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Review

A review of stock assessment packages in the United States

Catherine M. Dichmont[a], Roy A. Deng[a], Andre E. Punt[b,c,*], Jon Brodziak[d], Yi-Jay Chang[e], Jason M. Cope[f], James N. Ianelli[g], Christopher M. Legault[h], Richard D. Methot Jr[f], Clay E. Porch[i], Michael H. Prager[j], Kyle W. Shertzer[k]

[a] CSIRO Oceans and Atmosphere Flagship, Ecosciences Precinct, Dutton Park, QLD, 4750, Australia
[b] CSIRO Oceans and Atmosphere Flagship, Castray Esplanade, Hobart, TAS, 7001, Australia
[c] School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, WA, 98195, USA
[d] National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Honolulu, HI, 96818, USA
[e] Joint Institute for Marine and Atmospheric Research, University of Hawaii—NOAA Fisheries, Honolulu, HI, 96818, USA
[f] National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA, 98112, USA
[g] National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA, 98115, USA
[h] National Marine Fisheries Service, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA
[i] National Marine Fisheries Service, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL, 33149-1099, USA
[j] Prager Consulting, 2124 SE Grant Street, Portland, OR, 97214, USA
[k] National Marine Fisheries Service, Southeast Fisheries Science Center, 101 Pivers Island Road, Beaufort, NC, 28516, USA

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ABSTRACT

Stock assessments provide scientific advice in support of fisheries decision making. Ideally, assessments involve fitting population dynamics models to fishery and monitoring data to provide estimates of time-trajectories of biomass and fishing mortality in absolute terms and relative to biological reference points such as B_{MSY} and F_{MSY}, along with measures of uncertainty. Some stock assessments are conducted using software developed for a specific stock or group of stocks. However, increasingly, stock assessments are being conducted using packages developed for application to several taxa and across multiple regions. We review the range of packages used to conduct assessments of fish and invertebrate stocks in the United States because these assessments tend to have common goals, and need to provide similar outputs for decision making. Sixteen packages are considered, five based on surplus production models, one based on a delay-difference model, and the remainder based on age-structured models. Most of the packages are freely available for use by analysts in the US and around the world, have been evaluated using simulations, and can form the basis for forecasts. The packages differ in their ease of use and the types of data inputs they can use. This paper highlights the benefits of stock assessment packages in terms of allowing analysts to explore many assessment configurations and facilitating the peer-review of assessments. It also highlights the disadvantages associated with the use of packages for conducting assessments. Packages with the most options and greatest flexibility are the most difficult to use, and see the greatest development of auxiliary tools to facilitate their use.

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* Corresponding author at: CSIRO Oceans and Atmosphere, Castray Esplanade, Hobart, TAS, 7001, Australia.
E-mail address: aepunt@uw.edu (A.E. Punt).

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1. Introduction

Management of many of the world's marine fish and invertebrate stocks is supported by scientific advice based on stock assessments (Mace et al., 2001). Stock assessments are typically used for one of two (related) reasons: 1) as research tools to examine underlying fishery/biological relationships (e.g., spawner-recruit relationships) in a population model context, and 2) to provide management advice and estimate quantities of management interest. Many fisheries in countries such as the United States (US), Canada, Australia, and New Zealand, as well as fisheries in European waters and international fisheries managed by Regional Fishery Management Organizations, base management advice on estimates of abundance and fishing mortality derived from stock assessments. These estimates are typically expressed both in absolute terms and relative to reference points. They often are used as the basis for applying harvest control rules or evaluating proposed regulatory measures (such as total allowable catches or limits on fishing effort) that will frame management actions. The value of this technical approach to fishery management is exemplified in Worm et al. (2009).

