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Knowledge-based systems as decision support tools in an ecosystem approach to fisheries: Comparing a fuzzy-logic and a rule-based approach

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ABSTRACT

In an ecosystem approach to fisheries (EAF), management must draw on information of widely different types, and information addressing various scales. Knowledge-based systems assist in the decision-making process by summarising this information in a logical, transparent and reproducible way. Both rule-based Boolean and fuzzy-logic models have been used successfully as knowledge-based decision support tools. This study compares two such systems relevant to fisheries management in an EAF developed for the southern Benguela. The first is a rule-based system for the prediction of anchovy recruitment and the second is a fuzzy-logic tool to monitor implementation of an EAF in the sardine fishery. We construct a fuzzy-logic counterpart to the rule-based model, and a rule-based counterpart to the fuzzy-logic model, compare their results, and include feedback from potential users of these two decision support tools in our evaluation of the two approaches. With respect to the model objectives, no method clearly outperformed the other. The advantages of numerically processing continuous variables, and interpreting the final output, as in fuzzy-logic models, can be weighed up against the advantages of using a few, qualitative, easy-to-understand categories as in rule-based models. The natural language used in rule-based implementations is easily understood by, and communicated among, users of these systems. Users unfamiliar with fuzzy-set theory must "trust" the logic of the model. Graphical visualization of intermediate and end results is an important advantage of any system. Applying the two approaches in parallel improved our understanding of the model as well as of the underlying problems. Even for complex problems, small knowledge-based systems such as the ones explored here are worth developing and using. Their strengths lie in (i) synthesis of the problem in a logical and transparent framework, (ii) helping scientists to deliberate how to apply their science to transdisciplinary issues that are not purely scientific, and (iii) representing vehicles for delivering state-of-the-art science to those who need to use it. Possible applications of this approach for ecosystems of the Humboldt Current are discussed.

1. Introduction

Management of human activities in the ocean is increasingly based on integrated ecosystem considerations, instead of isolated assessments of seemingly disconnected issues such as temperature change, single-species issues in fisheries, and/or pollution. Along with this development, scientific advice in support of ecosystem-based management must encompass a multitude of information sources, evaluate uncertainties and risks, and combine this information into a single, coherent framework in a logically consistent, defendable and transparent way.

The problems of integrating disparate kinds and sources of information are encountered in many arenas. For example, Roetter et al. (2005) describe a system for land use planning in Asia, Paterson et al. (2008) developed a decision support model for wildlife translocations into communal conservancies in Namibia, and Guimarães Pereira et al. (2005) show how an innovative information tool is applied to a groundwater governance issue in France. This last study emphasized the usefulness of knowledge tools for initiating and informing debates, rather than simply for legitimising decisions.

Knowledge-based systems (also termed "expert systems") are a particular class of computer-based decision support systems that can be subdivided into four major components: (i) a structured

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knowledge base storing the underlying information, (ii) an information system accessing and retrieving the information, (iii) a modelling component predicting the outcome of a problem posed ("inference engine"), and (iv) a framework that facilitates communication between the user, the knowledge base and the inference engine.

Knowledge bases that are formalised within "rule-based models" applying classical, Boolean ("crisp") logic (Starfield and Bleloch, 1983; Noble, 1987; Starfield et al., 1989) are well suited for the integration and interpretation of different knowledge sources. In the context of ecosystems, rule-based models can synthesize different ecosystem indicators so that, as a group, the indicators are interpreted effectively and consistently. For marine ecosystems in particular, Boolean, rule-based models have been constructed to predict recruitment strength of anchovy in the southern Benguela region (e.g., Korrûbel et al., 1998; Miller and Field, 2002).

Decision support tools in general, and knowledge-based systems in particular, have evolved considerably during the past two decades (Belton and Stewart, 2002; Guimarães Pereira et al., 2005). In particular, fuzzy-set theory (Zadeh, 1965; "fuzzy logic") has been promoted to deal with uncertainties in our understanding of aquatic systems (e.g., Mackinson, 2000; Cheung et al., 2005) and in evaluating the performance of a pelagic fishery (Paterson et al., 2007). Fuzzy logic potentially provides an elegant solution in information-rich contexts such as continuously measured variables, in circumventing possible rule proliferation in an attempt to accurately represent the data (e.g., Miller and Saunders, 2002).

