Multi-species Considerations in Planning Methodologies for Possible Joint South African – Namibian Hake Assessments

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Introduction

There are increasing pressures for an EAF (an Ecosystem Approach to Fisheries - Garcia *et al*. 2003) both in South Africa and Namibia as well as world-wide. The management of the major South African and Namibian fisheries is currently based on single-species approaches although it has been appreciated for some time that there is a need to consider the potential impacts of inter-species interactions. The latter needs to be done taking due account of uncertainty in both data inputs and current understanding of multi-species interactions.

As an example, the South African hake resources, *Merluccius paradoxus* and *M. capensis* are assessed as two separate stocks, within a single assessment framework (Rademeyer and Butterworth 2006) that does not take account of both inter-species and cannibalistic (including interspecific – hake-on-hake – predation) interactions among and between the two hake species. The commercially valuable hake consist of two species, a shallow-water (*Merluccius capensis)* and a deep-water species (*M. paradoxus)*, with (in particular) the larger of the shallow-water species eating the smaller individuals of the deep-water species. Given the observation that a large fraction of hake diet is hake (Table 1), hake dynamics may be modified further from normal single-species behaviour than would be the case elsewhere. Cannibalism may thus play a fundamental role in regulating hake abundance, thereby affecting both the structure of the population as well as the natural mortality rate. The latter is particularly important because of problems in the current assessment as regards specifying natural mortality and its age-dependence (Rademeyer and Butterworth 2006).

Off the South African west coast, the fur seal population (*Arctocephalus pusillus pusillus)* has been estimated to consume about as much hake as is landed by fishers. Hence the impact of other important predators, such as seals, on the hake resources needs to be investigated (the last major evaluation of seal-hake interactions was conducted more than a decade ago – Punt and Butterworth 1995). Consideration of biological interactions could result in improved and more robust fisheries management recommendations. There is thus a need for further work in both South Africa and Namibia (ideally jointly) to develop multi-species models of the shallow- and deep-water Cape hake species, associated fisheries and other important interacting groups such as seals.

Multi-species models focusing on hake –what's been done previously?

Punt and Butterworth (1995) modelled the biological interaction among Cape fur seals and the Cape hakes to examine the effects of possible culls of seals on catches and catch rates of the bottom-trawl fishery for the Cape hakes off the South African west coast. Their approach involved the construction of a "minimal realistic model" of the hake-seal system. Their analyses suggested that a reduction in the number of seals would result in less hake overall because the associated increase in the numbers of shallow-water hake (the preferred prey of seals) would in turn result in increased predation on small deep-water hake, leading to less hake overall.

A noteworthy feature incorporated in the Punt and Butterworth (1995) approach involved taking explicit account of uncertainty and management issues through the use of a simulation framework that used the feedback control rules actually in place for setting TACs for the hake fishery (Plagányi and Butterworth 2005). The purpose of this approach was to check whether, even if a seal reduction did increase hake sustainable yields, the management system applied to compute TACs was such as to be able to take advantage of this.

The software package ECOPATH with ECOSIM (EwE) (e.g. Christensen and Pauly 1992, Walters *et al.* 1997, 2000) is dominating attempts world-wide to provide information on how ecosystems are likely to respond to changes in fishery management practices. Considerable work in implementing EwE has already been carried out for the southern African region (e.g. Roux and Shannon 2004, Shannon *et al.* 2000, Shannon *et al*. 2003). Shannon *et al.* (2003) included both small and large hake categories as well as seals in their model. Their analysis suggested that the total hake production is apportioned equally to seals and to the fishery.

What approaches are available to deal with the issue?

Plagányi (in review - commissioned by the FAO (Food and Agriculture Organization, Rome)) recently reviewed a range of methods for assessing the indirect ecosystem aspects of fisheries. The review summarized a number of ecosystem approaches which merit further investigation and which could usefully be adapted in a local southern African context, for example, ATLANTIS, Bioenergetic models, BORMICON (A BOReal Migration and CONsumption model), ECOPATH with ECOSIM (EwE), GADGET (Globally applicable Area-Disaggregated General Ecosystem Toolbox), Minimally Realistic Models, MSVPA (Multi-Species Virtual Population Analysis) and its forward derivative MSFOR, MULTSPEC, OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation), and SEPODYM/ SEAPODYM (Spatial Environmental POpulation DYnamics Model).

In the longer term it could be advantageous to construct an ATLANTIS-type model (Fulton *et al.* 2004) for the region, but this approach is hugely data intensive and complex. ATLANTIS focuses on the entire ecosystem rather than a much smaller subset and it may be better to start simpler and gradually add in complexity.

Another approach which is likely to be both data intensive and time-consuming to adapt is the multi-species trophodynamic modelling approach described in Koen-

Alonso and Yodzis (2005). They modelled the interaction between squid, anchovy, hake and sea lions off the Patagonian shelf. Koen-Alonso and Yodzis (2005) used a system of four ordinary differential equations, with basal equations to model squid and anchovy and consumer equations for hake and sea lions.

