Using decision analysis to evaluate candidate OMPs for the South African west coast rock lobster fishery

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Simulation models frequently are used to provide information to assist in decision-making in natural resource management. The sheer volume of information to process can be overwhelming, however, and there is a danger that some management objectives are not adequately considered, because of the difficulties of making decisions when there are multiple, conflicting objectives. Formal decision-analysis methods have been used in conservation biology to choose among simulation model results. This paper suggests that they can also be used in South African fisheries management, where simulation models are used extensively in developing operational management procedures.

Decision analysis is a structured way of helping to make wise decisions.[1] It is a useful technology when complex, confusing and/or stressful decisions need to be made. Sometimes, such decisions are linked to the outputs of models of varying complexity, and when faced by an abundance of data, it can be difficult to choose among different options and to use consistent criteria in making choices. These difficulties are compounded when there are conflicting objectives that need to be considered, as is the case in many resource management situations. Rall and Starfield[2] showed how two structured decision-making methods could be applied in conservation biology where management decisions were based on the output of simulation models. They used these methods to help choose a management strategy to address the problem of 'mobbing' in the endangered Hawaiian monk seal, by evaluating the implications of different courses of action.

In South African fisheries management, operational management procedures (OMPs) are used as the basis for management of fisheries involving sardine (*Sardinops ocellatus*) and anchovy (*Engraulis capensis*), hakes (*Merluccius* spp.), and west coast rock lobsters (*Jasus lalandii*).[3] The essence of the OMP approach is to use an algorithm (which can be a set of rules or an equation) to derive a management outcome. Importantly, the algorithm is tested by simulation in advance of its adoption. The testing procedures attempt to account for all reasonable sources of uncertainty, and this results in a large number of candidate OMPs with many simulations, the outputs of which need to be evaluated. Typically, this evaluation is carried out by one of the resource working groups of the Branch: Marine and Coastal Management Coordination of the South African Department of Environmental Affairs and Tourism. The final choice of an OMP lies with the minister, who is advised by the Consultative Advisory Forum.

In fisheries management, there are usually conflicting management objectives,[4] and different people have different ideas about what constitutes a good management strategy. In this paper we suggest that the process of choosing among candidate OMPs can be made more rigorous by using decision analysis methods, as described for conservation biology applications by Rall and Starfield.[2]

Choosing an OMP for the west coast rock lobster fishery

To illustrate the decision analysis approach, a hindsight example is used, based on the development of the OMP for the South African west coast rock lobster fishery. Full descriptions can be found elsewhere of the history of this fishery and the development of the OMP,[5] which was applied for the first time in 1997. The west coast rock lobster fishery is managed on the basis of a total allowable catch (TAC), based on the outputs of the OMP. The management of this fishery has multiple objectives, involving trade-offs between, for example, biomass recovery of the resource (which is believed to be below acceptable levels) and catch levels that will provide livelihoods for as many stakeholders as possible. The OMP was developed over a period of approximately two years, during which time many alternative

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candidate OMPs and numerous simulation results were presented to the rock lobster working group of the then Sea Fisheries Research Institute (now Marine and Coastal Management). The working group consisted of eight members and a varying number of observers. The eventual development of six candidate OMPs was achieved mainly by consensus within the working group. These candidate OMPs were presented to the Sea Fisheries Advisory Committee (SFAC, since replaced by the Consultative Advisory Forum), which chose one to recommend to the minister for implementation.

In evaluating the candidate OMPs, a set of summary statistics of simulation results or 'performance statistics' was used. These performance statistics were generated in each simulation, and they were used both to compare different candidate OMPs, and to evaluate the results of robustness trials of the OMPs. At times, this resulted in large amounts of information being presented to the working group for evaluation. The OMP development was an iterative process, guided by the working group, whose decisions involved much discussion. The SFAC also provided guidance on some of the management objectives. However, for both groups it was difficult to ensure consistency in choices, because of the protracted process and the fact that the methods were evolving.

