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Which assessment configurations perform best in the face of spatial heterogeneity in fishing mortality, growth and recruitment? A case study based on pink ling in Australia

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ABSTRACT

Most fisheries stock assessment methods are based on the assumption that fish are homogeneously distributed across the area being assessed or that fish movement is such that local fishing pressure does not lead to heterogeneous spatial patterns of abundance. However, this assumption is seldom valid in practice. Seven alternative approaches for conducting assessments when confronted with possible spatial variation in fishing mortality, growth and recruitment are identified. These approaches range from ignoring spatial structure, to conducting a multi-area assessment that accounts for spatial variation in biological and fishery processes. These seven approaches are tested using simulations in which there is a single population with spatial heterogeneity, and the only linkage among areas is larval movement. The simulations are based on fishery and biological characteristics for pink ling, *Genypterus blacodes*, off southeast Australia. Non-spatial assessment configurations that aggregate spatially-structured data provide more precise, but nevertheless biased estimates of initial and final spawning biomass, as well as biased estimates of the ratio between initial and final spawning biomass. Assessment configurations that allow for spatial structure can provide imprecise and highly biased estimates, although these can be improved by changing the relative weighting applied to different data types. A spatially-structured assessment configuration that correctly matches the structure of the model used to generate the simulated data sets is unbiased but imprecise. When confronted with possible spatial heterogeneity in biological and fishery parameters, we propose conducting sensitivity analyses based on several model configurations to select the appropriate structure for an assessment. The capacity to examine model residuals spatially remains valuable for inferring problems with model specification.

1. Introduction

Fishery stock assessments are conducted to evaluate the status of stocks relative to target and limit reference points and/or to form the basis for the application of harvest control rules. Stock assessments are based on many assumptions, such as that the assessment applies to a closed population, i.e., there is no immigration or emigration. Stock assessments also often rely on one of two assumptions: (1) the population being assessed is homogeneously distributed across the region being assessed or (2) the fishery is such that the probability of being caught is the same for all fish of a given size/age, irrespective of where they are found. These assumptions will almost always be violated to some extent given that fish and fishing vessels tend not to be distributed homogenously across the area inhabited by a fish stock. Simulation studies (e.g., Punt and Methot, 2004; Fu and Fanning, 2004; Cope and Punt, 2011; Garrison et al., 2011; McGilliard, 2012; Dougherty et al., 2013; Guan et al., 2013; Martien et al., 2013) have shown that stock assessment methods which assume that the stock is distributed homogeneously across space will produce biased results when this assumption is violated to a substantial extent, with the magnitude and direction of bias depending on the extent to which the assumptions underlying the stock assessment are violated. Garrison et al. (2011) and McGilliard et al. (2015) found that applying spatially-structured stock assessment methods reduced or eliminated the bias. Studies exploring the impact of spatial structure on the performance of management strategies have found that conservation performance can be poor if the data on trends in abundance are only collected

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from a part of the area in which the stock is found and are hence not representative of the trends in total population size (e.g., IWC, 1992), and that management performance can be poor if source sink dynamics are not accounted for (Tuck and Possingham, 2000).

Spatially-structured stock assessments are rare. However, several methods that account for spatial structure have been developed, and these have been applied to tuna populations (e.g. Davies et al., 2011), school and gummy shark, *Galeorhinus galeus* and *Mustelus antarcticus*, off southern Australia (Punt et al., 2000; Pribac et al., 2005), hoki, *Macruronus novaezelandie*, off New Zealand (McKenzie, 2013), sharks (Aires-da-silva et al., 2009), Patagonian toothfish, *Dissostichus eleginodes* (Day et al., 2014), Lake Erie walleye (Berger et al., 2012), walleye pollock in Alaska (Hulson et al., 2011), and rock lobster stocks off Australia and New Zealand (Breen et al., 2006; Haist et al., 2009; McGarvey et al., 2010; De Lesting et al., 2011). At least three major stock assessment packages: MULTIFAN-CL (Fournier et al., 1998), CASAL (Bull et al., 2012), and Stock Synthesis (Methot and Wetzel, 2013) now include the ability to represent spatial structure explicitly.

One reason for not including spatial structure in a stock assessment is the difficulty of estimating movement rates in the absence of tagging data. However, Garrison et al. (2011) and McGilliard (2012) show using simulations that movement rates can be estimated from differences among areas in length- and age-compositions, and such differences have formed a key basis for estimating movement rates for hoki off New Zealand. One group of species for which spatially-structured population dynamics models are expected to improve estimation performance are those that are sufficiently sedentary that only a few age-classes move. Species that are sedentary as juveniles and adults, but whose larvae are distributed spatially fall into this group.

