Ecosystem Approaches to Fisheries in the Southern Benguela
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ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT IN THE SOUTHERN BENGUELA: A WORKSHOP OVERVIEW

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A workshop was held in Cape Town in December 2002 to introduce the concept of an ecosystem approach to fisheries (EAF) management in the southern Benguela, and to examine the options for implementing an EAF in South Africa. The workshop considered alternative modelling approaches that may have potential for an ecosystem approach to fisheries. Consensus was that an EAF should be implemented in South Africa through an incremental process, starting immediately. Ecosystem models can be used to provide guidance on reference points and broader management objectives still currently set on the basis of single-species assessments. Such additional information would be incorporated into the decision-making process, and comments received at a management level would also feed back to the modelling process. It was suggested that, at the scientific level, an ecosystem modelling perspective could be incorporated into existing single-species management recommendations by testing them with ecosystem models. Compilation of an "ecosystem considerations" document was recommended to initiate the process. It was proposed that a dedicated EAF working group be established in South Africa to advise on the process of implementing an EAF in the various fisheries, and to provide overarching guidance and to ensure consistency in integrating existing data and information for informing the management process.

Key words: Ecosystem approach to fisheries, ecosystem modelling, fisheries management, southern Benguela

A three-day workshop on ecosystem modelling approaches for South African fisheries management was convened in Cape Town in December 2002. The workshop aimed to introduce the concept of ecosystem-based fisheries management to local fisheries scientists (especially scientists involved in management) and to present alternative or complementary modelling tools to provide scientific advice on how to achieve the first objective. The second objective of the workshop was to propose a framework of practical ways in which South Africa could try to incorporate ecosystem considerations (using information from multispecies approaches) into current Operational Management Procedures (OMPs) and other decision-making approaches for local marine resources. This framework could guide future ecosystem research and also facilitate the inclusion of ecosystem considerations into South African fisheries management.

The workshop marked the first attempt to bring together experts on single-species, multispecies and ecosystem modelling approaches to initiate an ecosystem approach to fisheries (EAF) management in South Africa, with emphasis on the southern Benguela upwelling ecosystem. It was clear that various modelling (and other) approaches would be useful to address different aspects of fisheries management. An implication of EAF is that an overarching framework will be required to coordinate, reconcile and manage the individual fisheries and other resource users, and to consider the overall effects of all utilization and management within a given ecosystem (including how those in one fishery may impact those in another). Ecosystem models will be important to assist in informing and developing the overarching framework.

South Africa has a sound history of multidisciplinary research conducted under the auspices of the Benguela Ecology Programme (Moloney *et al.* 2004). With this in mind, background to the basics of an EAF and how this could impact the major South African fishery subsectors has been provided by Cochrane *et al.* (2004), in which particular mention was made of the FAO Guidelines "The ecosystem approach to fisheries" (FAO 2003), which was compiled as a follow-up to the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem in October 2001. The Guidelines proposed that it should be possible to begin to implement an EAF immediately, and that the process will need to be tackled incrementally. Whereas considerable progress should be possible in most cases on the basis of existing information, ongoing research would be

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important to inform the process and to address some fundamental uncertainties that exist, e.g. how do ecosystems function, and what is the functional form of interspecies interactions?

The FAO Guidelines acknowledge that there has been only limited experience to date in implementing an EAF, but there have been some useful case studies. Some of this experience was reported upon at the workshop so that South Africa could benefit from the lessons learnt elsewhere. For example, extensive multidisciplinary, spatially structured ecosystem modelling has been undertaken in Port Philip Bay, Australia (Fulton and Smith 2004), as part of the implementation of an EAF in that country. Early considerations of the implications of an EAF in Namibia have shown that ecosystem models are important, because many present concerns about Namibian marine resources cannot be addressed using single-species stock assessment methods (Roux and Shannon 2004).