SEAPODYM is a two-dimensional coupled physical-biological interaction model at the ocean basin scale, developed for tropical tunas in the Pacific Ocean (Lehodey *et al.* 2003). The model includes an age-structured population model of tuna species, but there are plans to develop additional modules for other oceanic predators (P. Lehodey, CLS, Toulouse, France, pers. commn). It is a useful modelling framework because it focuses on a relatively small subset of the ecosystem and includes spatial structure to account for fishing effort distribution, the widely ranging swimming behaviour of tuna and environmental variations. It would require considerable effort to adapt this approach to the southern Benguela region.

Data in the region are insufficient for developing a full MSVPA, but there is the possibility of applying a hybrid MSVPA version to a small subset of the ecosystem (such as hake-seals-fishery) (Plagányi and Butterworth 2005). A promising example to follow in the current context is that of Mohn and Bowen (1996) who modelled the impact of Grey seal (*Halichoerus grypus*) predation on Atlantic cod (*Gadus morhua*) on the eastern Scotian Shelf.

OSMOSE (Shin and Cury 2001, Shin *et al*. 2004) is a spatialised individual-based model that uses simple individual predation rules to model trophic interactions. It is based on the hypothesis that predation is a size-based opportunistic process, depending only on size suitability and spatial co-occurrence between predators and their prey. The focus of OSMOSE is on piscivorous fish species, with top predators such as marine mammals represented simply by including an additional natural mortality term. It is thus a useful tool for investigating selected aspects of the hake centric ecosystem discussed here, but is limited in other respects such as its representation of top predators.

A number of modifications and improvements have recently been added to EwE. Given fairly recent improvements in terms of age-structure handling, many of the older models have or are in the process of being modified and this is likely to result in valuable new insights. EwE has in the past been criticised for inadequate handling of issues of uncertainty (e.g. Plagányi and Butterworth 2004) but the more recent versions include improved capabilities to balance models based on uncertainty, examine the impact of uncertainty as part of the management process and quantify input parameter uncertainty to run ECOSIM using a Monte Carlo approach to fit to time series (V. Christensen, University of British Columbia, Canada, pers. commn, Kavanagh *et al.* 2004). A large project is also underway to develop a new generation of EwE (see www.lenfestoceanfutures.org) that will be fully modularized. A building-block version is to be created that will facilitate construction of individually tailored versions (V. Christensen, University of British Columbia, Canada, pers commn) (scheduled for release by September 2007).

The Punt and Butterworth (1995) MRM approach to the local seal-hake-fishery system needs to be revisited *inter alia* because of changes in and extensions to the data used as inputs as well as an improved understanding of the distribution and dynamics of the species involved. In particular, there is a need to examine more recent data to check the validity of the assumption in the original model that seals feed mainly in shallow waters, and hence that their hake consumption is presumably nearly all *M. capensis*. A second aspect of the Butterworth *et al*. (1995) seal model which may need to be revised concerns the absence of any feedback between a paucity of hake and a population-dynamic response in (for example) weight-at-age, survival and reproduction of seals, i.e. it was assumed that there was always sufficient "other" food for such predators. The daily hake ration of a predator of species *j* (either seals, *M. capensis* or *M. paradoxus*) was assumed to be given by a Holling Type II feeding function relationship, as recommended by Butterworth and Harwood (1991), on the grounds of simplicity and availability of sufficient data to allow parameter estimation. Given the importance (applicable to all the models discussed) of investigating sensitivity to alternative interaction representations, rather than recoding from scratch, it may be sensible to "revisit" an approach such as that of Punt and Butterworth using the GADGET software which already has this capability built-in.

Current case studies using GADGET (Globally applicable Area-Disaggregated General Ecosystem Toolbox, (Begley 2005, see also webpage http://www.hafro.is/gadget ; coordinator G. Stefánsson) include the Celtic Sea, Icelandic waters and the North Sea and North Atlantic herring. Plagányi and Butterworth (2005) note that GADGET is still being developed but shows great promise for modelling indirect interactions between marine mammals and fisheries (and has been recommended for such – NAMMCO, 2002).

Data requirements

Dietary data

The major data requirement to construct a combined Namibia-South Africa multi-species model is dietary data. A "Trophic interactions" project in Namibia involved the collection of dietary data from the hake species, Cape fur seals and other predatory fish (Roux and Shannon 2004) and hence some of the required data are available. In South Africa, it would be desirable to analyse hake stomach content data for the period 1995-2005 using an analogous method to that applied by Punt and Leslie (1995) to data available for the period 1988-1994.

A summary of the total number of hake stomachs (disaggregated by species and length-class and for years 1988-1994) considered in the Punt and Leslie (1995) study is given in Table 1 of this document. Given that the sampling intensity per survey (6 fish per species per 1-cm length class) has remained the same, the number of hake stomach samples for this later period should be similar to that used by Punt and Leslie in their original analyses.

Ideally more intensive stomach sampling exercises should be conducted to improve understanding of differences due to, for example, spatial, seasonal and sex effects. Studies such as that by McQueen and Griffiths (2004) provide an excellent example of investigations as to spatial and temporal variations in a predator's diet.

