SISAM 2012

ICES Strategic Initiative on Stock Assessment Methods

ICES CM 2012/ACOM/SCICOM:01

Ref. ACOM, SCICOM

Report on the Classification of Stock Assessment Methods developed by SISAM

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2012. Report on the Classification of Stock Assessment Methods developed by SISAM. ICES CM 2012/ACOM/SCICOM:01. 15 pp.

Contents

Executive Summary

This report provides a new classification of stock assessment methods that has been developed by the Strategic Initiative on Stock Assessment Methods (SISAM). The classification approach is carried out according to the amounts and/or types of data they use and the degree of age-structured population dynamics. This classification will be useful for organizing information about available approaches and subsequently providing a guide to assist ICES Working Groups and other fish assessment groups around the world in the selection of the most appropriate methods to consider for assessment of their stocks. While a number of axes are relevant for model classification, as model features are multi-dimensional, the "age" axis has been chosen here as it encapsulates an important differentiation between models as one transition from the simplest to the most complex. The eight core groupings of the classification scheme are catch only, time series, biomass dynamics models (also termed production models), delayed difference models, age-structured production models, VPA based approaches, statistical catch-at-age models and integrated analysis models (which can be length or age based). The rationale and broader description for the classification scheme is described in the report. Some of the features used in differentiating these model categories will occur at multiple levels. The degree to which Bayesian statistical procedures are used varies throughout the spectrum of models. Procedures to model process and measurement error also vary among the many assessment model implementations.

1 Introduction

The Strategic Initiative for Stock Assessment Methods (SISAM) is designed to assure that ICES scientists can apply the best methods when developing management advice. Other RFMOs and national fishery organizations have a similar goal, so success of SISAM will have benefits for the entire international fishery science community (see membership and support in annex 1). SISAM will contribute to the improved application of assessment methods, but it must be recognized that "best methods" is not a static definition. Rather, the set of available methods will continue to evolve and improve in response to lessons learned in their current application. SISAM needs to do more than define the current state-of-the-science, it should help chart the future course of this scientific enterprise. Long-term success in application of the best methods is an iterative, multi-step process. These steps should involve:

1) identification of the current set of available methods;

2) guidance in the selection of the most appropriate methods for a particular application;

3) education and access to expert information regarding method usage;

4) encouragement for further testing and development of methods to more closely align with particular management needs to take advantage of advances in statistical theory, computing power, and new knowledge.

SISAM can contribute to this process by directly advancing steps 1 and 2 and serving as a valuable catalyst for steps 3 and 4. SISAM proposes to accomplish this by producing a technical report, sponsoring an international symposium on fishery assessment methods, and publishing key papers in the ICES Journal of Marine Science. SISAM will seek to encompass approaches that range from quantitative procedures applicable in data-poor situations, through tactical assessment approaches that typify assessment advice today, to multi-species and environmentally-linked models that are at the forefront of research today. Within this range, the principal focus will be on the tactical assessment approaches, with briefer consideration to the data-poor and advanced model categories.

With this regard, the first output of SISAM is the following classification method for Stock Assessment Methods.

WORLD CONFERENCE ON
STOCK ASSESSMENT METHODS

2 The SISAM Classification of Assessment Models

The purpose of this document is to describe a classification of fish assessment approaches according to the amounts and/or types of data they use and the degree of age-structured population dynamics. This classification will be useful for organizing information about available approaches and subsequently providing a guide to assist ICES Working Groups and other fish assessment groups in the selection of the most appropriate approaches to consider for assessment of their stocks. While a number of axes are relevant for model classification, as model features are multi-dimensional, the "age" axis has been chosen here as it encapsulates an important differentiation between models as one transition from the simplest to the most complex.

2.1 Terminology

"**Catch**" refers to total catch (including discards to extent feasible) in biomass or numbers, but without information about the age and/or length structure of the catch.

"**Abundance index**" generally refers to a relative index assumed to be proportional to the abundance of fish as modified by the assumed or estimated size and age selectivity of the fishery or survey that is the source of the data.