The comprehensiveness of stock assessments, and the number of data sources, is continuing to increase. The assessments conducted in the 1970s and 1980s that estimated biomass and fishing mortality[1] were typically based on Virtual Population Analyses (VPA; Laurec and Shepherd, 1983; Pope and Shepherd, 1982; Shepherd, 1999) or surplus production (biomass dynamics) models (Schnute, 1977; Butterworth and Andrew, 1984). These methods relied on estimates of catch, effort, and, in the case of VPA, catch-at-age data. The trend in stock assessments since 1982 has been towards 'integrated' or 'statistical' methods that separate the model of the population dynamics from the error model, i.e., the model that relates observations to predictions of the population dynamics model (e.g., Fournier and Archibald, 1982; Deriso et al., 1985; Methot, 1990). In contrast to earlier approaches, "integrated" assessment methods allow more and diverse data sets to be included in assessments (Maunder and Punt, 2013). These methods also allow uncertainty to be propagated through the model and be quantified using frequentist and Bayesian methods (Magnusson et al., 2013; Stewart et al., 2013), and they allow much more complex population dynamics models as the basis of stock assessments. Few assessments explicitly allow trophic interactions to influence management actions (but see Plagányi et al., 2014). However, increasingly, assessments used to provide scientific advice allow for spatial structure (e.g., Punt et al., 2000; Thorson and Wetzel, 2015) and analyse data for multiple stocks of the same species (e.g., Punt and Kennedy, 1997; Porch et al., 2001; McKenzie, 2015) and even multiple species (e.g., Dichmont et al., 2003) simultaneously.

The increasing complexity of stock assessments has not come without cost. In particular, the technical skills required to apply modern stock assessment methods has increased substantially, not only because analysts need to select the model type and specification to use, but because, with multiple data sources, it is necessary to weight each data source as well as each data point within each data source, and the results of stock assessments can be sensitive to how data are weighted (Richards, 1991; Francis, 2011). In addition, there may be many options within any one modelling package. Unfortunately, there are an insufficient number of suitably qualified scientists to conduct stock assessments. The lack of assessment analysts has been best documented in the US (DoC, 2008), but is a worldwide issue. Effective use of existing stock assessment tools requires training, and in the US at least, the key federal agency supporting stock assessments, the US National Marine Fisheries Service (NMFS), has invested in supporting university faculty to increase the number of new scientists capable of conducting stock assessments (e.g., Berkson et al., 2009), as well as in funding for students studying population dynamics.

The importance of stock assessments as the basis for fisheries management advice has meant that the need for an effective peer-review process has increased in concert with the complexity of the stock assessment methods used to provide advice. Affected members of fishing and conservation communities do not always understand the technical details of assessment methods, so they rely on an independent review process that is impartial, scientifically rigorous and open to the public, to ensure that the assessment results provide the best available information for management. Peer review evaluates many aspects of a stock assessment, including choice of assessment method, selection and weighting of data (e.g., catch, abundance, and life history), selection of options when applying the assessment method, and model fit to available data. Often, alternative model configurations are developed by the analysts, and the peer review process leads to a selection of which, if any, of those configurations should form the basis for management advice. Peer review of stock assessments is made more challenging if the reviewers are not familiar with the assessment method, including whether it performs as expected. Reviewers are more likely to be familiar with standard packages than with stock-specific models.

Both to facilitate peer review and accommodate increasing complexity, there is a trend towards use of stock assessment packages. For example, in 1999, all assessments for fish stocks in Australia's Southern and Eastern Scalefish and Shark Fishery were based on stock-specific models coded by the assessment analysts. However, in 2015, all but one of these assessments were conducted using a stock assessment package (Stock Synthesis) developed in the US (Methot and Wetzell, 2013). This trend is evident in several other fisheries management jurisdictions, because use of packages reduces the time it takes to conduct a stock assessment and can benefit from improvements based on repeated use and past simulation testing. However, use of packages is not without disadvantages.

This paper provides overall summaries, minimum data requirements, key technical aspects, outputs and projection capability, and information about software and maintenance of sixteen stock assessment packages developed for application to fish and invertebrate stocks under federal management in the US, and discusses the advantages and disadvantages of using packages for stock assessment. The paper also has a second goal to help distinguish the different assessment packages from each other to help with model

[1] Other methods such as yield-per-recruit analysis were, and continue to be, applied but do not provide estimates of biomass and fishing mortality.