SOME MODELLING (AND OTHER) APPROACHES OF POTENTIAL USE IN IMPLEMENTING AN EAF FOR THE SOUTHERN BENGUELA

ECOPATH with ECOSIM

Much of the present work on ecosystem dynamics in the fisheries context has been undertaken with the ECOPATH with ECOSIM (EwE) modelling software (Christensen and Pauly 1992, Walters *et al.* 1997), and EwE formed the basis of several presentations made at the workshop (Fulton and Smith 2004, Roux and Shannon 2004, Shannon and Moloney 2004, Shannon *et al.* 2004). Questions surrounding the use and applicability of EwE in large marine ecosystem and food-web management were considered. Aydin (2004) compared surplus production energetics in ECOSIM and in age-structured single-species models. Some of the limitations and problems with the EwE approach were discussed by Plagányi and Butterworth (2004). EwE models of the southern (Jarre-Teichmann *et al.* 1998, Shannon 2001, Shannon *et al.* 2003, 2004) and northern Benguela ecosystems (Jarre-Teichmann and Christensen 1998, Shannon *et al.* 2001, Roux and Shannon 2002, 2004, Heymans *et al.* 2004) have proved a useful summary of the existing (but often poor) understanding of the ecosystem and have been a useful tool for identifying data gaps and assisting in prioritizing research. A preliminary updated ECOPATH model of the southern Benguela for the period 2000–2001 was opened for discussion and suggestions were made on how to improve the model. It was agreed that it would be useful to put effort into disaggregating the model by season and area, so that spatial aspects could be considered. Investigations will be undertaken into the impacts of variability/uncertainty about some of the input parameters to southern Benguela EwE models, obtained from single-species stock assessment models of anchovy *Engraulis encrasicolus*, sardine *Sardinops sagax* and the Cape hake *Merluccius capensis* (shallow-water Cape hake) and *M. paradoxus* (deep-water Cape hake). This would allow the robustness of EwE models of the southern Benguela to be assessed, beyond the sensitivity analyses already undertaken (Shannon 2001).

An important advantage of EwE is that it provides a user-friendly framework that enables a user with limited mathematical and programming skills to construct a useful model of an ecosystem or portion of an ecosystem. This is particularly useful in countries or areas with limited scientific capacity. However, its ease of use makes it susceptible to misuse, and as with all models and especially user-friendly packages, it is essential that use of EwE is accompanied by intelligent and informed judgement and interpretation (Cochrane 2001).

A fundamental issue in modelling, including ecosystem modelling with EwE, is the extent of the complexity that should be included in the model. There was widespread agreement at the workshop that EwE offered considerable flexibility in this regard; EwE could be used to construct a minimum realistic model (MRM) that includes only those ecosystem components considered to drive the dynamics of a stock or stocks under consideration. There was also wide agreement that, in order to avoid unnecessary and confounding complexity, ecosystem models should focus on important groups and omit those that merely add noise to the model and that do not contribute substantively to the key dynamics. In general, adding complexity to any model should only be attempted if there is good reason to look at those particular aspects in more detail, i.e. if the information content is improved.

The workshop considered at length the validity of, and possible alternatives to, the "foraging arena" hypothesis that underlies EwE (Christensen and Walters 2000). No agreement was reached on whether or not the foraging arena hypothesis was or was not the best assumption, but it was felt that it was important to test the sensitivity of model output to the underlying assumptions of the foraging arena hypothesis (Plagányi and Butterworth 2004). Diet composition, selectivity of predators, and the variability of both according to relative and absolute abundances of prey, were recognized to be very important inputs to EwE, and to any model of the foodweb or food chain. Collection of additional data on diets and feeding behaviour is required. The degree of overlap of prey foraging arenas is a problem that may be addressed using the ECOSPACE routine in EwE. ECOSPACE is the dynamic, spatial part of the EwE package and can be useful in exploring, for example, spatial mismatch of species interactions (Walters *et al.* 2000). Another recent and promising aspect of the EwE approach is the fitting of dynamic ecosystem models to time-series data for the various ecosystem components (e.g. biomass, catches, effort, catch per unit effort; Shannon *et al*. 2004). In addition, policy-search options provide a valuable opportunity for undertaking a broad-brush examination of the performance of different management strategies (reflected in the form of effort or fishing mortality per fleet) against biological, ecological, economic and social objectives.