Each model category is characterized according to:

a) Population dynamics structure (sometimes including also assumptions about the abundance indices used in the model fitting)

b) Minimum data requirements

c) Typical data used when fitting the model

d) Examples of models or software in that category

e) Management advice that can be provided

f) Limitations.

Comments on management advice generally refer to MSY-related concepts. When these can be provided, so can the replacement yield (RY) that will maintain current abundance, though not vice versa.

2.2 Additional comment

Some of the features used in differentiating these model categories will occur at multiple levels. For example, multi-area configurations with stock-structure data might be used in a biomass dynamics model, while full integrated analysis models can be configured to operate with limited data and be configured to perform as biomass dynamics models. The degree to which Bayesian statistical procedures are used varies throughout the spectrum of models. Procedures to model process and measurement error also vary among the many assessment model implementations. Table 1 summarizes information about the model categories described, including some additional characteristics that help distinguish their general features.

2.3 The World Conference on Stock Assessment Methods (WCSAM)

The World Conference on Stock Assessment Methods for Sustainable Fisheries will take place in Boston, USA from 16–18th July 2013. For details go to http://ices.dk/iceswork/symposia/wcsam.asp

3 Classification of models with regard to use of age data and age-based population dynamics

3.1 Catch only

a) Population dynamics – often none assumed, but some use basic biomass dynamics.

b) Minimum data – catch.

c) Typical data – catch, some expert opinion on natural mortality and stock depletion or sustainability of the recent catch.

d) Example – Depletion Corrected Average Catch (DCAC; MacCall, 2009).

e) Management advice – advice on whether recent average catch is sustainable or not.

f) Limitations – on the whole, they provide only a placeholder for management advice until direct information on stock status and/or trends can be obtained.

3.2 Time series models

a) Population dynamics – none or minimal assumptions, just examining catch and/or index as time series. Formal time series methods may be used to examine the predictability of the time series.

b) Min data – catch or abundance index time series.

c) Typical data – catch and abundance index.

d) Example – AIM (NOAA Fisheries Toolbox), empirical management procedures

e) Management advice – at one end of the range, restricted to qualitative advice about whether the stock is trending up, down, or is stable, and on whether the stock is approaching a possible trigger for management action (e.g. the lowest point in the abundance index time series); at the other end may (perhaps given further assumptions) provide RY, or even catch limits related to an abundance target objective.

f) Limitations – cannot provide advice on the absolute level of the fish stock or the direct effect of fishing on the stock as models in the following categories are able to do.

3.3 Biomass dynamics models (also termed Production models)

a) Population dynamics – aggregate biomass dynamics controlled by a low number of parameters: typically just K (carrying capacity), r (intrinsic growth rate), initial population biomass and a catchability coefficient related to fishing mortality.

b) Min data – catch and one relative abundance index.

c) Typical data – catch and one or several abundance indices.

d) Example –Dynamic Schaefer or Pella-Tomlinson model, ASPIC (Prager, 1994).

e) Management advice – with sufficient contrast in the time series, these methods can provide estimates of MSY, current biomass relative to BMSY, current F relative to FMSY and are able to estimate the current catch that would correspond to FMSY.

f) Limitations – require good contrast in the time series, preferably by having observations above and below BMSY, as well as periods where the abundance index increases over time; they cannot incorporate any biological information regarding individual body growth, maturity or natural mortality rate.

3.4 Delay-difference models

a) Population dynamics - similar to biomass dynamics but with at least two life stages, one typically for fish before recruitment and another one for the fishable pool of the stock; often some somatic growth relationship and natural mortality included in the population dynamics.

b) Min data – catch, abundance index, inputs for body growth function and natural mortality.

c) Typical data – min data with the abundance index consisting of a recruitment index and a recruited (adult) index.

d) Examples – Deriso (1980), Catch-Survey Analysis (Collie and Sissenwine, 1983), various others involve approaches to dealing with process error and/or state-space formulations.

e) Management advice – generally similar to that provided by biomass dynamics models; depending on complexity, age-related reference points such as Fmed may be possible.

f) Limitations – generally similar to biomass dynamics models, although they have more flexibility and nominally some more biological realism than the biomass dynamics models.

