therefore MPAs could be having a major impact on commercially targeted species that are trophically related these echinoderms, via modification of predator-prey dynamics.

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