Other ecosystem modelling approaches

Individual-based modelling (IBM) has been undertaken in the ecosystem context by Shin *et al*. (2004) to explore the ecosystem effects of hypothetical fisheries scenarios. Those authors show that the size-based, spatially-structured model of the southern Benguela ecosystem produces similar results to the non-spatial, mass-balance trophic model (EWE). Nonetheless, the distributions of plankton biomass were not made spatially explicit in the two models; adding spatial information, for example using SeaWiFs images of phytoplankton as a proxy, might change the results of this comparison.

A new and developing modelling approach for an EAF is that based on the viability theory (Aubin 1991, 1997), recently applied to fisheries (Mullon *et al.* 2004, Cury *et al.* in prep.). The southern Benguela ecosystem has been used as a case study to illustrate how the viability approach could allow multiple management objectives to be considered simultaneously. In the viability approach, management objectives are phrased as limit reference points to be avoided, and not as target reference points to be reached, as is the case in most other management approaches. This approach looks promising, but its high requirements in computational resources make it applicable to only a few species or species groups at present.

The MRM approach was used by Punt and Butterworth (1995) to explore the interaction between Cape fur seals *Arctocephalus pusillus pusilllus* and Cape hake and the Cape hake fishery on the South African west coast. The approach allows focus on the species of interest, fits the model formally to existing data on abundance, diet, etc., and takes some account of second-order effects (e.g. density-dependence in Cape hake though cannibalism and predation). The MRM approach encounters the same difficulties as EwE in determining the amount of ecological detail (specifically the number of species or species groups) to include in the model. An MRM approach is currently being applied in preliminary modelling of whale-seal-krill interactions in the Antarctic (Mori and Butterworth 2004).

Alternative multispecies modelling approaches are being used in Iceland, such as BORMICON (BOReal MIgration and CONsumption model) and GADGET (Globally Applicable Area-Disaggregated Generic Ecosystem Toolbox). The possibilities and suitability of applying this modelling approach with a focus on the South African hake fisheries is being explored.

Non-modelling ecosystem studies and approaches

The SCOR/IOC Working Group 119 on "Quantitative Ecosystem Indicators for Fisheries Management" met the week prior to the EAF workshop (www.ecosystemindicators.org; Cury and Christensen 2002). The objective of that working group was to develop, select and evaluate indicators to characterize processes and changes in marine ecosystems, from environmental, ecological and fisheries perspectives. Ecosystem indicators are likely to provide a means of translating ecosystem considerations highlighted in scientific studies into useful inputs to fisheries management. It was agreed by the working group that a suite of indicators for EAF would be necessary, because no single index could capture the multidimensional character of an ecosystem state. It was postulated that the regulatory framework of an EAF would need to be adaptive, its knowledge base should rely on meta-indicators, and that the reconciliation of multiple objectives would require the participation of multiple stakeholders (Degnbol and Jarre 2004). As a consequence, the introduction of the EAF and the use of indicators would require changes in the institutional set-up for fisheries management – but in turn, the knowledge base for an EAF needs to be developed in intricate interaction with the development of the institutional framework in which the EAF is to be applied. It was emphasized at the workshop that indicators for an EAF are there to inform management and not science. It was also suggested that an EAF cannot be entirely prediction-based, not only because of cost-complexity constraints, but also so that stakeholders have confidence in the fisheries management knowledge base.

