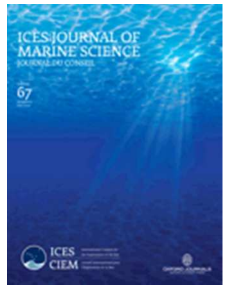


# What if stock assessment is as simple as a linear model? - The a4a Initiative


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# What if stock assessment is as simple as a linear model?

## The a4a Initiative

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**Abstract**

This manuscript discusses the benefits of having a stock assessment model that is intuitively close to a linear model. It creates a case for the need of such models taking into account the increase in data availability and the expansion of stock assessment requests. It explores ideas around the assessment of large numbers of stocks and the need to make stock assessment easier to run so that more scientists from distinct backgrounds can be involved. It shows as an example the model developed under the European Commission Joint Research Center's “Assessment for All” Initiative (a4a) and how it fits the on the a4a strategy of making stock assessment

both simpler and more powerful.

## Background and needs

### *Background*

The volume and availability of data useful for fisheries stock assessment is continually increasing. Time series of 'traditional' sources of information, such as surveys and landings data, are getting longer, and cover more species than before.

In Europe, for example, the 2009 revision of the Data Collection Regulation (EU, 2008a) has changed the focus of fisheries sampling programmes away from providing data for individual assessment of 'key' stocks (*i.e.* those that are economically important) to documenting fishing trips, thereby shifting the perspective to a large ocean monitoring programme. The result has been that data on growth and reproduction of fish stocks are being collected for more than 300 stocks in waters where the European fleets operate, and catches from all major fisheries are monitored with on-board and market sampling programmes. Moreover, scientific surveys are carried out through out European waters collecting fisheries independent data, which is afterwards available for stock assessment.

In the US, the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 requires annual catch limits for all federal fisheries to be set, including setting appropriate limits to account for scientific and management uncertainties. Such demanding management frameworks require data collection, and data analysis, on a larger number of stocks.

FAO and Norway have been running the Nansen project[1] that surveys the African coast since 1975 (Sætersdal et.al. 1999). The project collects information about the size and age structure of several fish stocks in African waters, as well as biological information.



In contrast, data collection in Australia and New Zealand is closely linked with the economic value of the fishery. Although such an approach avoids spending funds on stocks that are not assessed, limiting data collection to only the currently economically important stocks misses the potential of developing a long term strategy with regards to fisheries resources management.

We are thus currently sitting on the largest assemblage of fisheries data ever available, one which is still growing in size. These data provides the opportunity for assessing the status of not just the economically important stocks, but also of stocks that may become economically important in the future, or those that play other important roles, such as in ecosystem function. Furthermore, it raises the possibility of assessing the status and trends of all stocks in a sea-basin or ecosystem, bringing us closer to

1 http://www.eaf-nansen.org

ecosystem-based fisheries management (FAO, 1995; Pikitch, 2004). Furthermore the European Marine Strategy Framework Directive (EU, 2008b), the UNESCO initiative on biodiversity[2] or the Intergovernmental Platform on Biodiversity and Ecosystem Services – IPBES[3], all support the extension of fisheries advice and management systems towards considerations on the wider effect and consequences of fishing activities in the marine environment.

In spite of this notable increase in data availability, Beddington et al (2007) calculated that in the United States the stock status of 30% of the 230 major stocks and stock complexes was undetermined in 2006; in Australia (48%), New Zealand (78%), and the Northeast Atlantic (61%). In the European Union coastal waters, only about 100 stocks are currently assessed with analytical methods by either ICES or the GFCM, while Cope (2013) has recently shown that there is still a large number of stocks missing scientific advice in the US.

All of this suggests that data is likely to be less and less often the limiting factor to the provision of quantitative management advice, while the demand for the necessary tools and skills is already increasing to the point of becoming an essential strategic question in the near future.

