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Age sample sizes and their effects on growth estimation and stock assessment outputs: Three case studies from U.S. West Coast fisheries

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ABSTRACT

Age estimates are often used as conditional age-at-length (CAAL) data in stock assessment models to internally estimate growth and other life history parameters of fish populations. Obtaining sufficient numbers of age estimates is not a trivial task, as it requires considerable sampling effort, the development of aging criteria, the validation of age observations, and, finally, the production aging of sufficient numbers of age structures to inform the assessment models. In this study, we evaluated the influence of CAAL data in several assessment models of West Coast groundfish, by both randomly selecting only portions of available CAAL data and by selecting intermittent numbers of years of CAAL data for inclusion in models. These sensitivity tests were conducted on recent stock assessment models for Blackgill Rockfish (*Sebastes melanostomus*), Bocaccio (*Sebastes paucispinis*), and Pacific Sanddab (*Citharichthys sordidus*), as these three species represent a fairly wide range of life history types. The results showed that for the Bocaccio model, the assessment outputs from model runs with reduced numbers of CAAL data were very comparable with the model run with all available data. However, when CAAL data were reduced, the Blackgill and Sanddab models estimated different spawning outputs, stock depletions, and growth functions. Reducing CAAL data in these two models also resulted in larger estimation uncertainties in the assessment outputs. Overall, our results suggest that it is important to obtain more age data from long-lived species over as long a time span as possible, and aging samples from intermittent years may be considered if there are constraints in time or effort to age all available samples.

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1. Introduction

Length and age composition data are essential for modern age-structured stock assessment models (Punt et al., 2006a; Ono et al., 2015; Francis et al., 2015; Thorson and Minte-Vera, 2015). They are important for estimating selectivity of fisheries and fishery-independent surveys (Hilborn and Walters, 1992; Punt and Hilborn, 1997; Maunder and Punt, 2013; Maunder and Piner, 2015), and critical for the estimation of biological parameters such as natural mortality, recruitment variability, and growth (Chen et al., 2003; Conn et al., 2010; Szuwalski and Punt, 2012; Methot and Wetzel, 2013; Maunder and Punt, 2013; Kolody et al., 2015). Historically, many of these parameters, particularly those related to growth, were estimated externally and then used as fixed parameters in stock assessment models, due to the challenges in estimating them internally. However, most contemporary stock assessments, particularly those using integrated analysis, allow for internal estimates of growth and natural mortality (Maunder and Punt, 2013; Methot and Wetzel, 2013). This approach has been shown to produce less bias in estimated biological parameters (Punt et al., 2006b; Szuwalski and Punt, 2012). For example, growth rates of young fish can be overestimated if they are estimated externally because faster growing individuals are subjected to fishing earlier, and thus are more frequently encountered in sample data than slower growing individuals of the same age. Consequently, using growth data from these fast growing individuals to externally estimate growth of the population can produce biased estimations of growth (Punt et al., 2006b).

In many recent stock assessment models, age data have often been used as conditional age-at-length estimates (CAAL), which are conditioned on length composition data already included in the models (He et al., 2013; Methot and Wetzel, 2013). In other words, these data represent the age structure of the population within a given (typically narrow) length range, which allow the data to be considered independent of the corresponding length observations themselves. Addition of CAAL data facilitates the estimation of important model parameters, such as growth and natural mortality, within assessment models because it ties the length to the age and therefore provides more information than just length compo-

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sitions and age compositions alone (Francis et al., 2015; Piner et al., 2015). For example, if in a given length range there are 10 aged fish that are distributed evenly (or unevenly) among 5 age classes, using CAAL would allow the assessment model to estimate age-at-length and its variability for this specific length range. In the past, age data have been structured as age composition inputs to assessment models. This approach requires adjusting weighting factors of length and age composition data in the assessment models, since using both sets of data could represent "double use" of size information from the same fish. Using CAAL data is increasingly accepted as more efficient as it eliminates "double-use" of age data and at the same time enables the models to estimate variances of fish growth. This approach has been commonly used in stock assessments in the U.S. West Coast groundfish assessments in recent years (He et al., 2013; Hamel et al., 2013; Hicks et al., 2013).

The development of CAAL data requires intensive effort in data collection and laboratory analysis, which consequently makes such data more "expensive" to collect and develop than length data alone. Moreover, the development of age estimates, typically through the analysis of growth rings in otoliths (ear bones), requires intensive laboratory processing and adherence to rigorous methodologies (e.g., Matta and Kimura, 2012; Pearson et al., 2015). For example, Bocaccio (*Sebastes paucispinis*), which is one of the most important commercial and recreational target groundfish species in California waters, has been subjected to twelve stock assessments since 1986. Limited age data were used in four assessments between 1984 and 1996, but all age data have been excluded from all assessments since 1999; this was because the data were considered unreliable due to a systematic pattern of aging errors (MacCall et al., 1999), as well as observations of conflicting signals in estimated recruitment between length and age composition data (Ralston and Ianelli, 1998).