The importance of incorporating predation considerations into fisheries management was discussed at the workshop, with a focus on the food requirements of seabirds foraging on small pelagic fish off South Africa (Crawford 2004). The issue of defining minimum viable and target population sizes of predators was considered. The role of models linking seabirds, their fish prey and commercial fisheries was discussed. So far, South African fisheries management strategies have not taken explicit account of predator requirements. Recommendations were made for obtaining accurate dietary descriptions for predators in the southern Benguela, based on a study of the predatory large, pelagic snoek *Thyrsites atun* (McQueen and Griffiths 2004). Snoek are flexible in their feeding choices and exhibit prey-switching in the short and medium term, feeding mostly in winter and spring when they spawn. Participants agreed that models must quantify the variability in diet composition and take into account prey-switching (i.e. addressing the question whether the predators are eating what is there or being selective).

A geographic information system (GIS) has been developed for the southern Benguela to explore and quantify the spatial aspects of species interactions in this ecosystem (Drapeau *et al.* 2004, Pecquerie *et al.* 2004). The need to consider spatial aspects of fisheries and the usefulness of marine protected areas for fisheries/ecosystem management was highlighted. The concept of management by means of zoning (fishing in certain zones) was also discussed at the workshop. It was suggested that consideration be given to reorganizing the basis of management of fisheries in South Africa, such that rights be given to fishers to fish in allocated areas, allowing them to harvest across a range of species in their given zone. Also, it was stressed that the social and economic implications of such a change would need to be considered before it could be evaluated realistically, but it was acknowledged that the proposed spatial approach would be most feasible for inshore marine resource management, and that a strictly geographic approach may not be appropriate for mobile species.

Exploratory model simulations are one way of trying to quantify the effects of fishing at an ecosystem level. Routinely collected fisheries data can also be used directly to quantify the ecosystem effects of fishing, for example by examining changes in community structure and size composition of affected ecosystem components, such as the South African linefish community (Yemane *et al.* 2004).

Comparing modelling approaches

It was emphasized at the workshop that the type of model used would depend on the objectives set and what one is attempting to achieve. Multispecies models focusing on a few well-known species are commendable, but they run the risk of overlooking poorly known groups or species (e.g. mesopelagic fish and round herring *Etrumeus whiteheadi*, which are important prey species for many of South Africa's commercially valuable fish species). The contrasting problem of models including a large number of species groups, is the risk of introducing additional uncertainty without adding significantly to the accuracy of the predictions. Robustness of models to environmental effects and the degree of variability in recruitment are important, and it is likely that addressing these aspects will require models, and scientific understanding, beyond those currently available. The time frame used in models is important; it is necessary to use that which is most appropriate, e.g. given the regime or ecosystem state being examined.

There was general agreement that a range of models was required, and that comparing the various model outputs would help identify the range of possible answers. Knowing the magnitude of this uncertainty is essential for management. Similarly, a suite of ecosystem indicators is required for fisheries management, because a flexible and adaptable framework in which to operate will always be required.

Drawing from the comparison of different modelling approaches by Fulton and Smith (2004), four issues were considered to be important (E. A. Fulton, CSIRO, Tasmania, pers. comm.).

1. When developing ecosystem models, the taxonomic/functional groups of key interest should be identified, other useful groups should be aggregated as appropriate, and other less-useful groups should be omitted altogether.
2. As with all models, the trade-off between variance and bias needs to be considered. A danger in reducing model complexity is that important interactions can be omitted. In addition, ecosystem changes such as regime shifts can alter the relative importance of interactions, effectively changing the values of model parameters.
3. The importance of modelling spatial aspects of fisheries and marine ecosystems has been widely recognized and the general consensus at the workshop was that such modelling needs to be undertaken more extensively to allow important behaviour and interactions to be described and explored. ECOSPACE can be used to explore spatial aspects of ecosystems, but the model seems to be underutilized at present.
4. It was also recognized that hybrid modelling approaches, for example linking biomass size spectrum models and minimum realistic models, could assist in simulating key ecosystem driving forces and dynamics.

