Can biomass time series be reliably assessed from CPUE time series data only?

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In a letter to Nature[2], Myers and Worm present, for a wide range of oceanic ecosystems, an analysis of catches per unit of effort (CPUE) data, leading them to the conclusion of "a rapid worldwide depletion of predatory fish communities": After a sharp initial reduction, CPUE appears stable since more than twenty years at a level of about 10% of their initial value. Such a result makes quite evident the necessity of a worldwide common "rebuilding effort" for stocks and ecosystems. Through the estimation of initial CPUE their results also provide a very useful benchmark for goal identification and estimation of the needed level of this rebuilding effort.

Those conclusions are based on the critical assumption that CPUE is proportional to abundance. This means (i) that catchability is constant and (ii) that all the biomass is catchable. If so, relative variations in CPUE indicate the same relative variations in biomass. Myers and Worm consider the first part of this hypothesis as wrong because of increasing efficiency of fishing. Therefore, a stable CPUE level, with increasing catchability means a further decrease in biomass, which makes conservatives the obtained results on biomass decreases and stronger the conclusions they present. Myers and Worm do not consider the second part of the hypothesis, and hence make the implicit assumption of entirely catchable biomass.

Those results and conclusion may appear contradictory. The initial decrease indicates a reduction in a few years below the half of the initial biomass, which means that fishing mortality was above F_{MSY} level in the very first years of fishing. As nominal effort and cathability may be assumed both increasing since the beginning of the fishery, this means that there should be no more fish...

This leads to the question of the remarkable result of stable CPUE from another point of view. The equation used by Myers and Worm is

$$N_t = N_0 \left((1-\delta) \exp^{-(\rho t)} + \delta \right), \qquad (1)$$

In which δ is "the fraction of the community that remains at equilibrium", which imply the presence of a "residual biomass" which level is $N_0\delta$.

It is more correct to acknowledge that data are CPUE and to make explicit the hypothesis of constant catchability "q". This leads to write:

$$q N_t = q N_0 \left((1-\delta) \exp^{-(\rho t)} + \delta \right) \qquad (2)$$

Therefore, according Myers and Worm, recent CPUE corresponds to catches made on the residual stable or decreasing ***catchable*** residual biomass and provides a (possibly optimistic) estimation of this biomass. In such a stationary situation, these catches are equal to the production of this biomass.

If we do not assume that all the residual biomass is catchable, another possibility is to consider the possible existence of some uncatchable quantity of biomass. This may result from several causes in the (joint) behaviour of fish and fishermen. If so, the residual CPUE may no more reflect a whole residual biomass but mainly its production. In such a case with an infinite fishing effort for example, those CPUE do not reflect the residual biomass but only its production, and biomass becomes no more estimable with such data.

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[2]R. A. Myers and B. Worm 2003. Rapid worldwide depletion of predatory fish communities. Nature 425, 280-283

As an example, we consider such an hypothesis with simulated CPUE data from 1961 to 1999 (assuming no fishing the first year) from the equation used by Myers and Worm with ρ=0.12 and δ=0.1 (figure 1, top, dashed). From those data we fit a "Schaefer like" model assuming the presence of a constant value of uncatchable biomass, expressed as a proportion α of the carrying capacity (virgin biomass) K:

$$dB_t/d_t = r\,B_t\,(1 - B_t/K) - q_t\,f_t\,(B_t - \alpha K) \qquad (3)$$

Here fishing effort f_t and catchability q_t are considered as time process represented by logistic curves, accounting for possible trends of nominal fishing effort and fishing power (efficiency). With given fishing effort and power process and given values of parameters r, K and α, we may compute CPUE time series from equation 3.

We may then address the following question:

"Does a fishing effort and a fishing power process exist which, together with r K, and α values, lead to a CPUE time series similar to the time series presented in figure 1?"

To do that we "estimate"[3] the value of the parameters through minimisation of the sum of squared differences of CPUE from this model and CPUE from the equation proposed by Myers and Worm. The answer to the addressed question is yes if the two CPUE are sufficiently similar (which may of course depend on the reader's appreciation).