In this study, we examined the influence of age data on the outputs of the stock assessment models and estimated growth functions. Specifically, we focused on how numbers of CAAL data and numbers of years with CAAL data affect stock estimated assessment outputs and growth. We used three stock assessment models from the U.S. West Coast groundfish: the previously discussed Bocaccio model (based on the most recently adopted model with new age data included), as well as Blackgill rockfish (*S. melanostomus*) and Pacific Sanddab (*Citharicthys sordidus*). The stock assessment outputs included stock depletion estimates, recruitment relationships, and internally estimated growth functions. We compared these outputs among different availability of the CAAL data. Based on our findings, we suggest some general guidelines for future age sample collections and age sample processing.

2. Methods and materials

2.1. Stock assessment models

All three stock assessment models (Blackgill, Bocaccio, and Pacific Sanddab) used in this study were approved by the Pacific Fisheries Management Council (PFMC), and the first two were adopted for fisheries management (Field and Pearson, 2011; Field, 2013; He et al., 2013). The Stock Synthesis Program (Version 3.24O, Methot and Wetzel, 2013) was used in all three stock assessments. Biology, stock dynamics, and main parameters used in these models are listed in Table 1. These three stocks represent a broad range of life histories, from the rapidly growing and early maturing Pacific Sanddab to the extremely slow growing and very late maturing Blackgill rockfish. In all three assessment models, the Schnute (1981) parameterization of the von Bertalanffy growth function was used. The same data-weighting procedures used in the original assessment models were also used for all models in this study.

Blackgill rockfish are a slope rockfish most common in depths between 300 and 500 m in Southern and Central California. Blackgill are a very long-lived, slow growing and late maturing species; the most recent estimates of the age at 50% maturity is 25 years based on histological staging, representing a fairly extreme example of the very slow life history strategy common in the very deep water habitats of the California Current (Lefebvre and Field, 2015). However, age criteria were very difficult to develop for this slow growing species, and age estimates were associated with considerable error, which is also observed in other slope rockfish species (such as Aurora, *S. aurora*, and Rougheye rockfish, *S. aleutianus*) with comparable life histories (Hamel et al., 2013; Hicks et al., 2013). The 2011 stock assessment model for Blackgill rockfish assumed a plus group age of 60 years (Table 1), although some studies have found that this species can live as long as 90 years (Stevens et al., 2004). Fishery landings peaked in the mid-1980s at just over 1000 mt, but have declined to approximately 100–150 mt in recent years. The last assessment was conducted in 2011; the stock status was estimated to be 30.2% of the unfished level, having increased from a low of 18% of the unfished level in the early 1990s (Field and Pearson, 2011). In the 2011 stock assessment model, growth for both sexes was internally estimated using age data from over 6000 otoliths. The slow growth and high aging error precluded the estimation of recruitment deviations, such that the extent of recruitment variability in this species remains uncertain. As a result, steepness in the stock–recruit relationship was not estimated and was fixed at 0.760.

Bocaccio rockfish are a shelf rockfish species widely distributed along the west coast of North America, but most abundant in Southern California waters, where it has long been one of the most important targets of both commercial and recreational fisheries. The 2013 stock assessment assumed a plus group age of 21 years (Table 1), although previously published maximum ages for Bocaccio have ranged from 37 years in Washington waters (Piner et al., 2006) to 57 years in Canadian waters (Stanley et al., 2009). Fishery landings peaked in the 1970s and early 1980s at over 8000 tons, mostly by commercial trawl fisheries. The stock was declared overfished in 2000. Since then, landings have been very low, ranging between 13 mt and 188 mt, with most landings coming from recreational fisheries, which in turn have been constrained by the allowable catches of Bocaccio and other species (Field et al., 2010). The last assessment was conducted in 2013, at which time the stock status was estimated to be 31.4% of the unfished level and expected to exceed 40% of the unfished level (the rebuilding target) by the year 2015 (Field, 2013). In the 2013 stock assessment model, most growth parameters for both sexes were estimated internally, except length at the minimum age, which was externally estimated and then fixed in the model. The steepness parameter, which describes the slope of the spawner–recruit curve, was also estimated in the assessment model.

The Pacific Sanddab is a left-eyed flatfish widely distributed along the Pacific west coast from the Bering Sea to Baja California. It is commonly found in the shelf waters of less than 250 m depth. It is a fast growing, early maturing and short-lived species, with a high natural mortality rate that reflects its significance as an important prey item for a wide range of piscivorous fishes, seabirds and marine mammals. The stock was assessed for the first time in 2013 (He et al., 2013), and the assessment assumed a plus group age of 11 years (Table 1). Fishery landings were first recorded in the late 1890s, peaked in the mid-1990s at around 1300 mt, and ranged between 200 and 400 mt in recent years. However, landed catches are assumed to substantially underestimate fishing mortality, as a large fraction of the catch is typically discarded because of its relatively small size. In the 2013 stock assessment (He et al., 2013), the