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Food for Thought

Overconfidence in model projections

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There is considerable public and political interest in the state of marine ecosystems and fisheries, but the reliability of some recent projections has been called into question. New information about declining fish stocks, loss of biodiversity, climate impacts, and management failure is frequently reported in the major news media, based on publications in prominent scientific journals. Public and political awareness of the generally negative changes taking place in marine ecosystems is welcome, especially if it results in effective remedial action, but the scientific basis for such action must be reliable and uncertainties arising from models and data shortcomings must be presented fully and transparently. Scientific journals play an important role and should require more detailed analysis and presentation of uncertainties.

Keywords: climate, fisheries, marine ecosystems, model reliability, projections.

Projections or predictions of future events or states are among the valuable products of applied science, providing a quantitative basis for evaluating options and taking appropriate action. ("Projection" is used here to mean a description of a future event or state under a specified set of assumptions. A "prediction" is the best projection under the most likely set of assumptions. "Accuracy" is a measure of closeness of the projection or prediction to the true value and "precision" is a measure of the spread of the estimates.) Weather forecasting and many forms of insurance are based on prediction or projection; the quality (accuracy and precision) of these projections is under continuous scrutiny and the consequences are under continuous practical testing. I check the weather forecast before cycling to work and plan accordingly.

Projections, using mathematical models of eumetric fishing and yield, have been applied to fish stocks since the 1950's (Beverton and Holt, 1957). Most fisheries management is based on models that explore the consequences of regulating the sizes and quantities of fish caught. Commenting on a paper about the application of mathematical models to fish populations (Gulland, 1962), the director of the Lowestoft Fisheries Lab, Michael Graham, wrote:

> The historical background to the equation described by Gulland is an interesting one. It was produced not by zoologists becoming devotees of mathematics, but because they were forced by policy to look for a more or less rigid equation useful as a guide to factors of first and second magnitude, and as a basis for advice to the Government which was engaging in international negotiations. It was also of value in defining the kind of data which needed to be obtained by such things as marking experiments to give critical information about important parameters.

Increasing concern over climate change and other pressures on marine ecosystems has led to increased demand for projections and predictions of likely impacts, and scientists have responded with a rising flood of publications (Table 1). Projections and predictions are not only demanded by national and international policy-makers, but are also of interest to the public, with frequent headlines in major news media (e.g. http://news.bbc.co.uk/2/hi/6108414.stm), following publication in prominent journals such as Nature and Science. Scientists gain kudos by producing such widely reported projections, but are the public and fellow scientists being misled about their precision and reliability?

Fisheries assessment scientists in the 1970's and 1980's became concerned that although data and methodology were continually improving, there was no systematic process for evaluating the output, i.e. the accuracy and precision of the projections, in relation to their function (Brander, 1987, 2003; Patterson *et al.*, 2001). Unlike weather forecasts, where anyone can (and will) quickly tell you that the forecast "got it wrong", fish stock projections are intrinsically hard to evaluate for three reasons: (i) the forecast is generally 1 year or more ahead, (ii) the state being forecast (typically stock biomass) is difficult to estimate until even further into the future, and (iii) the projection is conditional on various assumptions (including the amount of fish caught before the time being forecast). This makes it difficult to tell, even with the benefit of hindsight, how good the projection was.

Reflexivity—being aware of and able to make critical use of information about quality—is basic to improving projections and is arguably a cornerstone of scientific method. Unfortunately, the record of such self-evaluation and feedback in science (and in engineering, medicine, finance, and other fields) is patchy. With the exception of weather forecasters and insurance actuaries (for whom reflexivity is inescapable), experts tend to be overconfident about the quality of their predictions and projections (Burgman, 2005). If they are making conditional projections of hard-to-estimate states or events some way into the future, then they do not need to worry about being called to account if they are wrong, and even when they are predicting something that can easily be checked, they are rarely called to account for their lack of skill, as Daniel Kahneman, winner of the 2002 Nobel Prize in Economics, entertainingly describes (http://www.nytimes.com/2011/10/23/magazine/dont-blink-the-hazards-of-confidence.html?pagewanted=all).

