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To split or not to split: Assessment of Georges Bank sea scallops in the presence of marine protected areas

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ABSTRACT

Marine protected areas (MPAs) may create challenges for stock assessments because most models are based on the assumption that fishing mortality is uniform in space. Using both actual data and simulations, we explored two approaches to the stock assessment of Georges Bank Atlantic sea scallops (*Placopecten magellanicus*), where fishery closures were implemented in December 1994. One approach modeled the stock in "aggregate", using domed commercial selectivity functions for the time periods when the MPAs were closed to scallop fishing. In the second "split" approach, separate models were used for the scallops inside (closed areas) and outside (open areas) the MPAs. The aggregate model converged only in 17% of the simulated runs, compared with 93% convergence for the open and closed runs using the split approach. With actual data, and in those simulations where both methods converged, the two approaches gave similar results, although biomass estimates in the most recent years from the aggregate model tended to be biased low. The closed area model, and to a lesser extent the aggregate model, estimated natural mortality M fairly precisely, but open area model estimates of M were poorly defined. Retrospective patterns were reduced using the split approach and when natural mortality was estimated. We conclude that the split assessment approach is better for sea scallops, but it may be best to use both approaches for comparative purposes.

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1. Introduction

Marine protected areas (MPAs) have received increased attention for both conservation and fishery management purposes. Gains in biomass within MPAs are common, particularly for sedentary, heavily exploited species (Lester et al., 2009; Molloy et al., 2009). However, the efficacy of MPAs for fishery management is more equivocal. Realistic models indicate that long-term closures typically increase fishery yields only when stocks are overfished, and in particular, recruitment overfished, i.e., when stock biomass is low enough to substantially reduce recruitment (Gerber et al., 2003; Hart, 2006; Hilborn et al., 2006). Often, MPAs suffer from limited monitoring, making it difficult to evaluate their impact on exploited populations and fisheries.

MPAs may cause difficulties for many commonly used stock assessment models because these models are frequently based on the assumption that fishing mortality of all individuals the same age (or size) is the same and not dependent on location (Field et al., 2006). This assumption is often violated if a portion of a stock is contained within one or more MPAs, especially for sedentary species.

We consider two simple methods for accounting for MPAs in stock assessment models. In the "aggregate" method, open and closed areas are modeled together as a single homogenous stock. This method uses domed fishery selectivity to account for the reduced fishery vulnerability of larger, older animals that are disproportionately more likely to occur within MPAs than outside. The second "split" method involves fitting separate models to the open and closed areas, and then combining the results to estimate conditions in the stock as a whole. Punt and Methot (2004) examined the accuracy of these alternatives using simulations and an age-structured stock assessment model. Their results suggest that split models are generally more precise than aggregate models but that the best approach may be case-specific.

MPAs may be also useful for estimating life history attributes such as growth and natural mortality (Punt and Methot, 2004; Hart and Chute, 2009a; Garrison et al., 2011). Fishing can obscure the effects of these processes, so studying populations in areas were fishing does not occur may increase the precision of estimates of these life history parameters. In particular, MPAs may be useful for estimating natural mortality, which is normally especially difficult to estimate, because there is no need to partition mortality into natural and fishing induced components as would be required in the absence of MPAs.

We compare these two approaches using both actual and simulated data for the U.S. Georges Bank sea scallop (*Placopecten*

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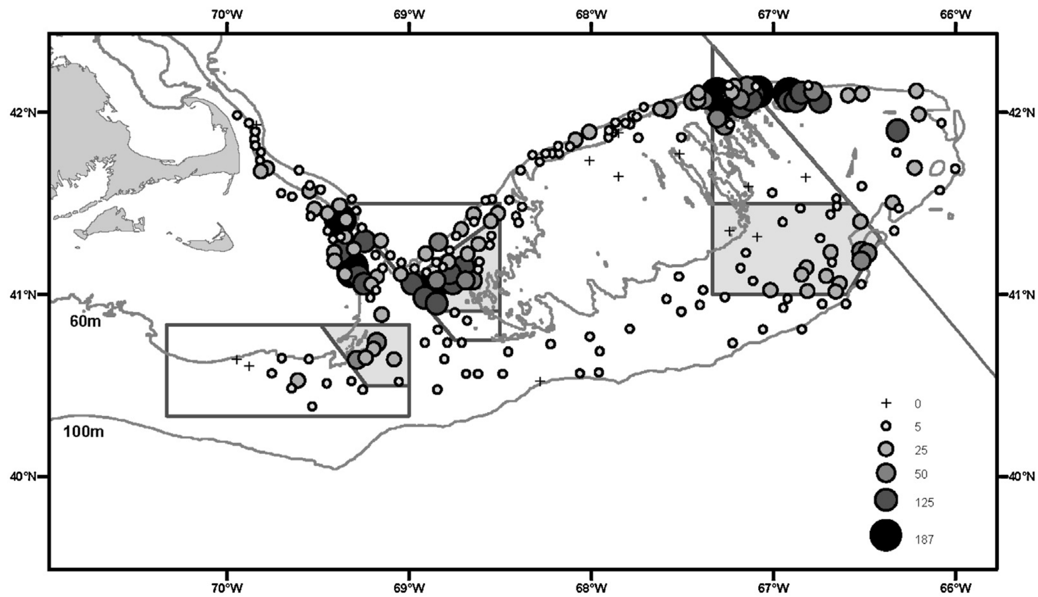