Using decision analysis methods to choose an OMP

The two structured decision-making methods that were used by Ralls and Starfield[2] and that will be applied here are 'goal filtering' and 'simple multi-attribute ranking technique' (SMART).[1,6] The methods are applied to the simulation results obtained from six candidate OMPs, as described by Johnston and Butterworth.[7] These candidate OMPs aimed to rebuild the rock lobster resource at two different rates (20% and 50% biomass recoveries over 10 years), and for each recovery rate three different potential 1997 TAC values were tested: 1750 t, 1870 t and 2040 t. It is important to note that these potential TAC values are not directly comparable with the TACs eventually set, because they result from simulations that assume that a certain set of conditions would exist at the time that the TAC was set. As it turned out, the data used in the final TAC calculations, which occurred after the OMP had been chosen, were more conservative than expected, so the 'real' equivalents to these potential model TACs are correspondingly smaller.

The outcomes of the six candidate OMPs were compared using five performance statistics: 1) the magnitude of the average catch over the 10-year period, 2) the variability of the average catch, 3) the biomass level after 10 years, 4) the TAC for 1997, and 5) the TAC for 2006. To determine how each of the candidate OMPs performed if certain model assumptions were incorrect, 12 robustness trials were conducted for each.[5,7] The robustness trials were mostly independent, and these independent trials were given equal weighting. However, where a set of trials represented variations on a theme, the weighting was split equally among these related trials. The robustness trials were as follows:

a) The base case, with best estimates of all parameters.
b) The effect of an episodic event in which 50% of all rock lobsters die in any one year.
c) The effect of an episodic event in which the two indices of rock lobster abundance fluctuate in a correlated fashion.
d) Three trials involving three contrasting ways in which rock lobster growth rates might change. Each is plausible, and could give very different results. They are each given a weight of one.
e) Three trials involving three contrasting ways in which recruitment might vary. Each is plausible, and could give very different results. They are each given a weight of one.
f) Three trials involving survivorship/mortality. These trials are variations on a theme, and should affect the results in a similar fashion, but at different magnitudes. They are each given a weight of 0.333.

This resulted in a three-dimensional matrix of performance statistics (6 × 5 × 12), containing 360 items of information. (In practice, there were actually 720 items, because the working group also considered strategies for 30% and 40% biomass recoveries.) The decision-making methods presented here condense this information in a structured fashion. The 'decisions' resulting from this exercise are used to produce a hindsight choice for the 1997 OMP. It is emphasized that this exercise is for illustration purposes only, because there are other factors and issues that will have influenced the final choice of OMP, and that are not discussed here.

Management objectives guiding the choice of an OMP

The aim of this exercise was to choose the best OMP, given certain criteria. A critical first step is to identify the objectives of the process, and hence define a good decision. It is important to focus on the objectives and not the solutions (that is, focus on the management aims and not on the TACs). In practice, this important first step of defining the objectives should be carried out with the participation of all stakeholders, and it should involve careful and thorough discussions. This was not done for this paper. The choices presented below are those of the first author, and although they capture the essence of the working group discussions, they have not been scrutinized and commented upon in a true management situation.

Five objectives were chosen to reflect the main policy objectives for the rock lobster fishery, based on the performance statistics that were used in assessing the candidate OMPs. The objectives broadly aim to rebuild the rock lobster stock while minimizing the impact on the fishery in terms of the magnitude of the TAC and its interannual variability. In order of priority, the objectives are as follows:

1) The population biomass of the rock lobsters (B) should recover over a 10-year period.
2) The TAC in 1997 (TAC_{97}) should be large.
3) Variability (V) in the catch over the 10-year period should be small.
4) The average catch (C_{ave}) over the 10-year period should be large.
5) The TAC in 2006 (TAC_{06}) should be large.

The priorities were assigned on the basis of discussions in the working group, and instructions to the working group from the (then) SFAC. Stock rebuilding was identified as the top priority by the SFAC, and it is ranked first here. Another priority was to give short-term relief to the industry, which had recently faced several large TAC cuts, and for this reason maximizing the 1997 TAC was assigned second priority. For the remaining three objectives, minimizing variability in TAC was deemed to be more important than long-term catch objectives, and maximizing the average catch over 10 years gave more immediate relief to the industry than would a large catch in 2006.