Does it matter whether the quality of projections in marine science and fisheries management is properly estimated and presented? Yes, if such projections are intended to help make better decisions about policies and courses of action then estimates of risks and uncertainties that include all sources of error must be an integral part of the advice. This is well understood in fisheries management, in which a great deal of work goes into evaluating fisheries management systems (Kell *et al.*, 2007). The same is true more generally in conservation and environmental management (Burgman, 2005; Beddington *et al.*, 2007). Nevertheless, many recent prominently reported projections of states of marine systems pay insufficient attention to estimating the reliability of their conclusions and presenting this information openly. Science is supposed to advance by continuous testing and reappraisal of published results, yet critical reviews of prominently reported projections of states of marine systems that point out obvious errors and uncertain assumptions are generally ignored (Banobi *et al.*, 2011).

Table 1. The number of publications found by searching "marine" and "climate" and "impact" in Google Scholar has doubled every 5.3 years since 1990.

Year	Number
1990	2 940
1995	5 140
2000	11 200
2005	20 800
2010	37 300

A widely reported recent paper illustrates the kinds of methodological and empirical issues that affect the reliability of projections. The paper "Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems" (Cheung *et al.*, 2012) predicts that by 2050 fish species are expected to shrink in size by up to 24% because of global warming. "So in, say, the North Sea", says Dr Cheung, "one would expect to see more smaller-body fish from tropical waters in the future" (http://www.bbc.co.uk/news/science-environment-19758440).

Predicting that increasing temperature and declining oxygen levels will result in smaller fish size, due to changes in species distribution and metabolic costs, is not contentious and would probably not attract any media attention, but the projected scale and speed of the change (24% smaller by 2050) is remarkable. How credible is it? The authors point out a number of limiting factors in their study, including uncertainties in the predictions for the climate and the oceans, but the accuracy and precision of the projection is not presented. There are both methodological and empirical reasons for doubting the reliability of the projection.

Methodological shortcomings include (i) assimilated consumption (the "anabolic" part of the growth equation) is assumed to be proportional to oxygen concentration, but oxygen is a limiting factor for growth not a controlling factor, i.e. it only affects growth if the oxygen concentration is below a critical value (Brett, 1979), and the equation they use is not documented in their reference, which is an unrefereed book, (ii) the bioenergetic model assumes that the term scaling directly with weight is due to catabolism, but there is a strong case that reproductive investment is the principal factor (Day and Taylor, 1997; Charnov *et al.*, 2001; West *et al.*, 2001), (iii) scaling relationships derived from interspecies comparisons are applied intra-specifically, implying that they are assumed to be the same, and (iv) only one distribution model is used here, but a multimodel approach is recommended, because of uncertainty in species distribution models (Jones *et al.*, 2012). A recent paper (Forster *et al.*, 2012) estimates the response of body mass to temperature and oxygen to be an order of magnitude less than Cheung *et al.*

Empirical support for the projected decline in fish body size comes from a published study of haddock (*Melanogrammus aeglefinus*) in the North Sea (Baudron *et al.*, 2011) and an analysis of growth in Atlantic cod (*Gadus morhua*). The apparent effect of temperature on the asymptotic length (L_∞) of haddock is so strong over a temperature range from 6.4 to 7.5°C in the North Sea that when it is extrapolated over the known thermal range of haddock (4–10°C), it produces unrealistic values ($L_\infty = 9.3$ cm at 10°C), which suggests that other unaccounted factors (regime shifts in the North Sea, changes in prey, effects of fishing, distribution changes) are involved. A wealth of data has been collected on growth of Atlantic cod throughout its range over the last 50 years, but the data used by Cheung *et al*. are from a single paper published more than 50 years ago (Taylor, 1958), containing 11 values of the asymptotic length (L_∞) mainly from two stocks (Iceland and NE Arctic) during the early years of the 20th century. Five of the 11 values of L_∞ ranging from 109.6 to 200.3 cm are from Iceland (Saemundsson, 1923). These data cannot reliably be associated with temperature values, because cod around Iceland form a variable mosaic of migratory and local components (Pampoulie *et al.*, 2012) and the mean bottom temperature around Iceland ranges from <2 to >7°C (Schnurr, 2012). The only reliable way to measure the ambient temperature experienced by individual fish in such situations is by using data storage tags (Pampoulie *et al.*, 2008). The three values of L_∞ for the Arcto Norwegian stock are from N Norway (154.0 cm), the Barents Sea (134.0 cm) and Lofoten (95.9 cm), but because this stock migrates from the Barents Sea around the north of Norway to Lofoten to spawn (at an average temperature of ~4°C), it is impossible to ascribe different temperatures to these three L_∞ values. The reliability of the temperature data used by Cheung *et al.* (from Taylor, 1958) is also questionable as it comes from the 1944 US Navy Hydrographic Office World Atlas of Sea Surface Temperature. Cheung *et al.* (2012) use seabed temperature, not surface temperature in their model.