3.5 Age-structured production models

a) Population dynamics – full age structure, uses a spawner-recruitment relationship (the estimable parameters of which play the role of the r and K of the biomass dynamics models) and may or may not include estimation of stochastic annual deviations in recruitment; information on natural mortality, body-weight-at-age, maturity-at-age and fishery selection-at-age must be specified by the user; each fleet included in the model, and each abundance index used in the model fitting, can have its unique age-selection, so essentially this is a superset of the capabilities of the delay-difference, two-stage models. The population dynamics in an age-structured production model are carried forward into statistical catch-at-age and age-structured integrated analysis models.

b) Min data – catch, abundance index with specified selection pattern at age, natural mortality, body weight-at-age and maturity/fecundity-at-age.

c) Typical data – min data plus additional abundance indices. No age or size composition data from which selectivity might be estimated.

d) Examples – Age-Structured Production Model (ASPM); stochastic versions include Walters, Martell and Korman (2006) and Depletion-Based Stock Reduction Analysis (Dick and MacCall, 2011).

e) Management advice – generally similar to biomass dynamics models, but can more closely match the actual age-selection characteristics of the fisheries and abundance indices, thus reducing potential biases.

f) Limitations – when using a deterministic stock-recruitment relationship (as in "standard" ASPM), biases will arise if fluctuations in recruitment are a prominent feature of the stock's dynamics.

The model categories that follow below all use age or size-structured population dynamics and differ with regard the degree to which they depend upon age composition data. These categories are: Virtual Population Analysis (VPA), which is highly dependent on fishery catch-at-age data; Statistical Catch-at-Age (SCAA), which generally expects a reasonably complete set of catch-at-age data and that any fishery or survey composition data be transformed into age before being input to the model; and Integrated Analysis (IA), which is most flexible with regard to use of age and/or length data and strives to deal with data in as unprocessed a form as feasible. While SCAA models can be considered a subset of IA models, they are separated out in this classification scheme because of the broad extent to which SCAA models, as defined here, have been developed and applied. It is important to distinguish age-structured dynamics from the availability of age data. Models with age-structured dynamics can be used to examine simpler types of data (length composition and aggregate biomass), and length composition data can be sliced into age components to provide inputs to age-structured models that require data in the form of age composition.

3.6 VPA-based approaches

a) Population dynamics – population abundance at age directly calculated from catch-at-age (treated as known and without error in every time step) and natural mortality, starting from the latest year and oldest true age for each cohort (excluding the plus group); treatment of the plus group varies among software packages; often incorporate fits to age-specific abundance indices; minimal assumptions concerning selection-at-age patterns.

b) Min data – complete, high quality catch-at-age and weight-at-age for every time step and one abundance index for calibration (typically termed "tuning" in a VPA context).

c) Typical data – min data and several age-specific abundance indices.

d) Examples – XSA, ADAPT, VPA2BOX.

e) Management advice – advice is generally limited to estimates of time series of B and F; if a spawner-recruitment function is fitted to model outputs, complete advice on status determination and forecasts of limit and target catch levels can be provided.

f) Limitations – needs complete, high precision catch-at-age data, which is not met for many stocks; highly structured fishing mortality calculations allows less flexibility in distributing the goodness of fit than can be obtained with Integrated Analysis and statistical catch-at-age models; often packages use ad hoc approaches in estimating ("tuning") parameter values, so that the absence of a complete likelihood framework renders confidence interval estimation problematic. Works best when fishing mortality rates exceed natural mortality rates, so that measured cumulative removals by the fishery dominate the mortality process.