Fraction of hake in diet of other hake

Data are required regarding the average fraction of hake in the diet of other hake. For example, Punt and Butterworth (1995) assumed (based on data) that the average fractions of hake in the diet of 4-7-yr-old hake in 1991 should be as close as possible to 0.29 and 0.17 for *M. capensis* and *M. paradoxus* respectively. Similar data are required for Namibia and are presumably available.

Seal dietary information

Data from the different regions are required regarding the split of the hake component of the seal diet into *M. capensis/M. paradoxus* e.g. Punt and Butterworth (1995) assumed either all *M. capensi*s or a specified smallish proportion of *M. paradoxus* and the rest *M. capensis*.

Further data regarding the fraction of hake in the seal diet in a particular year/s would be useful. For example, Punt and Butterworth used a base-case value of 15% for 1991. These data are not easily obtainable because ideally the otoliths in the seal stomachs need to be analysed to age the hake.

Additional data as regards the daily ration of a seal of sex *s* and age *a* could be useful. Butterworth *et al*. (1995) based their calculations in this regard on estimates presented in Balmelli and Wickens (1994).

Data on Movement

Information on the extent of stock mixing is required in order to construct a combined Namibia-South Africa multi-species model. If no direct data on movement are available, alternative analyses will have to be used to compute the proportions of the stock in different size classes that move between regions.

Information on age-specific longshore movement in South Africa (across the west coast/south coast boundary) and offshore movement (older fish tend to move to deeper waters) is also required. Offshore rates could be obtained from the pattern of age-by-depth obtained from surveys.

Suggested ways forward

Ideally a number of different modelling approaches should be attempted and their results compared in investigating multi-species aspects pertaining to the hake fishery as well as the inclusion of transboundary considerations. However, there may not be the necessary resources to do this and hence careful consideration needs to be given as to how best to focus efforts.

Work on EwE both in South Africa and Namibia has already been going on for some time. Whilst EwE can be extremely useful when applied prudently, there are a number of instances in which it may be preferable to develop more specific tailored multi-species approaches (e.g. Plagányi and Butterworth 2004). Thus whereas EwE can complement initiatives as suggested here, it is not adequate on its own (see list of features below) as a tool for this purpose.

A prudent approach to a more detailed quantitative modelling analysis may be to first consider only inter- and intra-hake species predation/cannibalism only, then add seals and then only to include other species in the model. The staging will likely also need to have regional components. For example, the Punt and Butterworth (1995) analyses were for the South African west coast region only following the recommendation that the west coast was less complex to model than Namibia and the south coast for which one would likely need more species in a (MRM) model (Butterworth and Harwood 1991). It seems that the South African west coast may thus be a sensible (and central) starting point for a transboundary multi-species model that is gradually expanded to include Namibia and the south coast.

In order to construct a model as outlined above, the following features are necessary:

- A sufficiently flexible modelling platform is required to be able to represent differences between the Namibian, west coast and south coast regions
- The model needs to be fully age- or size-structured
- A spatial component is necessary (with flows possible between model compartments)
- The model needs to be flexible in substituting different interaction representations (functional response types), recruitment formulations etc. to check that model results are robust across a range of uncertainties
- If the model results are to contribute to management advice, attention needs to be focused on adequate representations of uncertainty.

It seems that the best approach to pursue in this case might be GADGET because populations can be split by species, size class, age group, area and time step. Unlike the other approaches mentioned, it is a convenient tool to construct age- or length-structured models of the hake and other groups, whilst simultaneously including spatial considerations. Given limited understanding of the nature and extent of inter-species interactions, GADGET's flexibility is ideal in permitting the easy addition/substitution of alternative model components of biological processes such as growth, maturation and predator-prey interactions (Plagányi in review).

Movement is implemented by either directly specifying migration matrices or calculating these based on migration proportion input information describing the proportion of the stock that will migrate between different areas. This makes it an ideal framework to extend a multi-species model developed for the southern Benguela to include also the northern Benguela region.

GADGET includes a range of likelihood functions that can be maximized to obtain parameter estimates and their confidence intervals when fitting to data and hence is at the forefront of multi-species models attempting to represent uncertainty.

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Table 1. Summary of number of hake stomachs sampled across the whole study area over the period 1988-1994 (from Punt and Leslie 1995). These stomach content data were used (following further analyses) as inputs in the Punt and Butterworth (1995) model with the key values of the fraction of the diet of each of *M. capensis* and *M. paradoxus* consisting of Cape hakes shown in the lower part of the Table (from Punt and Leslie 1995).

a) Number of samples - all data pooled		
Length-class (cm)	*M. capensis*	*M. paradoxus*
1-20	214	299
20-30	425	509
30-40	524	454
40-50	468	396
50-60	485	382
60-70	437	353
70+	388	263
TOTAL	2941	2656

b) Fraction of diet (%) consisting of hake		
Predator age	*M. capensis*	*M. paradoxus*
1	0.8	0.8
2	7.4	1.4
3	9.2	3.2
4	19.3	11.4
5	20.2	4.8
6	37	22.4
7	40.3	27.9
8+	36.4	56.3