In defence of Cheung *et al.* (2012), it is worth pointing out that whereas widely reported claims of marine ecosystem and fisheries collapse are often based on interpretation of time-series, with little or no attempt to model the underlying dynamics, the Cheung *et al.* projections are based on models of the climate system coupled with physiological and bioclimate (thermal tolerance) models to explore the biological effects of changes in temperature and oxygen. Critiques and rebuttals of interpretations of time-series are mainly directed at the empirical basis. For example, the estimate of the rate at which predatory fish have been depleted (Myers and Worm, 2003) is unreliable because of misleading use of catch-per-unit-effort data (Walters, 2003; Hampton *et al.*, 2005; Maunder *et al.*, 2006). The projected "global collapse of all taxa currently fished by the mid-21st century" (Worm *et al.*, 2006) is unreliable because of inappropriate use of catch statistics (Hilborn, 2007; Murawski *et al.*, 2007; de Mutsert *et al.*, 2008).

Projections like that of Cheung *et al.* rely on knowledge of important processes at the level of individual organisms, which are scaled up to the entire population by a mathematical model. In weather forecasting, the quality of such scaled-up projections is continually tested by the actual weather. Such testing is rarely possible when the projection is on scales of ecosystems and climate change (Smith and Link, 2005), although hindcasting may be used in some situations (Jones *et al.*, 2012). Assuming that the mathematical scaling is sound, the quality of projections is determined by the estimates of initial state and by the correct representation of processes; process uncertainty is amplified when models are scaled up from individual to population level. It is therefore crucial that these processes are well understood theoretically as well as empirically, that they are clearly documented, and that the consequences for the projections of known uncertainties in the processes are explored (Hill *et al.*, 2007; Roe and Baker, 2007).

Even uncertain projections can be justified, if they help to identify future hazards and the issues that need to be investigated to better judge those hazards. However, the normal standards of care and peer review need to be maintained and the uncertainties need to be presented completely and transparently. A projection of future ocean primary production based on six different coupled climate models (Sarmiento *et al.*, 2005) shows how this can be done. It was published in a relatively low impact journal and did not get media coverage, but has been cited just as frequently as a paper in Nature by the same lead author in the same year. It assesses the quality of projections and their utility, even when the confidence limits are quite wide, by identifying the sensitivity of the results to particular empirical and methodological elements. The authors conclude: "Despite the fact that most of us are involved in one way or another with the development of prognostic ecosystem models for prediction of biological response to climate change, we maintain a healthy scepticism of such models and strongly urge further work on empirical approaches such as those we used here". Based on this paper, the IPCC cited temperature-dependence of primary production as a research priority (IPCC WG 2 report, 2007, p. 303).

Healthy scepticism may be in short supply; a recent review of 75 publications on projection of future spatial distributions of marine populations (Planque *et al.*, 2011) concluded that "unless uncertainty can be better accounted for, such projections may be of limited use, or even risky to use for management purposes". The review details the sources of uncertainty (empirical basis, model structure, parameterisation, completeness, etc.) and how these can be evaluated.

The forthcoming IPCC report will provide new projections of climate and of impacts on biology, geochemistry, and human activities and concerns. The IPCC requires that uncertainties in all projections are evaluated and presented and a Guidance Note sets out consistent procedures and terminology to use (Mastrandrea *et al.*, 2010). Perhaps, it is time that scientific journals adopted a similar policy when publishing model projections.

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