Some possible modelling approaches were introduced as a consequence of discussions at international workshops on marine mammal management, such as the International Whaling Commission modelling workshop (Butterworth and Plagányi 2004). Those authors noted that effective usage of ecosystem models for decision-making are still a way off, but ecosystem models may play a useful role by simulating future resource trends to test how alternative candidate "decision" models may perform. Considering the second objective of the workshop: "to propose a framework of practical ways in which to try to incorporate ecosystem considerations (including information from other types of multispecies approaches) into current OMPs and other management strategies for our local marine resources", Butterworth and Plagányi (2004) raise the following questions:

- In the OMP context, is the immediate role for multispecies/ecosystem models as testing or decision models?
- Do mass-balance constraints appreciably reduce uncertainty about current single-species management model estimates of abundance and productivity?
- What immediate relative emphasis should be placed on "Whole Ecosystem" versus "Minimum Realistic Model" analyses (e.g. of hake cannibalism/interspecies predation)?
- What are the most appropriate analytical platforms for such exercises?
- What are the cost implications for data collection and analysis?

It was suggested that ecosystem considerations could be fairly easily incorporated into the existing South African OMPs. For example, the pelagic OMP could incorporate a suitable or limit reference point for pelagic fish, such that sufficient fish would be left for seabird consumption.

FURTHER DISCUSSION ON HOW TO INCORPORATE ECOSYSTEM CONSIDERATIONS INTO SOUTH AFRICAN FISHERIES MANAGEMENT

Implementing EAF in South Africa

It was agreed that an EAF would be highly desirable, unavoidable and achievable in South African fisheries management. The priorities, in terms of primary policy goals and high priority objectives were seen to be:

(i) to rebuild depleted stocks;
(ii) to take into account wider fisheries effects (e.g. bycatch issues); and
(iii) to make better use of knowledge of the South African ecosystem, to reduce the risk of irrecoverable resource damage and economic/social crises.

It was felt that an EAF had a better chance than current single-species management approaches of achieving sustainable fisheries, because it aims for healthy ecosystems, which in turn should ensure optimal social and economic benefits. Management units should coincide with species distributions and boundaries. A recommendation was that ecosystem boundaries or sub-ecosystems ought to be considered to account for West Coast – East Coast differences and inshore-offshore differences in ecosystem structure and functioning.

Developing an EAF management procedure for the offshore fisheries

The major issues in developing an EAF management procedure for South Africa's offshore fisheries were identified as non-trophic, including degradation of benthic habitat by trawling and offshore mining, and climatic effects. Operational issues include discarding and bycatch, and gear interference (e.g. between longlines and trawls). Temporal and spatial aspects of the resources and fisheries will need to be considered. Biological issues seem to be extensive. A major issue identified was the interactions between species fished using different gears and with those that are important non-consumptive resources. For example:

(i) in the pelagic fishery, the population dynamics and productivity of anchovy and sardine are treated as independent, whereas there may be a combined limit to what the system can support (the bycatch of sardine in the anchovy fishery is included in the current approach);
(ii) in the Cape hake fishery, two species are currently managed as a single stock, cannibalism and interspecific predation are important processes, and natural mortality estimates need improvement. Ecosystem models could provide useful information on Cape hake interspecies predation and cannibalism, and could assist in deciding whether to expand a fishery on a species (e.g. horse mackerel *Trachurus trachurus capensis*) that is also an important prey species for other commercially valuable species.

Concerning the role of ecosystem research, the consensus at the workshop was that new insights may emerge from multispecies models without prior assumptions of particular theories. Ecosystem models could help quantify interactions that were previously only qualitatively defined, and may provide insight into processes and mechanisms not discernible with single-species models only. Further, by identifying inconsistencies in sets of parameter estimates provided by single-species models, existing ecosystem models could help refine understanding. Strengths, weaknesses and applicability of different modelling approaches need to be reviewed. Outputs of the different models could be used to define a range of possible trajectories for the ecosystem. It was advised that, with due allowance for uncertainties, parameters and results from ecosystem models should be used to provide feedback on parameters for single-species models and to guide research.