With, for example, a fixed value of r=0.4 (a typical value for a top predator population, MSY being equal to rK/4, i.e. K/10), we find a near-perfect fit (figure 1) which may lead to a positive answer to the question addressed. The estimated values of K and α are 170000 and 0.43 and f_t and q_t process are presented in figure 1. Note that the biomass time series looks here similar to the time series obtained by Hampton et al[4] (2003) accounting for the fact that longlines mainly catch "old" fish. According this solution, fishing power and effort were multiplied by 2 and 10. Note that increase in catchability only concerns catchable biomass. If we consider this catchability from a "whole biomass point of view", we may write:

$$q_t(B_t - \alpha K) = qw_t(B_t)$$

Hence $$qw_t = q_t(B_t - \alpha K)/B_t$$

If so, a positive trend of q_t may result in a negative trend in qw_t (figure 1)

According to this result the level of biomass cannot decrease below 43 percent of the virgin biomass and we could conclude that there is no problem of overexploitation…

[3] The computation is done using the software written for analysis of flexible multifleets-multispecies fisheries as described in Pech et al. 2001(fitting a flexible model multifleet-multispecies fisheries to Senegalese artisanal fishery data. Aquatic Living Resources 14, 81-98). In the present example there is one species and one fleet the units of which have only one available tactic. The fit is done by searching the parameters α and K and the parameters of the logistic functions describing the time series of size of the fleet and of the catchability. Natural mortality is assumed to be 0.2 (corresponding to r=0.4). The criterion to be minimized is the sum of squared differences between observed (simulated from the equation provided by Myers and Worm) and fitted CPUE. This software can be used with S-Plus 2000 package and may be sent on request to the author.

[4] J. Hampton, J.R. Sibert and P. Kleiber, 2003. Comment on Myers & Worm Nature, 423:280-283) http://www.spc.int/OceanFish/Docs/Research/Myers_comments.htm

