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Can an aggregate assessment reflect the dynamics of a spatially structured stock? Snow crab in the eastern Bering Sea as a case study

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ABSTRACT

The snow crab population in the eastern Bering Sea is panmictic, but it is spatially structured by inferred ontogenetic migrations, and fishing pressure is often spatially restricted by sea ice. This spatial structure is ignored when stock assessments are conducted, yet it is unclear if this omission influences management outcomes. We describe a process for evaluating the influence of spatial structure on the performance of stock assessments. This involves developing a spatial model which includes spatially explicit trends in recruitment, fishing mortality and rates of movement. The model is over-parameterized but provides good fits to the data for snow crab. It was used to simulate data sets to test the ability of a non-spatially structured (aggregate) assessment method in terms of estimating trends in abundance and fishing pressure in the presence of spatial structure. The aggregate assessment method performed well if survey selectivity was well known, but was unable to reliably represent the dynamics of the population without data on survey selectivity. Additional data on movement from tagging studies or winter surveys would be useful to improve the understanding of the influence of spatial structure on snow crab in the eastern Bering Sea.

1. Introduction

Spatial structure in exploited marine populations comes in many varieties: local densities can vary through space and/or time in a single panmictic population (e.g. Bentley et al., 2004), sink/source dynamics can be present in which metapopulations feed satellite populations (e.g. Porch et al., 2001), or genetically distinct stocks can be present in the same location (e.g. Taylor et al., 2009). Unaccounted for spatial structure in stock assessments may influence the ability of management systems to reach their goals (Cadrin and Secor, 2009; Ying et al., 2011; Guan et al., 2013). Attempts to incorporate spatial structure into stock assessments have been made to correct the potential biases in quantities important in management introduced by spatial structure (e.g. Booth, 2000; Punt et al., 2000; Goethel et al., 2011). However, accurately describing spatial structure in marine stocks is often difficult given commonly available data. Movement, selectivity, mortality, growth and recruitment are confounded in stock assessment models, and determining whether a population in a given region decreased because of higher natural mortality or emigration (for example) is often impossible without studies targeted at understanding each of these processes (e.g. Hilborn, 1990; Anganuzzi et al., 1994; Mullen, 1994).

Spatial structure is ignored when conducting stock assessments of the population of snow crab in the eastern Bering Sea (EBS). The National Marine Fisheries Service (NMFS) performs systematic trawl surveys of the EBS shelf each summer during which spatially explicit catch-at-length data are gathered and then aggregated to develop shelf-wide indices of abundance and length frequencies (Daly et al., 2013). Recruitment appears to occur primarily on the northeastern portion of the shelf (based on length frequencies from the NMFS survey, Ernst et al., 2005) and there is evidence from Regional Ocean Monitoring System-linked individual-based models that larvae released in the middle domain, the region between 50 and 100 m depth, disproportionately contribute to overall recruitment (Parada et al., 2010). An ontogenetic migration is inferred from survey data in which snow crab move from the northeastern portion of the EBS shelf to the southwest (Ernst et al., 2005), resulting in a gradient of both maturity and size across and down the shelf. Additionally, the fishery occurs primarily in the southwestern portion of the surveyed-region (Turnock and Rugolo, 2013; Fig. 1). There appears to be seasonal movement on the shelf based on tagging studies (Nichols and Somerton, 2012) and changes