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2 http://www.unesco.org/new/en/natural-sciences/special-themes/biodiversity-initiative/

3 http://www.ipbes.net

### *Needs identified*

The analysis above calls for some new solutions to those specific needs. Data availability and resolution, particularly for most biological parameters, will limit the level of complexity the model can realistically reach. Prior information should be thus sensibly used to fill the information gaps identified, while allowing the data to speak for itself when or if it is available.

In our opinion, the basic structure should be based around a fully statistical catch-at-age model, able to incorporate in its likelihood function any source of information available in a clear and coherent manner. The level of complexity necessary for such a model should still be compatible with an intuitive and elegant interface, able to provide users with enough control and flexibility, but without requiring the in-depth statistical knowledge generally available to very few.

Linear models provide us with the ideal interface for this task. Scientists should have been exposed, as a basic requirement, to simple statistical procedures such as linear models and generalized linear models. These are now part of most basic statistical training, and their use and familiarity has been greatly expanded by the adoption of the S/R language (Becker and Chambers, 1984), which provides a powerful but intuitive mechanism for constructing and evaluating linear models.

### *The Assessment for All Initiative (a4a)*

Recognizing that the context referred above required new methodological developments, the EC JRC started its "Assessment for All" Initiative (a4a), with the aim of developing, test and distribute the necessary methods to assess large numbers of stocks in an operational time frame, and to build the necessary capacity on stock assessment and advice provision.

The a4a initiative has at its core a team of fisheries scientists from the EC JRC carrying out the development of those methods, but supported by a small but global network of scientists from different fisheries research and advice institutions. This is in turn complemented by a larger network of scientists that act as "sounding boards" and sporadically contribute with comments or revisions from the point of view of their particular fisheries. More detailed information on the organizational arrangement of the initiative can be found at the a4a website[4], together with the full collection of software and documentation.

One major step to achieve the a4a goals was the development of a stock assessment model that could be applied rapidly to a large number of stocks and for a wide range of applications: traditional stock assessment, conditioning of operating models, forecasting, or informing harvest control rules in MSE algorithms.

4 https://fishreg.jrc.ec.europa.eu/web/a4a

## Stock assessment framework

The model chosen was a statistical catch-at-age model implemented in R (R Core Team, 2013), making use of the FLR platform (Kell et.al, 2007), and using automatic differentiation, as implemented in ADMB (Fournier et.al, 2012), as the optimization engine. The framework is fully open sourced and free to use and modify, to better promote the required transparency, transferability and repeatability that should form the basis of scientific advice on public natural resources. The R language provides a strong platform, with already implemented state-of-the-art statistical analysis tools, while ADMB is a sophisticated package for finding optimal solutions in highly non-linear models, supported on solid statistical theory, that allows estimation of the statistical characteristics of the parameters. Having a full statistical approach allows the usage of the common statistical tools for post processing of model results, like diagnostics, model comparison (*e.g.* AIC, BIC, cross validation), model averaging, simulation, etc.



### *Description*

The a4a framework (Millar et.al, 2013) can fit models with the basic structure:

$$C_{at} = F_{at}/Z_{at}\,(1 - \exp(-Z_{at}))\, R_{t-r} \exp(-Z_{a-1,t-1} - \ldots - Z_{r,t-r})\exp(e_{at}) \quad (1)$$

$$I_{ats} = Q_{ats}\, R_{t-r} \exp(-Z_{a-1,t-1} - \ldots - Z_{r,t-r})\exp(e_{ats}) \quad (2)$$

where, $C$ is the observed catch at age $a$ and time $t$, $I$ is the observed index, and the *e* are independent and identical distributed normal error terms. Each cohort decays deterministically, and initial cohort size is given by $R_{t\text{-}r}$, where *r* is the youngest observed age in the catch. Finally $Z = F + M$, where *Z* is the total mortality rate, *F* is mortality due to fishing, *M* is other (known) sources of mortality, and *Q* is the survey, s, and maybe year specific catchability at age.

