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ScienceDirect

Fisheries Research 86 (2007) 241–261

FISHERIES RESEARCH

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Influence of adaptive stations in a transect-based sampling design for a multispecies fish survey

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Received 21 November 2006; received in revised form 31 May 2007; accepted 25 June 2007

Abstract

A multispecies transect-based survey with an adaptive sampling design was evaluated to determine the import of adding stations adaptively at sea in order to better resolve the cross-shelf distribution of species in regions of rapid bathymetric change. The dataset came from a series of transects occupied in November, January, March, and May from May 2003 to November 2005 along transects northeast of Hudson Canyon and northeast of Baltimore Canyon in the Mid-Atlantic Bight region of the western Atlantic. The transect survey results demonstrate the necessity of high sample density in this region of the continental shelf where fish aggregate patchily over scales of a few kilometers. Species cross-shelf distributions were often bimodal. The adaptive sampling protocol demonstrated the expected tendency of fish to be underestimated or overestimated given inadequate sampling density. However, on the average, low sample density led to an underestimation of biomass or abundance and often strongly so. Modeling of the transect design reveals that the overestimates and underestimates, as well as the bias towards underestimation, originate from variations in patch location and, even more importantly, patch shape, with the sampling design. The transect model shows that extreme overestimates and underestimates can occur when patch size is small relative to the distance between stations, but the occurrence of routine, predictable, persistent underestimates in some species is not so easily explained. The model clearly resolves the importance of bimodality and a patch form represented by a dome shape in determining the vulnerability of a species to a biomass or abundance underestimate. Cases where the fixed stations alone provide data clearly inadequate for the estimate of abundance or biomass occur when sampling density is inadequate to identify the center of the patch or to identify the shape of the patch. It is the improved understanding of patch shape that is the single most important contribution of the adaptive sampling protocol, not a better knowledge of the location of the patches. Patch shape is a principal determinant of the adequacy of sample density.

Keywords: Transect-based survey; Adaptive sampling; Bimodal distribution; Patch shape; Sampling density; Multispecies fish survey

1. Introduction

Concern over the dynamics of the distribution of fish on the outer continental shelf of the Mid-Atlantic Bight resulted in the initiation in 2003 of a commercial-vessel-based multispecies survey designed specifically to provide detailed information on the cross-shelf distribution of a suite of commercially and recreationally important species. The impetus for this effort came from several diverse sources. First, many of the important species in this region carry out seasonal migrations, south and offshore during the fall and early winter, and north and onshore during the late spring (Colvocoresses and Musick, 1983; Shepherd and Terceiro, 1994; Murawski, 1993). Examples include *Loligo* squid (*Loligo pealei*), scup (*Stenotomus chrysops*), spiny dogfish (*Squalus acanthias*), and summer flounder (*Paralichthys dentatus*) (Jensen, 1965; Colvocoresses and Musick, 1983; NEFSC, 1998; NOAA, 1999; NRDC, 2001). Second, the federal stock assessment surveys, that have a stratified random sampling design, due to the wide area that must be sampled and constraints on total survey time, allocate minimum sampling intensity (two to three samples per stratum) to many of the offshore strata. The scale of species' patchiness may result in insufficient sampling density in some strata during some years. Scup is a good example. Third, a detailed depiction of the cross-shelf distributional patterns of species has become increasingly important as discard reduction plans began to include time–area closures to reduce fishing during times and in locations of overlap between species. The recent interest in the cross-shelf overlap between scup and *Loligo* squid distributions is an example (Powell et al., 2004).

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doi:10.1016/j.fishres.2007.06.022

Transect-based sampling approaches are often used for investigating questions related to the interaction of environmental gradients and species' distributions. Transect sampling has a long history in ecology (e.g., Flint and Holland, 1980; Bak and Luckhurst, 1980; Bunt et al., 1984; Dauer et al., 1984; Zonneveld, 1991; Fuller, 1999). Underwood (1978) provides a theoretical treatment of transect sampling for species' distributions. Such surveys have not been used very often in fisheries, however.

The disparate goals that led to the development of the commercial-based multispecies survey, however, led to a design that involved multiple sampling times and multiple transects, plus intensive sampling on each transect. The desire for multiple sampling times and multiple transects required that intensive sampling be efficiently designed, however. As a consequence, an adaptive sampling protocol was developed to provide increased cross-shelf resolution on each transect while minimizing total cross-shelf sampling. The use of adaptive sampling to enhance transect-based surveys while minimizing total sample density has not been investigated; thus, the survey design implemented provides a test of the utility of this approach.