3.7 Statistical catch-at-age (SCAA) models

a) Population dynamics – age-structured, incorporating natural mortality, recruitment deviations (but many of the models implemented do not employ internal spawner-recruitment relationships and treat recruitments as free parameters), and fishing mortality (the fishery selection-at-age may be constant or change over time according to some constraints); some implementations have a specialized approach to deal with discarded catch separately from landings; SCAA models, the stochastic versions of Age-Structured Production Models and Integrated Analysis models share many characteristics, and differ mostly in the particular features enabled in various software packages or custom model implementations; if reasonably complete age data are available, SCAA models are simpler to apply than the more general integrated analysis models.

b) Min data – catch, statistical sample of catch age composition, abundance index; some missing catch-at-age data are allowed (in contrast to VPA); some implementations allow the catch data to be separated into landings and discards.

c) Typical data – catch, abundance index, statistical sample of age composition of catch and abundance index.

d) Examples – ASAP, AMAK, SAM, many custom ADMB coded applications.

e) Management advice – generally complete advice on status determinations and forecasts of limit and target catch levels are attainable if spawner-recruitment dynamics are embedded. Otherwise, advice is limited to estimates of B and F time series.

f) Limitations – no generic limitations; flexibility of software package to include additional factors is highly diverse and not easily categorized; because the spawner-recruitment dynamics are not typically embedded in the model, a separate analysis is usually needed to derive MSY based quantities.

3.8 Integrated Analysis (IA) models

These models tend to be highly general with regard to the types of data that can be included and, on the whole, they strive to analyze data with as little pre-processing as possible, for example using length composition data and information in the age-length key directly, rather than inputting the derived age composition data to the model. The models in categories 5 and 7 above are special cases of integrated analysis models. Two sub-categories are defined based upon whether the population dynamics, internal to the model, are length-based or age-based.

A-IA models with length-structured population dynamics

a) Population dynamics – length-structured, with a length-based transition matrix to update the stock's length composition between consecutive time steps; can incorporate natural mortality, growth, recruitment (which may or not be based on a stock-recruitment relationship, with or without deviations), and fishing mortality at length; the inclusion of size composition data allows for the estimation of (possibly time-varying) fishery and abundance indices selection patterns, and the time sequence of recruitments; some implementations allow separate treatment of landings and discards.

b) Min data – catch, abundance index, length composition data (some missing data allowed).

c) Typical data – catch, abundance index, length composition data; some implementations allow the catch data to be separated into landings and discards.

d) Examples –CASAL, CASA (Sullivan *et al.*, 1990), Chen (2005) lobster model.

e) Management advice – generally complete advice on status determinations and forecasts of limit and target catch levels are attainable if spawner-recruitment dynamics are embedded. Otherwise, advice is limited to estimates of B and F.

f) Limitations – Less precision on recruitment estimation than can be obtained when age data are available; less accurate information on mortality of older animals than can be obtained from age data.

B-IA models with age-structured population dynamics

a) Population dynamics – basically same population dynamics structure as for all age-structured models. Typically models recruitment as deviations from spawner-recruitment function; may allow for multiple areas and multiple growth patterns; time-varying population and observational processes with possible environmental covariates; internal estimation of natural mortality; internal estimation of growth using age-at-length data; can account for ageing imprecision. These models strive for dealing with data in as unprocessed a form as feasible, thus are distinct from the SCAA models that tend to expect a relatively complete matrix of catch-at-age data. With high age data quality and allowing for a high degree of time-varying selectivity, IA models can approach a VPA configuration; in weak data situations, use of fixed parameters or priors mimics a simple stochastic age-structured production model. Thus, these provide a complete modeling framework. By including more processes in the model, these models strive to reduce bias caused by the simpler assumptions used in other models.

b) Min data – catch and an abundance index (some missing data allowed); some implementations allow the catch data to be separated into landings and discards.

c) Typical data – catch, multiple abundance indices, age and/or length composition data; may also include age-at-length data to assist in estimation of growth; may also include tag-recapture data to assist estimate fishing mortality, natural mortality and its age dependence and movement, and also stock structure (including genetics) data to estimate proportions of different stocks present in an area.

d) Examples – Stock Synthesis, CASAL, Multifan-CL, IWC minke whale multi-stock models.

e) Management Advice – generally complete advice on status determinations and forecasts of limit and target catch levels are attainable, as spawner-recruitment dynamics are usually embedded. Otherwise, advice is limited to estimates of B and F.

f) Limitations – the diversity of types of data that can be included can be daunting; model complexity is high and their use requires highly trained experts; given the flexibility intrinsically allowed by the framework, there is a danger of overparameterizing the model and overfitting the data (as with SCAA models).