To fit this model to data, there are three major aspects of the model that need to be given a structure: fishing mortality (*F*), survey catchability (*Q*) and recruitment (*R*). In the a4a framework these aspects are called sub-models. Sub-models for *F* and *Q* have the form:

$$\log F_{at} = b_1 + x_{1at} + \ldots + b_k + x_{kat} \qquad (3)$$

which are essentially linear models, but can incorporate linear functions of age and year and fixed degrees of freedom splines which can vary with age, year or both age and year, and potentially other covariates.

The recruitment sub-model can use linear models as well, or a stock-recruitment model, which is written in the following form

$$R_t = f(a, b; R, S)\ exp(e_t) \qquad (4)$$

where the function *f* is a standard stock recruitment model with parameters *a* and *b*, that takes as data previous recruitments (*R*) and spawning stock biomass (*S*) based on model estimates of *F* and *R*. The $e_t$ are independent and identical distributed normal errors with fixed variance set up by the user. There is also the option to parameterise the recruitment sub-model further by specifying a linear model for *a* or *b.*

### *Model building*

To set up a model the user needs to define each sub-model, which is easily done using the basic R syntax for equations. This is based on the notation for model building developed by Chambers and Hastie (1992), where models are specified using expression of the form:

$$\log F \sim age + year \tag{5}$$

To show the intuitiveness of the user interface, the great number of possible sub-model implementations, and the flexibility provided by the a4a framework, a case study is presented based on the North Sea Cod (*Gadus morhua*) stock. The dataset, as used by ICES contains 15 age classes, from 1 to 15, and 48 years, from 1963 to 2011. The plus group of the catch data is set at age 10. The abundance index comes from a single survey, which covers 5 ages (1- 5) and years from 1983 to 2011.

For the sake of simplicity in the example, the *Q* and *R* models are held constant, while the emphasis is placed on showing the effect of increasing complexity on the *F* model. The *Q* model was set to be constant in time and varying across ages independently, log *Q* ~ factor(*age*). The *R* model was set as a year effect model with independently varying recruitment in each year, log *R* ~ factor(*year*).

We started by fitting a basic model (6) which considers fishing mortality to have both year and age effects, independent from each other, with one coefficient for each age and year (analogous to a separable model with VPA).

$$\log F \sim \text{factor}(age) + \text{factor}(year) \tag{6}$$

To show some additional capabilities, we now model the fishing mortality using different smoothers and interactions on the exploitation pattern with age and year. Note that using R makes available a large number of modelling methods that can be applied without requiring a long process of implementation. In this case we will use the R library "mgcv" (Wood, 2006) to set up the smoothers based on splines. The second model (7) is a smooth version of the first where each effect, age and year, is modelled with thin plate splines which introduces correlation along age and year. The third model (8) mixes the previous two, by allowing the fishing mortality at age to vary independently while a thin plate spline is used to smoothly model the fishing mortality over the years.

$$\log F \sim \text{s}(age, k{=}4) + \text{s}(year, k{=}7) \tag{7}$$

$$\log F \sim \text{factor}(age) + \text{s}(year, k{=}14) \tag{8}$$

where $k$ is related with the smoothness of the spline's basis (for more details see Wood, 2006).

The last assessment model of this example (9) uses a tensor product of cubic splines over age and year, introducing correlation along the age and the year effects, but also cross correlation between ages and years.

$$\log F \sim \mathrm{te}(age,\ year,\ k{=}\mathrm{c}(4, 10)) \qquad (9)$$

The comparative fits of the four *F* models are summarized with the plot of the fishery mortality at age and year using a 3D plot (Fig. 1).

### *Intuitive model building*

In the a4a framework, tailored model building tools are used to make the model building and exploration process more intuitive, and distance the user from the details of specifying more complex linear model formulations, such as smoothers with breakpoints or time varying smoothers. These model building tools have also been designed to protect the user from specifying models that are plainly over-parameterised, and as such provides some protection from spurious model results due to numerical issues.

In addition to making the model building process easier, it is also envisaged that by building on a mature model specification "language" will help standardize stock assessment and forecast, and bring the ability to run and review relatively complex stock assessments to a wider audience.