The qualitative objectives were developed into explicit, quantitative criteria (Table 1). The selected threshold values needed to be less conservative (i.e. smaller) than the management objectives for stock rebuilding, and more conservative (i.e. smaller) for the catch objectives. For biomass rebuilding, a value of B_{06}/B_{96} greater than 1 and less than 1.2 was required; 1.1 was chosen, stipulating a biomass increase of at least 10% over 10 years. The

Table 1. Results of goal filtering. The decision-making criteria, ranked from highest to lowest priority, and the candidate OMPs. For each candidate OMP, the (weighted) numbers of robustness trials (maximum of 10) in which the criteria are met are indicated.*

Rank	Criterion	20% recovery			50% recovery		
		1750 t	1870 t	2040 t	1750 t	1870 t	2040 t
1	$B_{2006/1996} \geq 1.1$	5.3	5.3	5.3	6.3	6.3	6.3
2	TAC 1997 ≥ 1750 t	5	7	10	10	7	5
3	$V \leq 7.67$	5	5	**4**	**2**	7	8
4	$C_{ave} \geq 1870$ t	7	7	(7)	(4)	**4.3**	**4.3**
5	TAC 2006 ≥ 2040 t	6	6	(5)	(1)	(2)	(4)
Sensitivity tests 1							
1	$B_{2006/1996} \geq 1.0$						7.3
2	TAC 1997 ≥ 1800 t	**2**					**2**
3	$V \leq 7.0$	**3**	**4**		**1.7**	5	6
4	$C_{ave} \geq 1750$ t				6.3	6.3	5.3
5	TAC 2006 ≥ 1800 t	7	7	6		**4**	**4.3**
Sensitivity tests 2							
1	$B_{2006/1996} \geq 1.2$	**3**	**3**	**3**	5.3	5.3	5.3
2	TAC 1997 ≥ 1870 t	**2**	**2**	8	8	**2**	**2**
3	$V \leq 8.0$	6	6		**4**		
4	$C_{ave} \geq 2040$ t				**2**	**2**	**2**
5	TAC 2006 ≥ 1870 t	7	7	6		**4**	**4.3**

*Bold underlined figures indicate the stage at which a candidate OMP is filtered out of the process (<50% success); the subsequent figures in brackets are not used. Also shown are the results of sensitivity trials, where the criteria were altered. Only differences from the original results are shown.

threshold for the catch in 1997 was set at the smallest value stipulated in the candidate OMPs (1750 t). The threshold value for interannual variability was set at the average from all candidate OMP robustness test results. The average catch threshold was set at 10% above the 1997 catch threshold, and the catch in 2006 at 20% above the 1997 catch threshold. These last three choices were somewhat arbitrary, but sensitivity tests were conducted for all the threshold values.

Decision analysis: goal filtering

In goal filtering, candidate OMPs are filtered out of the selection if the simulation results do not meet pre-established standards. In their simulations, Johnston and Butterworth[7] presented performance statistics for each of the 12 robustness trials for each candidate OMP. We counted the number of times that a performance statistic for each candidate OMP exceeded the thresholds that had been established. (The counts for the three robustness trials dealing with survivorship were down-weighted to try and remove possible bias.) If this count was less than a pre-determined cut-off level, the candidate OMP was 'filtered out' of the selection. The order of filtering was determined by the ranks that had been given to the criteria (Table 1). In our example, the filter was set at 50%; if a (weighted) majority of the robustness trials (>5) failed to meet the standard, that candidate OMP was eliminated. We also conducted sensitivity tests to assess how the choice of thresholds might influence the process.

From Table 1 it is apparent that only two candidate OMPs (20% recovery, TAC_{97} = 1750 t and 20% recovery, TAC_{97} = 1870 t) met the filtering standards. The candidate OMP with 20% recovery, TAC_{97} = 2040 t, failed only to meet the standard for interannual variability, whereas the candidate OMPs that involved a 50% biomass recovery had difficulty meeting the standards for variability and long-term catches.

The ranges of threshold values used in the sensitivity trials were kept 'realistic', so we did not test thresholds that fell outside the broad expectations of the stakeholders in the rock lobster fishery. Thus, there was no point in setting TAC levels too low (<1750 t), but it was worth testing elevated levels. The results from the sensitivity tests confirmed that the candidate OMPs with a 50% biomass recovery generally were less able to meet the standards than those with a 20% biomass recovery (Table 1), mainly because the catch thresholds were too high. In both sets of sensitivity tests, additional candidate OMPs (50% recovery, TAC_{97} = 1870 t and 2040 t) met the filtering standards only if there was a decrease in the average catch over 10 years to 1750 t. By contrast, increasing the biomass recovery threshold to 1.2 removed all the candidate OMPs with a 20% biomass recovery, and increases in the various catches not surprisingly excluded all the candidate OMPs with 50% biomass recovery. In summary, the sensitivity tests confirm that the OMPs with a 20% biomass recovery best met the objectives, and the catch levels were important in the filtering process.