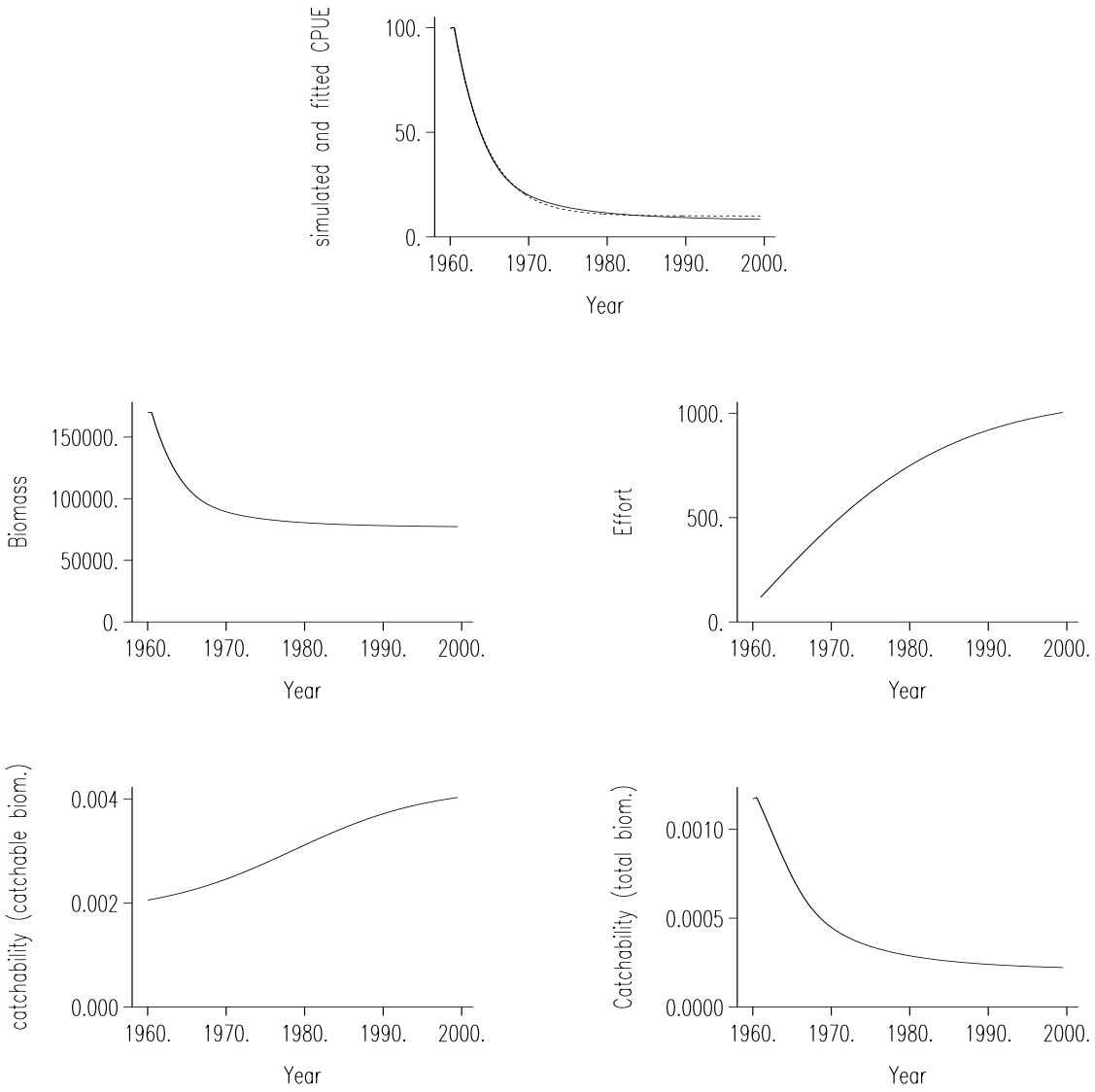

Figure 1 Solution with 43% of virgin biomass uncatchable: simulated (crosses) and fitted biomass (top); biomass (middle left), effort (middle right), catchability referring to catchable biomass (bottom left) and total biomass (bottom right)

Such a conclusion would be an error because the solution is not unique.

We also find "good solutions" for many other lower values of α. For example, results presented in figures 2 are obtained with α=0.05 which leads to a low residual biomass. Note also in this case that the increase of effort occurs very early, which may appear more or less realistic.