Scientists can then move their focus to better designing models that have a direct relevance to the stock or group of stocks under investigation, instead of being unduly concerned with model implementation. Some examples of this kind of approach currently available in the a4a model are, for example:

$$\log F \sim \text{separable}(age,\ year) \tag{10}$$

$$\log Q \sim \text{trawl}(trend = \text{"}linear\text{"}) \tag{11}$$

$$\log R \sim \text{bevholt}(a \sim \text{breakpoints}(year,\ 1988)) \tag{12}$$

### ***Simulation testing***

To test the model capacity to rebuild the underlying dynamics of stocks and fisheries, a large simulation testing exercise was carried out, using Fishbase's (Froese and Pauly, 2013) life history parameters to construct simulated populations covering a wide range of life histories. The approach taken is not to simulate exactly any specific species or stock, but instead aims to simulate fish stocks and exploitation histories that are respectively consistent with population dynamics theory and loosely based on the biology of existing species, so that a large range of life histories traits and commercial exploitation patterns can be considered. Details of the methodology and the code used are available in Jardim et.al (2013).

The results were integrated in an on-line application[5] using a database and a visualization tool that allows users to search and download subsets of the data, as well as visualizing directly the performance for particular scenarios.

Furthermore, the results provide information about the performance of the model in specific circumstances. This can inform about regions of the

[5] https://fishreg.jrc.ec.europa.eu/web/a4a/simulation-testing

parameters' space that may require more attention in order to overcome problems that already surfaced during the testing phase. It is important to bear in mind that simulation testing *per se* does not cover the full range of situations that may occur, as these are a lot wider than it is possible to simulate, but provides an useful solid benchmark against which model performance can be explored, understood and improved.

The results showed that the model was able to replicate the underlying dynamics with reasonable accuracy in most cases. Furthermore, it demonstrated that a massive number of stock assessments could be run on a broad range of stocks in a reasonable time frame.



**Final comments**

We need to change our perspective about single stock assessments. It is clear that single stock assessments are the foundation of quantitative fisheries science and advice. As reflected in the  outcomes of WCSAM (ICES, 2013) there's still a long way to go until multidimensional space-time stock assessments, or another 'perfect' model structure, become the standard. In the meantime we, as a community, should stop agonizing over the limitations of single stock assessments and focus on getting the most out of them. By including observational information on a multi-species systems, for example, single stock assessments are already indirectly taking into account multi-species interactions (Howell, 2013), a fact commonly overlooked.

So, why not start thinking about stock assessment as a starting point in this direction? We don't understand the ecological function of all species or to which ecosystem services they are contributing to. We can't even predict which species will be targeted, and with what intensity, in the future. Focusing in “key” species will be beneficial for very specific cases, like small pelagic fisheries, or fleets with very little adaptability (if there is such a thing).

So, why not aim to assess all species in a sea basin or ecosystem?

In our opinion we have the potential tools and there has been a large investment in collecting appropriate data. There are global projects aiming to manage and share that information (Pauly et.al, 2013). However, we would require a much larger number of active scientists involved and for that we need to provide tools that allow experts to do their work without getting bogged down in model implementation details.

That's the aim of the a4a initiative, to have a group of statistically robust standard methods that can be applied rapidly and without requiring a strong statistical technical background, but making the best use of the available technical knowledge on fisheries, stocks and ecosystems.

Applying these methods to all stocks in a sea basin could produce a reference dataset of biomass and fishing mortality estimates that would form the starting point for both advisory services and research work. Clearly, there will be an advantage in dealing simultaneously with stocks that are being caught by the same fleets, inhabiting the same areas and being exposed to the same management actions. Information can be shared across stocks, and modelling under a single framework will create the necessary environment to do so efficiently. The so called 'key' stocks, or those of special concern, can still be subject to more thorough analyses which, if required, could be performed with more complex stock assessment models like SS3 (Methot and Wetzel, 2013) and CASAL (Bull et.al, 2012), or tailor-made models developed using ADMB (Fournier et.al, 2012), JAGS (Plummer, 2003) or other suitable tools.