In the context of natural resource management in general, and fisheries management in particular, the need for communication of advice among stakeholders is increasingly recognised as an important component of the decision-making process (e.g., FAO, 2003; Degnbol and Jarre, 2004). In preparation of scientific advice for management, and in acknowledging the large uncertainties around seemingly accurate measurements, quantitative information often is categorized into few categories only (e.g., ICES, 2005; Caddy and

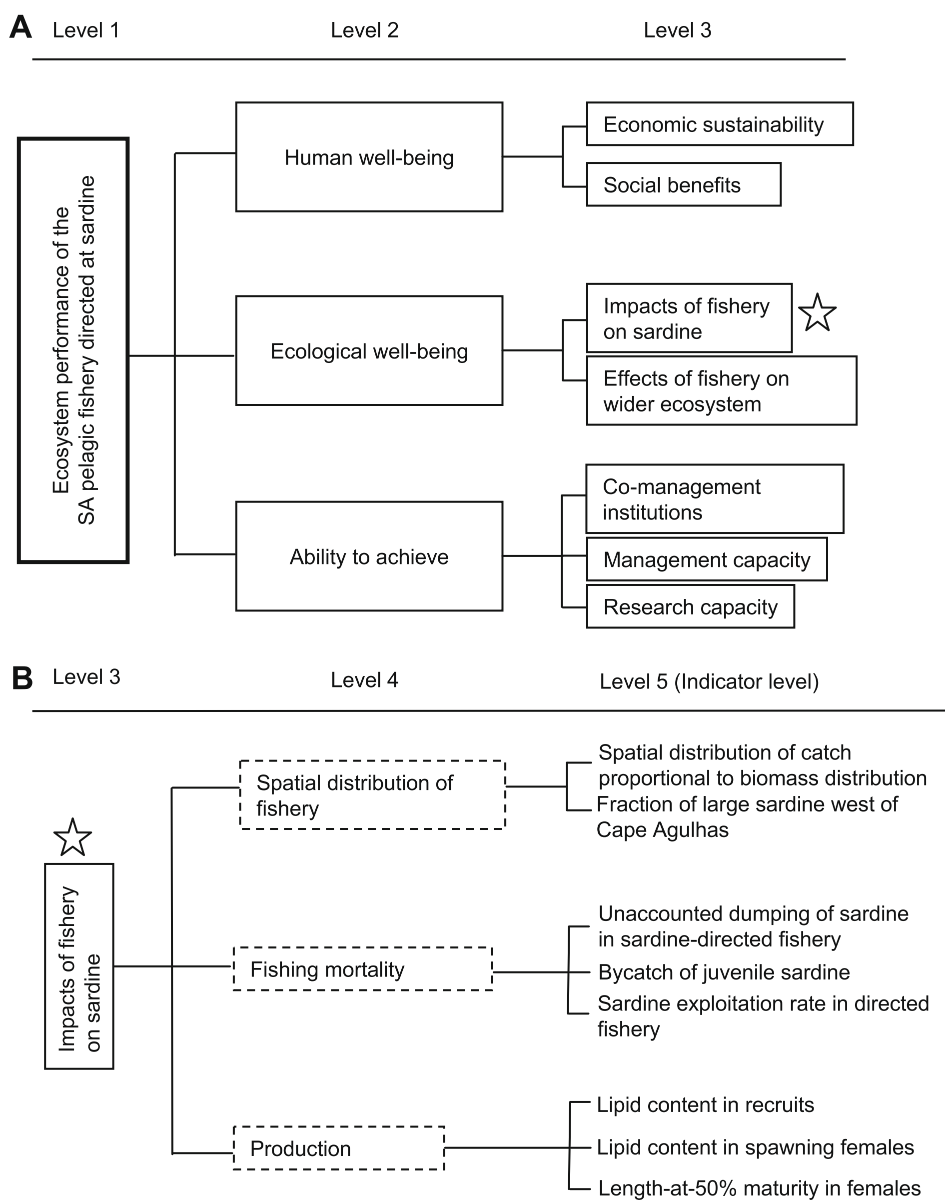

Fig. 1. Objective hierarchy (value tree) for the evaluation of the performance of the South African pelagic fishery directed at sardine in an EAF. (A) High-level objectives. (B) Specific objectives for the direct impacts of the fishery on sardine. Adapted from Paterson et al. (2007).