This paper identifies a range of stock assessment configurations which could be used to address spatial structure in growth, recruitment and fishing mortality in the situation when the only linkage among areas is larval movement[1]. It then describes simulation analyses that were used to determine the ability of each of these configurations to provide reliable estimates of female spawning biomass for the eastern stock of pink ling, *Genypterus blacodes*, off southeast Australia. Each configuration is implemented using the age- and length-structured Stock Synthesis framework. Pink ling forms the basis for major fisheries off Australia and New Zealand. Pink ling off southeast Australia is part of the Southern and Eastern Scalefish and Shark Fishery (SESSF; Smith and Smith, 2001), and this resource has been divided into two stocks (east and west of 147°E) for assessment and management purposes because of differences between areas in size- and age-compositions, as well as in trends in catch rates. However, no genetic differences have been identified between pink ling east and west of 147°E (Ward and Reilly, 2001; Ward et al., 2001). The east stock is the focus of the simulations described here and is divided for statistical purposes into three "zones" (10, 20 and 30; Fig. 1).

The results of the simulations will inform how assessments for the east stock of ling should be conducted but also will add to the knowledge base regarding the performance of spatial and non-spatial stock assessments, in particular when spatially-structured stock assessments will improve estimation performance and how best to conduct such assessments.

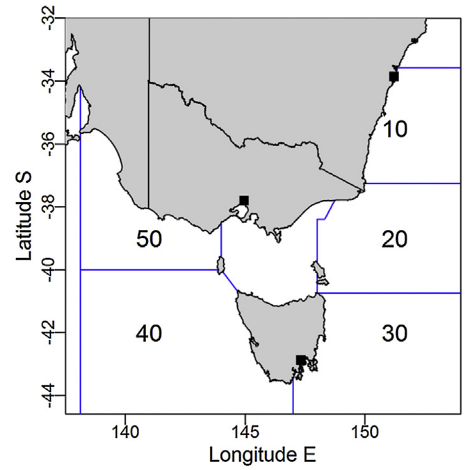

Fig. 1. Schematic map of the SESSF reporting blocks 10–50 with the fine blue lines representing block boundaries. The locations of Hobart, Melbourne, and Sydney are indicated by black squares from top to bottom. The east stock of pink link is found in zones 10, 20 and 30; the line between zones 30 and 40 is at 147°E. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Data available

Catches of pink ling have been recorded since the 1970s when the trawl fishery off southeast Australia began to move to waters of 200 m and deeper (Tilzey, 1994). Pink ling are caught using trawl and non-trawl (generally longline) gears. The data available for assessment purposes are catches, catch length-composition data, standardized catch-rate series, and conditional age-at-length data from the fishery catches. Each of these data sources is reported by zone and separately for trawl and non-trawl gears. However, all data sources are not available for all combinations of zones, years and gear-types (Supplementary Table 1), and this lack of complete data is likely to impact the performance of methods that estimate many parameters, such as those pertaining to total annual recruitment and the fraction of recruitment occurring in each zone.

2.2. Stock assessment configurations

2.2.1. Overview

The assessment configurations considered in this paper have the same basic structure to maximize the ability to compare model outputs. The most general case is when there are multiple spatial areas, the total recruitment is determined from a stochastic Beverton–Holt stock–recruitment function, the allocation of total annual recruitment to zone is stochastic, and growth is sex- and zone-specific. For the case in which two commercial fleets[2] operate in each zone (a trawl and non-trawl fleet for pink ling), the basic population dynamics are modelled by:

$$N^{s,z}_{y,a} = \begin{cases} 0.5 R_y p_{y,z} & \text{if } a = 0 \\ N^{s,z}_{y-1,a-1} e^{-Z^{s,z}_{y-1,a-1}} & \text{if } 1 \leq a \leq x-1 \\ N^{s,z}_{y-1,x-1} e^{-Z^{s,z}_{y-1,x-1}} + N^{s,z}_{y-1,x} e^{-Z^{s,z}_{y-1,x}} & \text{if } a = x \end{cases} \tag{1}$$

[1] More precisely those age- and length-classes before animals are vulnerable to the fishery or monitoring.

[2] A fleet is defined as vessels fishing using a particular gear in a given zone (c.f. Punt et al., 2014a). "Fleet" is also referred to in the literature as 'metier'.