Finally, to make progress understanding the natural processes and the human behavior associated with the fishing activity, we need to diversify our knowledge base, and bring into the process a wider range of disciplines: biology, ecology, economy, and engineering. In our opinion, the best way to bring quantitative fisheries science closer to all those fields is to provide us all with a tool that different people can easily understand. Linear models in R could be the common language able to lower the barriers that limit the ability of fisheries science to establish stronger links with those disciplines, and to attract people with diverse backgrounds.

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## References

Beddington, J.R., Agnew, D.J. and Clark, C.W. 2007. Current Problems in the Management of Marine Fisheries. Science: 316 (5832), 1713-1716.

Becker, R.A. and Chambers, J.M. (1984). S: An Interactive Environment for Data Analysis and Graphics. Pacific Grove, CA, USA: Wadsworth & Brooks/Cole. 552 pp.

Bull, B., Francis, R.I.C.C., Dunn, A., McKenzie, A., Gilbert, D.J., Smith, M.H., Bain, R. and Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. NIWA Technical Report

135. 280 p.

Chambers J.M. and Hastie T.J. (1992) Statistical Models (chapter 2) in Statistical models in S, edited by J.M. Chambers and T.J. Hastie. CRC press Florida. 608 pp.

Cope, J. 2013. The (d)evolution of U.S. west coast groundfish assessments: from data-poor to data-less poor and back. Presentation to the World Conference on Stock Assessment Methods for Sustainable Fisheries, Boston, USA, 17th-19th July.

EU. 2008a. Council Regulation (EC) No 199/2008 of 25 February 2008 - concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:060:0001:0012:EN:PDF . 12 p.

EU. 2008b. Parliament and Council Directive 2008/56/EC of 17 June 2008 - establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF . 22 p.

FAO. 1995. Code of Conduct for Responsible Fisheries. Rome, FAO. 41 p.

Fournier, D.A., Skaug, H.J., Ancheta, J. Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A. and Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Froese, R. and D. Pauly. Editors. 2013. FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2013).

Howell, D. 2013. Multispecies considerations in stock assessments: “yes we can.” Presentation to the World Conference on Stock Assessment Methods for Sustainable Fisheries, Boston, USA, 17th-19$^{th}$ July.

ICES. 2013. Report of the  World Conference on Stock Assessment Methods for Sustainable Fisheries, Boston, USA, 17th-19$^{th}$ July.

Jardim, E., Millar, C., Ferretti, M., Mosqueira, I., Osio, C. and Scott, F. 2013. a4a assessment model simulation testing. JRC Technical Report, p. 10

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E. et al. 2007. FLR: An Open-source Framework for the Evaluation and Development of Management Strategies. ICES J. Mar. Sci. 64 (4): 640–646.

Methot Jr., R.D. and Wetzel, C.R. 2013. Stock Synthesis: A Biological and Statistical Framework for Fish Stock Assessment and Fishery Management. Fisheries Research 142: 86-99.

Millar C.P, Jardim, E., Osio, G.C. and Mosquera, I. (2013). Assessment for all (a4a): a flexible and robust stock assessment framework. PLOSOne (in revision).

Pauly, D., Hilborn, R. and Branch, T.A.. 2013. Fisheries: Does Catch Reflect Abundance? Nature 494 (7437): 303–306.

E. K. Pikitch, C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, et.al. 2004. Ecosystem-Based Fishery Management. Science: 305 (5682), 346-347.

Plummer, M. 2003. JAGS: A Program for Analysis of Bayesian Graphical Models Using Gibbs Sampling. Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20–22, Vienna, Austria. ISSN 1609-395X.

