1. Introduction

The 21st century has ushered in a new era in fisheries management in which the prevalent terminology is the ecosystem approach to fisheries (EAF; Garcia *et al*., 2003) in contrast to more "dated" terms such as surplus production and single-species models. This is at least in part attributable to the increasing pressure exerted on species subject to fishing (and interconnected species in the ecosystem) and a growing realization of the need to consider broader socioeconomic effects as well as the ecosystem effects of fishing. Although computational restraints are much less of a problem due to improvements in modern computing power, progress in this field is still (and may always be!) impeded by imprecise parameter estimation given limited and noisy data and the associated limited understanding of ecosystem functioning.

Nonetheless, as powerful new tools such as ECOPATH with ECOSIM (EwE) (Polovina, 1984; Christensen and Pauly, 1992; Walters, Christensen and Pauly, 1997; Walters *et al.,* 2000) are further developed and distributed, there is a growing body of scientists being drawn to this challenging new field. In practice, single species models are still the dominant tool worldwide for providing timeous and reliable scientific advice regarding the management of commercially valuable stocks. As single-species and EAF approaches become increasingly merged in the development of management advice, it is important that modellers have a good understanding of both single-species and ecosystem approaches. Multi-species considerations are yet to be formally included in the stock assessment approaches for the major fisheries resources globally. However, considerable work has been conducted worldwide to construct multi-species models and, more recently, in implementing EwE (Walters, Christensen and Pauly, 1997), which is currently the most widely utilized approach worldwide.

The aim of this report is to review the methods available for assessing the impacts of interactions between species and fisheries, in particular ecological (indirect) interactions and their implications for fisheries management. A wide variety of different methods are at hand to address this issue (e.g. Pope *et al.,* 1988; Larska and Wootton, 1998; Boyd and Murray, 2001; Eisenack and Kropp, 2001; Kaschner *et al.,* 2001; Crawford, 2004; Dalton, 2004; Drapeau *et al*., 2004; Yemane, Field and Griffiths, 2004; Daan *et al.*, 2005), but the focus here is specifically restricted to modelling methods. Given that this is a large topic on its own, the field of ecosystem indicators (e.g. Rice, 2000) is not discussed and the reader is referred to the International Council for the Exploration of the Sea (ICES) Journal of Marine Science vol. 62, 2005 for a recent review of this topic. The scope of this report is on multi-species population dynamics effects, rather than on the full range of ecosystem aspects of fishing encompassing, for example, environmental effects and technical interactions (e.g. bycatch issues), although minor mention of these is made. Although some of the discussions are relevant to freshwater or estuarine fisheries, this report focuses only on marine fisheries. The potential of approaches to contribute broadly to fisheries management is discussed as well as their more specific potential to contribute to practical advice. To achieve the latter, a multi-species modelling approach should provide at least qualitative and ideally defensible quantitative guidance as to the management of marine natural resources. One of the most obvious uses relates to modifications in annual allowable catch levels deemed necessary because of the predicted effects that fishing on a target species will have on other components of the ecosystem (Plagányi and Butterworth, 2004), but ultimately these tools may be called upon to give advice on all potential management levels (including spatial management, temporal closures, gear restrictions and discarding

practices).

The first part of this review takes a broad overview of some of the most commonly applied multi-species/ecosystem approaches to fisheries management. The next section summarizes the results and conclusions reached by previous studies and workshops on the subject, including the ICES/SCOR Symposium on Ecosystem Effects of Fishing (ICES Journal of Marine Science 57, n.3, June 2000), the Workshop on the Use of Ecosystem Models to Investigate Multi-species Management Strategies for Capture Fisheries (Pitcher and Cochrane, 2002), the IWC Modelling Workshop on Cetacean-Fishery Competition (Journal of Cetacean Res. Manage. 6 (Suppl.) 2004) and the Workshop on Ecosystem Approaches to Fisheries in the southern Benguela (African Journal of Marine Science 26, 2004).

The need for an EAF is well recognized and indeed mandated. However, there is still a need for, on the one hand, many ecosystem modellers to better acquaint themselves with the practical realities of providing reliable management advice and, on the other hand, for single-species modellers to step back from the often frantic process of conducting stock assessments and use their expertise to guide the development and implementation of multi-species management tools. Given the potentially large scope of this study, the focus has been restricted to the most widely-applied or well-known approaches as well as those considered by the author to show promise in advancing this field. This manuscript is not intended as a final authoritative view to compare the different modelling approaches but is rather a working document to assist and direct further discussion of the various modelling approaches.

The choice of an appropriate model depends not only on the question to be addressed but also on other logistical constraints such as the person power and associated costs. The various modelling approaches discussed will roughly be compared giving consideration to the above.