Decision analysis: ranking on the sum of weighted criteria (SMART)

In goal filtering, a 'sudden death' philosophy operates. With SMART, all criteria are retained and given a score, and it is the overall score that determines which choice to make. In this example, the criteria (i) were ranked as for goal filtering (Table 1), and each rank was given a weighting w_i (Table 2). Three different methods of weighting were used, to test for sensitivity to the choice: reverse rank, square root of reverse rank, and fifth root of reverse rank. The performances of the candidate OMPs (j) were tallied in a similar fashion to that used for goal filtering, the tally t_{ij} being the (weighted) number of times that candidate OMP j met the explicit criterion i for the 12 robustness tests (Table 2). The final score for each candidate OMP is a weighted mean:

$$\text{Score}_j = \frac{\sum_{i=1}^{n} w_i t_{ij}}{\sum_{i=1}^{j} w_i} . \qquad (1)$$

From Table 2 it is apparent that for all weighting systems, the largest score was assigned to the candidate OMP with a 20% biomass recovery and TAC_{97} = 2040 t. For weighting by reverse ranking, the candidate OMP for 50% biomass recovery and TAC_{97} = 1870 t had the second highest score, whereas the other two weighting systems gave second place to the candidate OMP with a 20% biomass recovery and TAC_{97} = 1870 t. The most conservative candidate OMP (50% biomass recovery and TAC_{97} = 1750 t) tended to score badly, mainly as a result of low tallies for the three lowest ranked criteria (Table 2). The criterion for TAC_{97} >1750 t had a large influence on the result, because it is ranked second and there is a relatively large spread of tallies among candidate OMPs.

Table 2. Results of SMART. The decision-making criteria, ranked from highest to lowest, and the tallies and scores for each of the candidate OMPs.*

Rank	Criterion	Weight	20% recovery 1750 t	20% recovery 1870 t	20% recovery 2040 t	50% recovery 1750 t	50% recovery 1870 t	50% recovery 2040 t
Weight = reverse rank								
1	$B_{2006/1996} \geq 1.1$	5	5.3	5.3	5.3	6.3	6.3	6.3
2	TAC 1997 ≥ 1750 t	4	5	7	10	10	7	5
3	$V \leq 7.67$	3	5	5	4	2	7	8
4	$C_{ave} \geq 1870$ t	2	7	7	7	4	4.3	4.3
5	TAC 2006 ≥ 2040 t	1	6	6	5	1	2	4
Weighted mean score			5.4	6.0	**6.5**	5.8	6.1	5.9
Weight = square root of reverse rank								
1	$B_{2006/1996} \geq 1.1$	2.2	5.3	5.3	5.3	6.3	6.3	6.3
2	TAC 1997 ≥ 1750 t	2.0	5	7	10	10	7	5
3	$V \leq 7.67$	1.7	5	5	4	2	7	8
4	$C_{ave} \geq 1870$ t	1.4	7	7	7	4	4.3	4.3
5	TAC 2006 ≥ 2040 t	1.0	6	6	5	1	2	4
Weighted mean score			5.5	6.0	**6.4**	5.3	5.8	5.7
Weight = fifth root of reverse rank								
5	$B_{2006/1996} \geq 1.1$	1.38	5.3	5.3	5.3	6.3	6.3	6.3
4	TAC 1997 ≥ 1750 t	1.32	5	7	10	10	7	5
3	$V \leq 7.67$	1.24	5	5	4	2	7	8
2	$C_{ave} \geq 1870$ t	1.15	7	7	7	4	4.3	4.3
1	TAC 2006 ≥ 2040 t	1.00	6	6	5	1	2	4
Weighted mean score			5.6	6.0	**6.3**	4.9	5.5	5.6

*The criteria have been given three different sets of arbitrary weights (reverse rank, square root of reverse rank, fifth root of reverse rank), to test the sensitivity of the results to the weighting system used. For each candidate OMP, a tally indicates the (weighted) numbers of robustness trials (maximum of 10) in which the criteria were met. A weighted mean score is calculated for each candidate OMP. Largest scores are in bold.