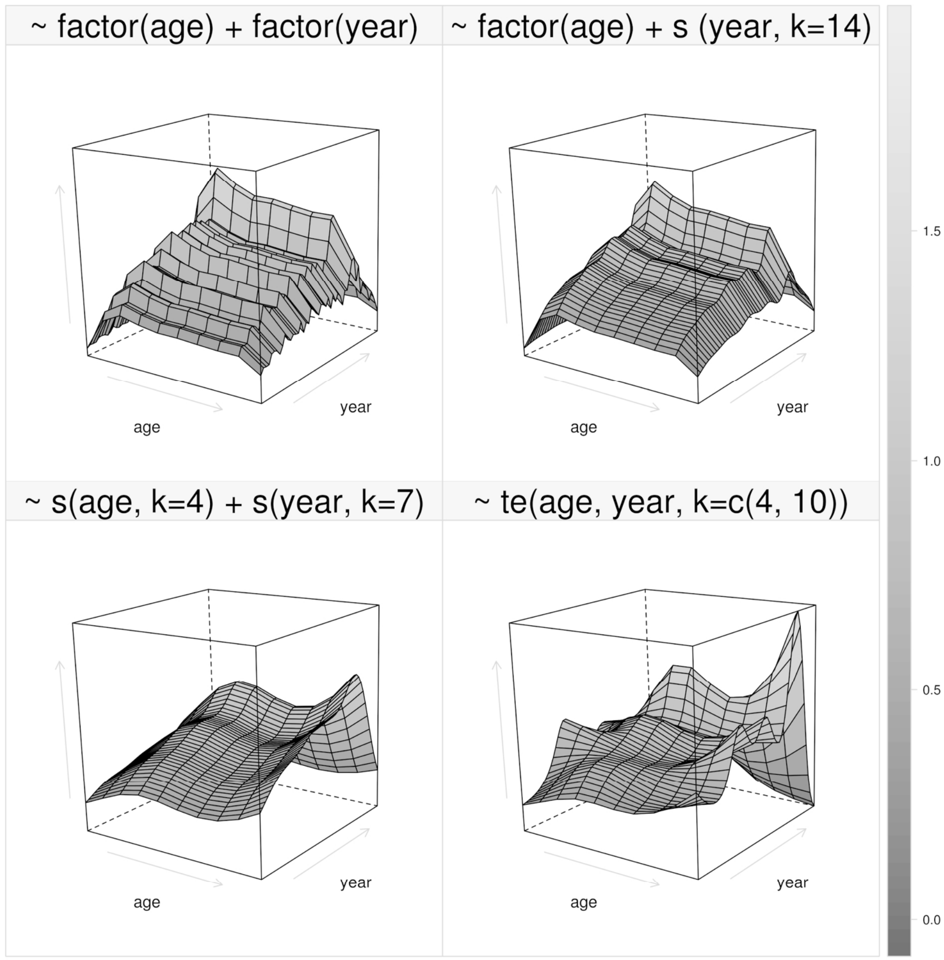
R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Sætersdal, G., Bianchi, G., Strømme, T. and Venema, S.C. 1999. The DR. FRIDTJOF NANSEN Programme 1975–1993. Investigations of fishery resources in developing countries. History of the programme and review of results. FAO Fisheries Technical Paper. No. 391. 434 p.

Wood, S.N. (2006) Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC.

## Figures

Figure 1. A graphical depiction of four fishing mortality models. Top-left: the basic model which considers fishing mortality to have a year and an age effect, independent from each other, with one coefficient for each age and year (analogous to a separable model with VPA). Bottom-left: a smooth version of the basic model where each effect, age and year, is modelled with thin plate splines which introduces correlation along age and year. Top-right: a mixture of the previous two, allowing the fishing mortality at age to vary independently while a thin plate spline is used to smoothly model the fishing mortality over the years. *k* is related with the smoothness of the spline's basis (for more details see Wood, 2006). Bottom-right: using a tensor product of cubic splines over age and year, introducing correlation along the age and the year effects, but also cross correlation between ages and years. Each panel contains the pseudo-code for fitting each model.

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