Northwest Atlantic Fisheries Organization

Serial No. N5128 **NAFO SCR Doc. 05/42**

SCIENTIFIC COUNCIL MEETING – JUNE 2005

Multispecies Bioenergetic-allometric Models and Ecosystem-based Management: a Synoptic (Personal and Probably Biased) View of the Lessons Learned and the Road Ahead

Mariano Koen-Alonso[1,2]
[1] Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada
[2] Memorial University of Newfoundland

Abstract

This lecture is *in memoriam* of Peter Yodzis (1943-2005); a great mentor, amazing scientist, and even better friend

The idea of Ecosystem-based Management (EBM) has received considerable attention in recent years. Despite this attention, there are still many open questions about EBM, and how it should be implemented.

Although an assessment of EBM is beyond the scope of this presentation, some of its core features can be highlighted here. Regardless of the specific wording (e.g. Christensen *et al*., 1996; Garcia and Staples, 2000; Jamieson *et al*., 2001), most EBM definitions include a) the concept of sustainability, both in terms of the ecological and socio-economic systems, b) the requirement of integrating the management of all human activities which take place and/or use a common ecological system, c) an objective-oriented framework, and d) the conservation emphasis is put on preserving ecosystem structure and function, not just specific components of the ecosystem.

Following Dengbol (2002), three approaches for building the EBM knowledge base can be distinguished: adaptive learning, soft predictability, and hard predictability.

The "adaptive learning" approach implies abandoning any attempt of detailed understanding and it is focused in regulating the overall pressure on the system. It relies on meta-indicators which synthesize the overall state of the ecosystem without attempting to track specific interactions (e.g. mean trophic level of the catch, diversity indices), and the control of overall pressure can only be done through adaptive management. There is not necessarily *a priori* understanding of the processes which link human activities and indicators, and hence long term impacts of specific activity levels cannot be predicted.

The "soft predictability" approach is based on structured sets of indicators. For example, in the Pressure-State-Response framework, a typical soft predictability approach, indicators are classified as indicators of pressures (e.g. effort), states of the system (e.g. size-spectrum), and responses (e.g. management actions). They are structurally linked and management is based on monitoring pressures and states of the system under examination. Relationships between pressure, state, and response indicators are typically assumed linear, or at least monotonic, and only direct pressure indicators are considered. This approach relies more heavily on qualitative or semi-quantitative predictions of the links/relationships in the system, together with a timely monitoring of the preselected indicators.

The "hard predictability" approach is seen as an extension of current single species approaches which incorporate ecosystem considerations into the evaluation of impacts and responses to regulation. Typically it takes the form of quantitative dynamic models which can be multispecies and/or single species but with explicit inputs from the community/ecosystem. This approach relies more heavily on quantitative and highly accurate predictions of the dynamics of the exploited system.

The marine community of northern and central Patagonia is structured around the trophic triangle conformed by anchovy (*Engraulis anchoita*), squid (*Illex argentinus*) and hake (*Merluccius hubbsi*). Although all of them are commercial species, only squid and hake sustain major commercial fisheries. Another important industry in the region is wildlife-based tourism, and the sea lion (*Otaria flavescens*) is the most abundant marine mammal which actually forages on the Patagonian Shelf. Therefore, there is potential for conflicts of interest among human activities. In simple terms, if sea lions compete with fisheries for food resources, more sea lions might be a good thing for tourism but a bad thing for fisheries. This scenario makes this system a nice study case for exploring the different approaches to the EBM knowledge base.

Early comparisons of top predators' food habits and the composition of fisheries catches have suggested that simple diet indicators can provide contradictory answers about the potential for competition between top predators and fisheries. Furthermore, these indicators usually assume a static view of the system (e.g. constant diets). To address some of these issues, multispecies models were developed (Koen-Alonso and Yodzis, 2005). These models were purely trophodynamic (i.e. no environmental effects were included) and based on a bionenergetic-allometric framework. This framework describes population dynamics using a bioenergetic rationale and assumes that core model parameters can be described as power functions of individual body mass (Yodzis and Innes, 1992). To assess structural uncertainty, five different models were compared. The difference among them was the formulation of the functional response (i.e. the mathematical representation of the predation process), and the Akaike Information Criterion was used for model selection. Parameter uncertainty was assessed for the selected models by exploring their behavior with extreme parameter values (i.e. parameter sets with the lowest likelihoods but still within the 95^{th} percentile range).

These simple models described the hake and sea lion dynamics fairly well, but the dynamics of lower trophic level species like squid and anchovy were poorly captured. Although the two selected models had similar fits to the data, they also produced different predictions under some exploitation scenarios (i.e. some predictions were model-dependent). In general, predictions from these models had high levels of uncertainty. Responses in the equilibrium biomasses to changes in exploitation rates were often counter-intuitive, typically nonlinear, and in most cases, non-monotonic (i.e. changes in exploitation rate not only can affect the magnitude of the response, but also its sign).

In terms of their implications for building the EBM knowledge base, these results reinforce the idea that monitoring indicators *per se* is not enough to assure a sustainable use of the system, we need to understand the processes which drive indicators to change. They also suggest that linear simplifications, although useful, are unlikely to suffice to achieve this goal; medium and long term planning should also consider indirect effects. We should expect nonlinear and non-monotonic responses to exploitation.

On more pragmatic grounds, although current multispecies modeling approaches can provide a much-needed complement to classical single-species stock assessment within an EBM context, they do not constitute a magic tool. Multispecies models add one more layer of complexity over single-species ones, and hence, they do not replace single-species assessments. Instead, they integrate them. Successful EBM will most certainly require more and better information, including single-species assessments.

Another necessary component that needs to be considered is the effect of environmental variables on system dynamics. Due to its ubiquitous role, temperature is a reasonable starting point. As part of current allometric theory (Brown *et al*., 2004), recent developments provide a mechanistic description for temperature-dependence of metabolic rates (Guillooly *et al*., 2001).

Because temperature is a modulator of individual metabolism, many temperature-related changes in a given population can be associated with temperature-dependent changes in the metabolism of the focal and other species in the system. The effects on these other species will reach the focal species through trophic interactions within the food web. Therefore, temperature-dependent metabolic rates in bioenergetic-allometric models should allow the incorporation of some of the potential effects of temperature. Fortunately, Vasseur and McCann (2005) recently expanded the Yodzis-Innes framework to allow for temperature-dependent vital rates. Now, we have the tools to start exploring some of the potential effects of temperature on multispecies dynamics within a mechanistic framework.

Although incorporating environmental variables like temperature will certainly contribute to the completeness of any EBM implementation, probably the biggest issue for EBM does not lie in the target ecosystem itself. Ecological systems are being exploited all over the world, and the global economy links them through a common market. For example, fishery products from any corner of the planet can be found in the typically well provided markets of Japan or Spain, while American and German tourists have the choice of doing whale-watching in Newfoundland or Patagonia. In our economically connected world, the socio-economical sustainability of exploited ecosystems not only depends on the ecological sustainability of its own resources, it may also depend on the management practices in faraway ecosystems. The integration of ecological and socio-economical sustainability is the ultimate challenge for EBM. These considerations suggest that we have a long and difficult road ahead of us.

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