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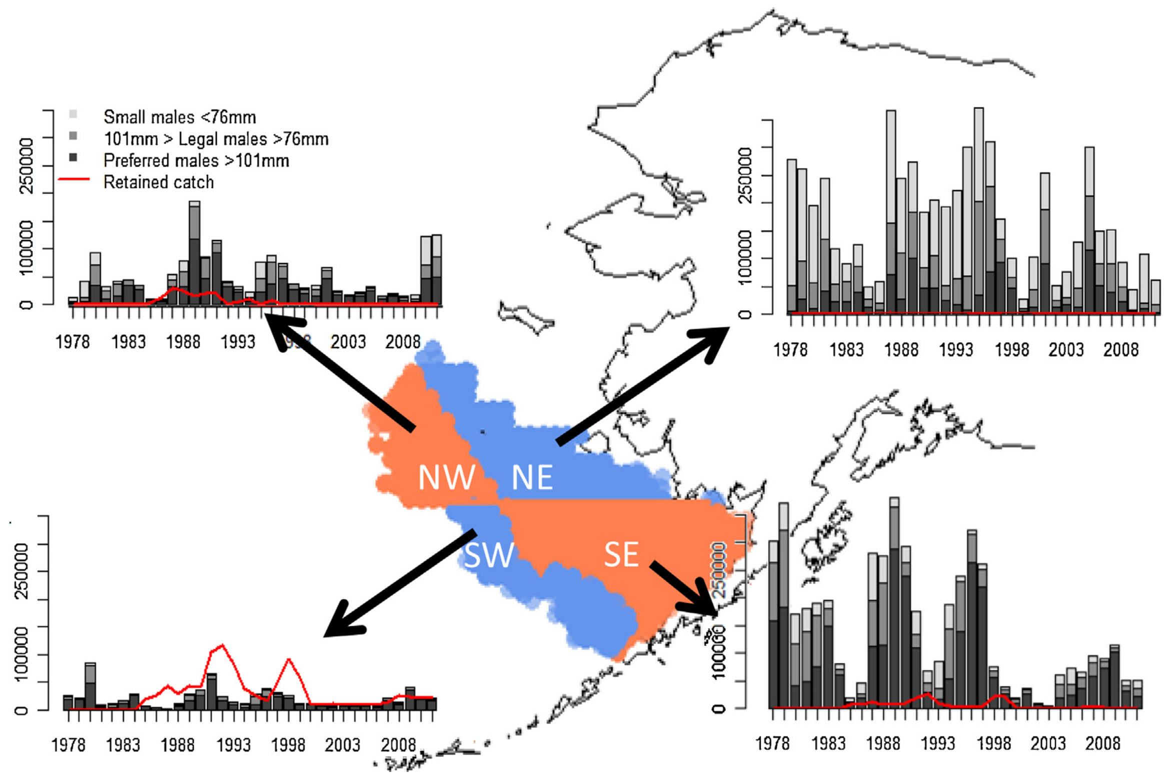

Fig. 1. Map of the regions in relation to the Alaska coastline (center) with raw area swept estimates of biomass of male crab from the survey (i.e. catchability equals 1) binned into 'small', 'legal' and 'preferred' size (i.e. the size preferred by fishermen and processors) classes by region (outer). Observed catch is overlaid in the red line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in the centroids of large males seen at the time of the survey and at the time of the fishery. However, the population appears to be genetically panmictic (Hardy et al., 2011), which may offer some counter-balance to the cited seasonal and ontogenetic movement patterns.

The current assessment method for snow crab in the EBS (Turnock and Rugolo, 2013) implicitly assumes: (1) no spatial structure, (2) recruitment is equally distributed over the range of the population, (3) the mature animals contribute equally to recruitment irrespective of their location in the EBS, and (4) fishing mortality is applied equally to the entire population subject to a selectivity ogive (which also incorporates availability). It is unclear whether these simplifications have impacted management performance, but the fishery was declared overfished in 1999. A rebuilding plan was subsequently enacted with the goal of returning the stock to its target biomass in ten years. However, this plan was declared a failure in 2009 (in 2011, the stock was declared rebuilt following a recalculation of target biomasses).

Attempts have been made to assess this stock using a spatially structured model (Murphy, 2011), and such models have been applied to other stocks in the Bering Sea (e.g. walleye pollock, *Theragra chalcogramma*, by Miller et al., 2008). The process of assessing a spatially structured population requires the use of all available data to attempt to estimate movement and spatial structure. If the data are not sufficient to estimate movement and spatial trends in quantities used in management, simulated populations with spatial characteristics consistent with current knowledge of the species' movement dynamics can be used to test assessment methods which have model complexity such that parameters are estimable. The limitations and potential biases introduced by model misspecification (e.g. using an aggregate model when spatial structure is present) can be used to guide management decisions and future research until data are available to accurately model movement.

This paper follows this plan of research by first exploring the feasibility of developing a spatially explicit assessment method for EBS snow crab which estimates movement, local densities, recruitment and trends in fishing mortality for male crab. A stock assessment method with four regions is explored, the limitations of this method are discussed, and recommendations are made for future research. The results from the spatial assessment are then used as an operating model to evaluate the ability of a non-spatially structured (aka 'aggregated') assessment method to estimate quantities important for management when the underlying population is spatially structured.

2. Methods

2.1. A spatially structured assessment method

The assessment model (coded in Auto-differentiation Model Builder (C++), Fournier et al., 2012) tracked numbers of male crab by size, maturity state and region (see the Turnock and Rugolo, 2013; appendix for model structure, likelihood components, weights, and estimated parameters). Only males are modeled because only males are retained in the fishery and management reference points are based on mature male biomass (NPFMC, 2008). Growth, natural mortality and fully selected discard mortality were fixed to the values assumed for males in a recent NMFS assessment (Turnock and Rugolo, 2011) because they are difficult to estimate with available data. Length frequencies and numbers from the NMFS summer survey of the Bering Sea, catch records of retained crab, and length frequencies of the total catch (i.e. all crab caught irrespective of whether they were discarded) from observers informed parameter estimates (Table A1). Data from side-by-side trawls to determine the catchability and selectivity of the NMFS survey gear performed by the Bering Sea Fisheries Research Foundation (BSFRF) were