Fig. 1. Georges Bank, including the surrounding areas of the Great South Channel and Nantucket Shoals, with observations of sea scallop biomass (kg/tow meats) from the 2010 NEFSC sea scallop survey. The three closed areas are shown as outlined polygons and the shaded portions within them are the scallop access areas. The diagonal line through the eastern portion of Georges Bank is the international boundary between the Exclusive Economic Zones of the U.S. and Canada.

magellanicus) fishery, and evaluate their abilities to estimate natural mortality. The response of sea scallops to MPAs is of particular interest both because the economic importance of this fishery and because, unlike many MPAs, intensive monitoring of the sea scallop resource and fishery occurred both before and after imposition of the MPAs.

Sea scallops are distributed in the Northwest Atlantic Ocean from North Carolina to Newfoundland (Hart and Chute, 2004), and support one of the most valuable fisheries in North America; the ex-vessel value of the U.S. sea scallop fishery in 2011 was about $580 million. Georges Bank, located off Massachusetts near the middle of the latitudinal range of the species, is one of the most productive sea scallop grounds. For stock assessment purposes, the U.S. Georges Bank sea scallop population includes scallops in the adjoining Great South Channel and Nantucket Shoals areas, but not those in the Canadian Exclusive Economic Zone (Fig. 1).

The Georges Bank sea scallop fishery began in the late 1920s, and rapidly developed after World War II (Hart and Rago, 2006). After a large year class recruited to the fishery in 1960, both effort and landings increased (Fig. 2a and b). This pattern of increasing effort, often induced by large year classes, caused long-term declines in biomass and commercial catch rates, and resulted in severe overfishing by the early 1990s (Fig. 2c and d). In response, various management changes were introduced in 1994, including limited access (where only a limited number of permits were issued for scallop fishing), limits on the number of individual vessel days-at-sea, crew size limits, and gear restrictions that gradually increased the minimum ring size on scallop dredges from 76 mm in 1994 to 102 mm since December 2004. These measures reduced fishing mortality and altered fishery selectivity toward larger scallops, resulting in increased long-term yields (Hart and Rago, 2006; NEFSC, 2010).

Three large areas on Georges Bank and Nantucket Shoals (Nantucket Lightship Closed Area, Closed Area I, and Closed Area II, Fig. 1) were closed to fishing for groundfish and sea scallops in December 1994 as an additional measure to help rebuild these stocks; fishing for pelagics and with lobster pots have continued in these areas. After a rapid buildup of scallop biomass within these areas (Fig. 2d, Murawski et al., 2000; Hart and Rago, 2006), limited fishing for sea scallops was allowed in portions of Closed Area II in 1999, in portions of all three areas from June 2000 to January 2001, and since November 2004. Each of the three closed areas has been divided into an "access area", where scallop fishing has been periodically permitted, and a remaining portion that has stayed closed to scallop fishing (Fig. 1). One or two of the access areas are open to fishing each year on a rotational basis (except in 2000 and 2012, when all three access areas were open), with the schedule being determined by resource conditions within these areas. These areas are not "marine reserves" where all fishing is prohibited, but can be considered MPAs using its more inclusive meaning.

2. Methods

2.1. Stock assessment model

The CASA size-based stock assessment model (Sullivan et al., 1990) with extensive modifications for use in actual U.S. sea scallop assessments (NEFSC, 2010) was used in testing both the aggregate and split model approaches. Scallops are tracked by year and size class (shell height) in CASA, but not by age. The model is fitted by maximum likelihood to abundance trend and size data obtained from NEFSC sea scallop dredge surveys during 1975–2010 (Hart and Rago, 2006) and SMAST video surveys during 2003–2010 (Stokesbury et al., 2004), as well as commercial landings and shell height data from port samples and at-sea observers. Growth is modeled using a stochastic growth matrix based on growth increments from scallop shell ring analysis (Hart and Chute, 2009a,b). The model accommodates measurement errors in shell heights, survey, and landings data (Jacobson et al., 2010). Instantaneous natural mortality was either fixed at $M = 0.12\ y^{-1}$ (NEFSC, 2010) or was estimated in the model. See NEFSC (2010, App. X) for a complete technical description of the CASA sea scallop model. The aggregate CASA model is based on data from the whole Georges Bank stock, whereas the "closed" model includes data from the areas closed to fishing in December 1994 (Fig. 1), including "access" areas that have been periodically fished starting in 1999 and areas that have not been fished since 1994. The open model is based on the data from the portion of the Georges Bank stock area outside the closed and access areas.