The survey goals can only be met if the patchiness of species is relatively well defined by the sampling program, as patch overlap between species is an important datum to be provided by the survey. Evaluating the shape of species' patches has long been an issue in ecology (e.g., Findlay, 1982; Lewis and Stoner, 1983; Mackas, 1984; Powell et al., 1987; White et al., 1989; MacDonald et al., 1989; Ghertsos et al., 2001). Sampling density is inherently an issue in such investigations (Elliott, 1977; Jumars et al., 1977; Findlay, 1982; Oden, 1984). Under scrutiny here is the implementation of an efficient sampling design to evaluate species' patchiness when patch size, location, and shape are unknown *a priori* and when total sample number is constrained. This will normally be the case in fish surveys designed to evaluate the overlap of species along environmental gradients.

The purpose of this study is to evaluate the effectiveness of the adaptive sampling design in delineating the cross-shelf distribution of species. To accomplish this, we first analyze the field data for the first 3 years of the survey for the two most completely sampled transects, from May 2003 to November 2005, for transects near Hudson Canyon and Baltimore Canyon. This field dataset includes 9 field programs and 18 transects. Then we model the sampling design and use the model to evaluate how different patch shapes and locations interact with the sampling design to produce the results observed in the field.

2. Methods

2.1. Survey structure

Sampling programs were carried out four times yearly, in November, January, March, and May from May 2003 to November 2005. The November to May emphasis brackets the time period of migration for most migratory Mid-Atlantic species. Analyses presented here are based on fixed transects oriented parallel to and just north of Baltimore Canyon (38°20′N) and parallel to and just east of Hudson Canyon (72°W) (Fig. 1).

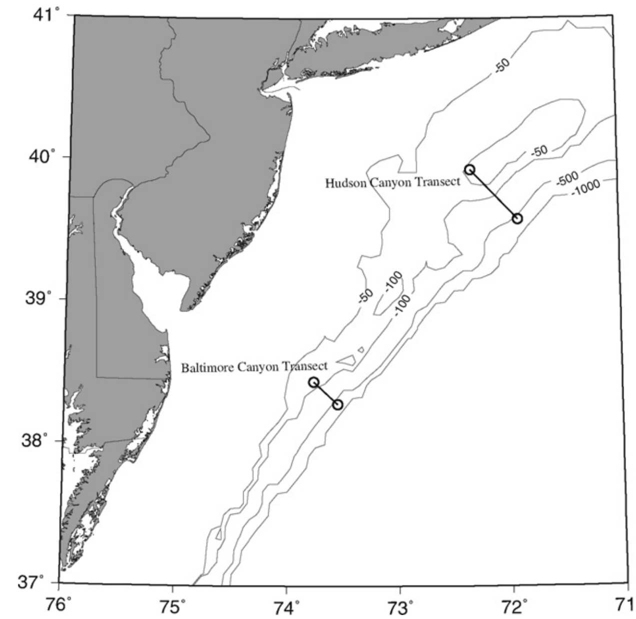

Fig. 1. Location of the Hudson Canyon and Baltimore Canyon transects in the Mid-Atlantic Bight (depth in m).

Stations were distributed perpendicular to the average trend of the depth contours. The implemented sampling design consisted of a 2:1 ratio of fixed to adaptive stations on each transect. Fixed stations were located at 40, 50, 60, 80, 100, 125, 150, 200, 225, and 250 fm on the Hudson Canyon transect. Topography prevented sampling of the 250-fm station on the Baltimore Canyon transect. An additional four-to-five adaptive stations, to achieve a 2:1 ratio of fixed to adaptive stations, were distributed along the transects based on the catches of target species recorded at the fixed stations. Target species were summer flounder, scup, black sea bass (*Centropristis striata*), monkfish (*Lophius americanus*), spiny dogfish, *Loligo* squid, and the sum of silver hake (*Merluccius bilinearis*) and offshore hake (*Merluccius albidus*). This latter sum was included because the two species are often not distinguished by the whiting fishery. Prospective adaptive station depths were depths halfway between fixed stations. Thus five of nine prospective depths were chosen for sampling at each sampling time on the Hudson Canyon transect and four of eight prospective depths were chosen for sampling on the Baltimore Canyon transect.

To choose adaptive stations, fixed stations providing the highest overall ranking based on the catch of each target species were identified using the following methodology. Let the accent → represent the rank of a variable and $\vec{v}_{ij}$ represent the rank given to each of the n_f fixed stations, i, for each of the n_t target species, j. As a consequence, each of the fixed stations has a set of n_t rank values, one for each target species, based independently on the catch record for that species among all n_f fixed stations. The adaptive choices are obtained by evaluating the choice variable C_i as the sum of the rank values for each species for that station:

$$C_i = \sum_{j=1}^{n_\mathrm{t}} \vec{v}_{ij}. \quad (1)$$