Discussion

The two decision analysis techniques employed here indicate that the candidate OMPs with a 20% biomass recovery meet the objectives and criteria better than those with 50% biomass recoveries. The goal filtering technique indicated that TAC_{97} values of 1750 t and 1870 t were better than one of 2040 t, but the last was the highest scoring candidate OMP using the SMART method. This candidate OMP was eliminated in goal filtering on the basis of catch variability, the threshold for which was the most arbitrary of all the criteria. Somewhat coincidentally, this was also the OMP eventually chosen for management of the rock lobster fishery,[8] based on different arguments from those presented here.

The combination of decision analysis methods allows one to evaluate the candidate OMPs in a number of ways. The goal filtering method allows one to assess on what criteria candidate OMPs might fail to meet the objectives. The SMART method allows one to give different weightings to the criteria, and thereby understand the extent to which the criteria can influence the outcomes.

The candidate OMP that scored highest in the SMART procedure was at the extreme of the range considered, because it allowed the greatest immediate catch (TAC = 2040) t and the smallest biomass recovery (20%). On reflection, the selection of this option was not surprising. A certain amount of prior filtering had been carried out during the process of developing the OMPs, because the main criterion of biomass recovery was set early on in the process. It was therefore logical for the size of the 1997 TAC to be the main determining factor in the final choice of OMP. In decision-making situations in fisheries management (in South Africa and elsewhere), this choice might appear less attractive than an intermediate option, because intermediate options are often perceived as good 'compromise' solutions by nervous decision-makers. Decision analysis methods can support seemingly extreme options, and show that these are not necessarily the most risk-prone (or risk-averse) when multiple objectives have to be considered.

Decision-analysis methods are not problem-free, and the structures presented here are relatively simple. A number of different approaches could be used in this example, including different management objectives, different rankings of criteria, and different weights for the criteria. It is also possible to manipulate the ranks and the weights, to achieve a desired outcome. However, this is not a disadvantage of the methods. Indeed, it is advantageous to know to what extent certain criteria might have to be weighted to make them dominate the outcome. And in the event that this occurs, the methods allow documentation of how decisions were reached, taking all information into account. Ultimately, both decision analysis methods ensure that the decisions or choices are consistent with all stated management objectives, and this is important in situations where there are multiple objectives.

Fisheries management decisions in South Africa, as elsewhere, make great use of simulation models to help understand the dynamics of the resource and the fishery. With rapidly improving computer technologies, more and more information is provided, but it is often difficult to digest it. We suggest that structured decision analysis methods provide a readily digestible format for presenting model results, so that the trade-offs among different options are apparent, and the reasons for accepting or rejecting certain results are consistent and obvious. Ultimately, this should lead to better understanding of the relationships between decisions and objectives.

1. Von Winterfeldt D. and Edwards W. (1986). *Decision Analysis and Behavioural Research.* Cambridge University Press, Cambridge.
2. Ralls K. and Starfield A.M. (1995). Choosing a management strategy: two structured decision-making methods for evaluating the predictions of stochastic simulation models. *Conserv. Biol.* **9**, 175–181.
3. Geromont H.F., de Oliveira J.A.A., Johnston S.J. and Cunningham C.L. (1999). Development and application of management procedures for fisheries in southern Africa. *ICES J. Mar. Sci.* **56**, 952–966.
4. McAllister M.K., Starr P.J., Restrepo V.R. and Kirkwood G.P. (1999). Formulating quantitative methods to evaluate fishery-management systems: what fishery processes should be modelled and what trade-offs should be made? *ICES J. Mar. Sci.* **56**, 900–916.
5. Johnston S.J. (1998). *The development of an operational management procedure for the South African west coast rock lobster fishery.* Ph.D. thesis, University of Cape Town.
6. Goodwin P. and Wright G. (1991). *Decision Analysis for Management Judgement.* John Wiley, Chichester.
7. Johnston S.J. and Butterworth D.S. (1997). *OMP results for a number of 'strategies'.* SFRI document WG/07/97/WCL23. Cape Town.
8. Verheye H.M. (Ed.) (1998). *Research Highlights 1997–1998.* Sea Fisheries Research Institute, Cape Town.