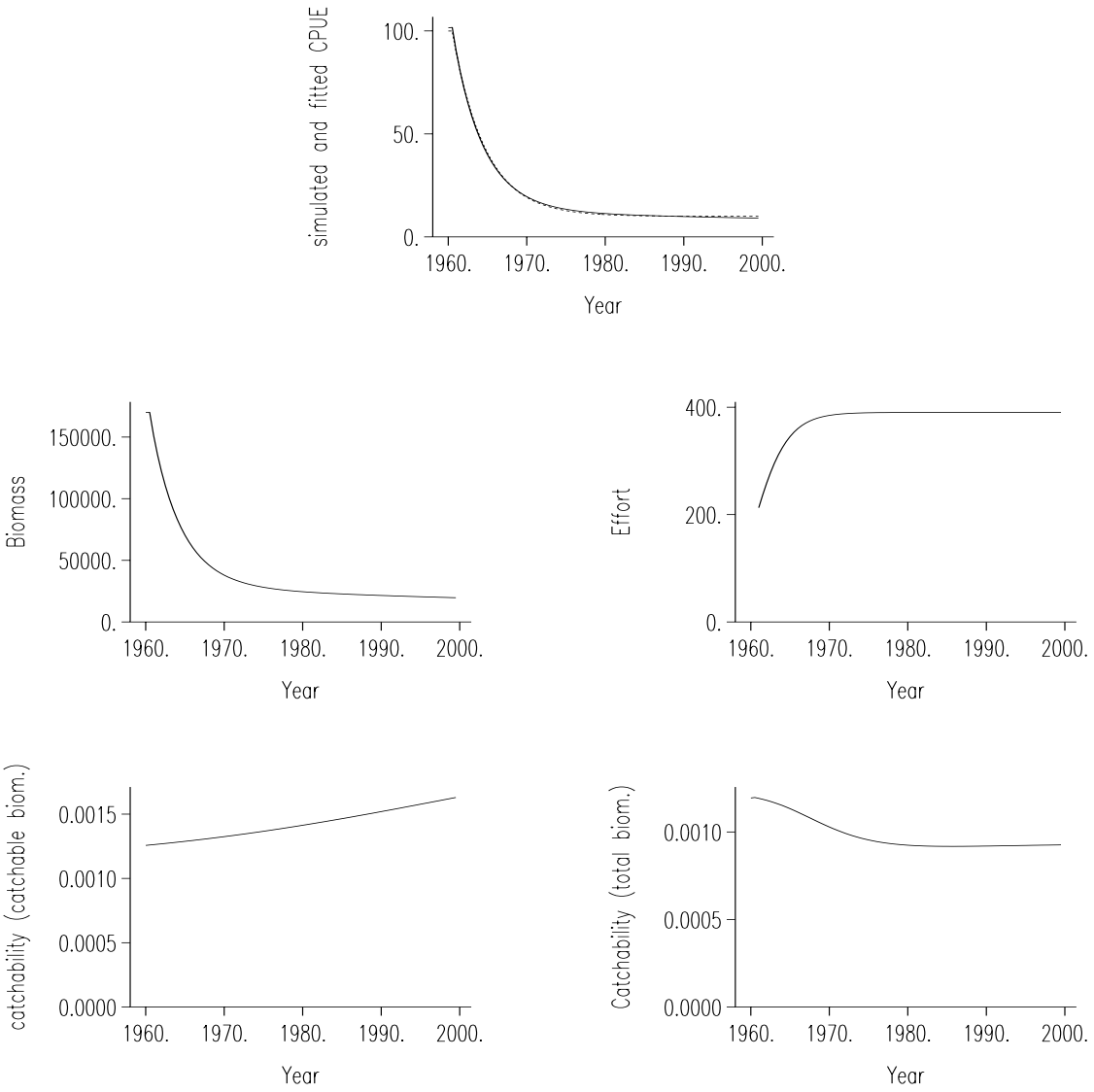

Figure 2 Solution with 5% of virgin biomass uncatchable: simulated (crosses) and fitted biomass (top); biomass (middle left), effort (middle right), catchability referring to catchable biomass (bottom left) and total biomass (bottom right)

What does it mean?

More generally, this example provides an illustration of a classical problem of modelling when we try to fit data that are quite "simple" (here the decrease of CPUE comes from a non linear function with two parameters) with a quite sophisticated model accounting for more of the complexity of the phenomenon (here with ten parameters, eight for process of effort and fishing power, and two for virgin biomass and the proportion of virgin biomass remaining uncatchable). This simply means that the general question about the trend of biomass can hardly be answered with such data.

Data used by Myers and Worm are highly summarized from much more large sets of data including, for example, nominal effort data. It would be necessary to use more complete data sets in order to select from among the set of solutions that provide near-perfect fits, which of them appear likely or not. For example, use of data on nominal effort could help to make selection between the two presented cases (may be they can both be rejected). But this would

also be highly questionable since, for example Schaefer's model with inaccessible biomass may provide results quite equivalent to those obtained with Pella Tomlinson model with all the biomass accessible and some value of the shape parameter (Laloë, 1995)[5].

Therefore, we have not shown in this note that "residual biomass" is at some given level. We only have shown that we cannot estimate such a level from such data.

The residual biomass may or not be below 10% of its virgin value. If so, it would be very important to show it as rigorously as possible, with all available data and knowledge on fishermen and fish. Myers and Worm are far from having done that, and this could be dangerous if things are really as they think they are.

[5] Laloë F. 1995. Should Surplus Production Models be fishery description tools rather than biological models? Aquating living Resources vol. 8, 1, p. 1-16.