Implications of EAF for South African fisheries management

It was noted that the Marine Living Resources Act and other relevant Acts, international agreements and conventions would need to be taken into account in implementing an EAF in South Africa. A separate, overarching management plan (i.e. Ecosystem Sector Plan – ESP) is envisaged, listing the bioregions/ecosystems within South Africa's borders, the reference points that should be informed by ecosystem models, and the time-frames of importance in management. A possible hierarchical structure for an ESP was proposed, starting with the ecosystem under consideration, important subsystems of the ecosystem, and individual Sector Management Plans. An ESP would have to be implemented in a stepwise, transparent fashion, and may need to prioritize the different fishery sectors. It was agreed that consideration should be given to subjecting new fisheries to an ecosystem approach, so initiating the process in South Africa.

Wide representation across stakeholder groups and ways to balance conflicting objectives will be required for the successful implementation of an EAF. Potential areas of conflict are numerous, and include: reduced quotas to fisheries in order to address ecosystem issues such as the needs of predators; conflicts between consumptive and non-consumptive objectives and stakeholders; conflicts between different primary fishery sectors such as demersal and pelagic; conflicts between different groups of users within each primary sector, such as the handline and trawl sub-sectors; conflicts between mining and fishery stakeholders; conflicts between the aquaculture industry and, for example, capture fisheries; conflicts between the users causing marine environmental degradation and fishers; and conflicts between new fisheries and existing ones. A starting point would be the development of a draft EAF policy that includes inputs from all stakeholders and takes due consideration of relevant socio-economic factors.

In addition to the monitoring and research currently undertaken for single-species fisheries, focus areas for EAF monitoring and research should include species of conservation concern, and the consideration of broader ecosystem issues, which will require contributions from social scientists and economists. Implementation of an EAF will require effective control and enforcement capabilities. Specific areas requiring serious review are gear selectivity and bycatch issues, and the ecosystem effects of trawling and mining on outer shelf benthos.

CONCLUSIONS

Key proposals and concerns of the workshop included the following:

1. In line with shifts in fisheries management approaches worldwide, including the Plan of Implementation of the 2002 World Summit on Sustainable Development, South Africa will be obliged to adopt an EAF. It is essential that all stakeholders become involved in the EAF process and its development.
2. Models are tools; they do not reproduce reality and there are always inherent uncertainties in their parameters and assumptions. This problem is magnified in any form of ecosystem model, given current limited understanding of ecosystem and multispecies dynamics. It is important to differentiate between the two complementary types of ecosystem models, strategic/testing and tactical/decision models (Butterworth and Plagányi 2004). Whereas there is clearly an immediate role for ecosystem testing models, development of tactical/decision ecosystem models is still to be successfully completed. Consideration could be given to indicator species as surrogates for some overall ecosystem properties.
3. A suite of ecosystem models should be used to address any issue and flexibility encouraged to facilitate cross-validation of different model results and comparison of model output and data. The most suitable models could be used to address specific objectives, e.g. models with few components but containing much intraspecies detail versus models with many components, but incorporating less detail on each species.
4. Models need to be based on sound science, and it is important to understand that the ultimate aim of many of these models is to assist in decision-making. The potential implications and use of scientific advice in the implementation of management decisions should be carefully considered when modelling. Such advice can be very useful. For example, results of models developed in Australia (Fulton and Smith 2004) have shown that, in an ecosystem

context, input controls (such as controls of access to resources) may be more useful than output controls (controlling catches).

5. Shortcomings of ecosystem modelling studies to date include the following:

   (i) short-term variability is often ignored or considered to be stochastic;
   (ii) regime shifts and other longer term ecosystem dynamics are generally not adequately addressed by ecosystem models. In particular, some key components, such as phytoplankton, are not well understood;
   (iii) predator-prey functional responses are poorly understood and need further investigation;
   (iv) full sensitivity testing is not always possible in modelling, but attention should be paid to the robustness of the models in relation to any major uncertainties.

It was suggested that a dedicated EAF working group be established at Marine and Coastal Management to advise on the process of implementing an EAF in the various fisheries, to provide overarching guidance and to ensure consistency in integrating existing data and information for informing the management process.

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