4 References

Chen, Y., Kanaiwa, M., and Wilson, C. 2005. Developing and evaluating a size-structured stock assessment model for the American lobster, Homarus americanus, fishery. New Zealand Journal of Marine and Freshwater Research, 39(3):xx

Collie, J. S., and Sissenwine, M.P. 1983. Estimating population size from relative abundance data measured with error. Canadian Journal of Fisheries and Aquatic Sciences, 40: 1871–1879.

Deriso, R. B. 1980. Harvesting strategies and parameter estimation for an age-structured model. . Canadian Journal of Fisheries and Aquatic Sciences, 37: 268–282.

Dick, E.J., and MacCall, A.D. 2011. Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. Fisheries Research, 110: 331–341

MacCall, A. D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES Journal of Marine Science, 66: 2267–2271

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fishery Bulletin, 92: 374–389.

Sullivan, P.J., Lai, H.-L., and Gallucci, V.F. 1990. A catch-at-length analysis that incorporates a stochastic model of growth. Canadian Journal of Fisheries and Aquatic Sciences, 47: 184–198.

Walters, C. J., Martell, S.J.D., Korman, J. 2006. A stochastic approach to stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences, 63: 212–223.

Table 1. Summary of SISAM Classifications of Stock Assessment Methods

Category	**Age-dynamics**	**Stock-recruitment function and density-dependence**	**Growth dynamics**	**Age data**	**Index**	**Multiple fleets**	**Multiple Areas**	**Time-varying characteristics**	**Example**
Catch-only	No	Implicit	No	No	No	No	No	No	DCAC
Time series	No	No	No	No	One	No	No	No	AIM
Biomass dynamics	No	Implicit S-R in logistic population model (r,K)	No	No	Multiple	No	No	No	ASPIC
Delay-difference	Partial	No	Yes	No	One, Two	No	No	No	Deriso
Age-structured production	Yes	Spawner-recruitment	Varies	No	Multiple	Varies	No	No	Anon ("standard" ASPM); stochastic versions by Walters&Martell, DB-SRA (Dick&MacCall)
Models with length and/or age composition data									
VPA	Yes, as backwards calculation	Almost always no	Empirical wt-at-age	Mandatory	Multiple	No, except Two-Box	Two-Box (Porch)	Yes for fleet, not for index	XSA, ADAPT
SCAA	Yes	Usually no	Empirical or model-based	Yes	Multiple	Varies	No?	Varies	Numerous
Integrated Analysis (IA)									
Length-structured	No. Length-based instead	Varies	Yes	No. Length instead	Multiple	Yes	Yes	Yes	CASAL, CASA, lobster and crab models
Age-structured	Yes	Usually yes	Yes	Length and/or age	Multiple	Yes	Yes	Yes	CASAL, Stock Synthesis, Multifan-CL

Annex 1. Members of SISAM Steering Group.

Name	**Organisation/ country**	**email**
Rick Methot	USA	richard.methot@noaa.gov
Doug Butterworth	South Africa	doug.butterworth@uct.ac.za
Carmen Fernández	ICES	carmen.fernandez@ices.dk
Steve Cadrin	USA	scadrin@umassd.edu
Mark Dickey-Collas	ICES	mark.dickey-collas@ices.dk
Jean-Jacques Maguire	ICES	JJ.Maguire@ices.dk
Yimin Ye	FAO	Yimin.Ye@fao.org
Victor Restrepo	ISS Foundation	VRestrepo@iss-foundation.org
Ana Parma	Argentina	parma@cenpat.edu.ar
Tony Smith	Australia	Tony.D.Smith@csiro.au

Contributions to SISAM have been made by:

José De Oliveira (jose.deoliveira@cefas.co.uk)

Anna Rindorf (ar@aqua.dtu.dk)

Jason Link (jason.link@noaa.gov)

SISAM is supported by ICES, FAO, NAFO, ISSF and NOAA.