Exploring Options for the Long Term Future of Australia's Fisheries Using a Scenario Modelling Approach

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Abstract: The fisheries sector is a natural, renewable resource of significant economic, social and environmental value to Australian society and thus its long-term sustainability is an issue of importance. We have undertaken to explore possible long-term futures of the sector using a scenario modelling approach. In an attempt to investigate the long-term issues in the more general area of natural resource management that Australia faces, we have developed a simulation model known as the *Australian Stocks and Flows Framework* (ASFF). This model simulates Australia's economy in terms of physical transactions and allows users to explore the physically feasible long-term futures and the conflicts, constraints and opportunities that may arise. Within the context of this approach we are developing a module that describes the nation's fisheries. Catch data have been collected and consolidated for the majority of fisheries across Australia, from different habitats (freshwater, estuarine, coastal and marine) and different sectors (wild, aquaculture and recreational). Data for important inputs and outputs from fisheries such as domestic consumption (via population and consumption rates), trade (via imports and exports) and physical activity (via energy, vessels and labour) have also been collected with the purpose of integrating all the information. This paper describes the nature and structure of the model and the data that have been incorporated. It describes how scenario modelling of this issue is being approached, the process involved in developing scenarios and the preliminary results. Two basic scenarios based on conservative and "best-knowledge" estimates of possible production volumes form the basis for exploring future possibilities.

Keywords: Fisheries; Modelling; Scenarios; Futures

1. INTRODUCTION

Australia's fisheries sector contributes significant economic, social and environmental benefits to the nation. It is a natural resource that is under increasing pressure from human exploitation and environmental changes and its long-term sustainability and productivity are issues of national concern. A significant portion of fisheries modelling is concerned with the provision of accurate estimates of sustainable levels of catch rates or effort, usually in specific fishing areas, for the purposes of fisheries management on a year to year basis. There are few analytical approaches to issues surrounding fisheries production in the long term. The modelling framework presented here is one approach to exploring natural resource issues, such as fisheries, in the long-term and at a national scale.

2. SCENARIO MODELLING AND THE DESIGN APPROACH

Scenario modelling is an analytical technique whose main purpose is to explore alternative futures, rather than attempt to predict likely outcomes. This quality makes it suitable for investigating complex, long-term resource and environmental issues. ROBBERT Associates have created the *whatif* ® software tools [www.robbert.ca] to apply a particular method of scenario modelling known as the design approach [Gault et al., 1987].

In the design approach, the model consists of two distinct components: an open simulation framework that represents the physical processes of the system and the user (acting as decision maker) who is the source of novelty and learning. The simulation framework keeps track of the stocks of physical entities (eg. people, boats, fish) and flows of energy and materials (eg. energy expended, fish caught). The feedback loops of the simulation framework are left incomplete and the framework imposes no global optimisation or equilibrium conditions. As a result, physically inconsistent or socially unacceptable outcomes may develop. Control is given to the user to explicitly choose to resolve any such incompatibilities (called 'tensions') so that policy decisions are made transparently. The process of repeated simulation, both to resolve tensions within scenarios and to explore new scenarios, provides the user with learning and new information regarding the system and its behaviour. An illustration of this process is given in Figure 1.

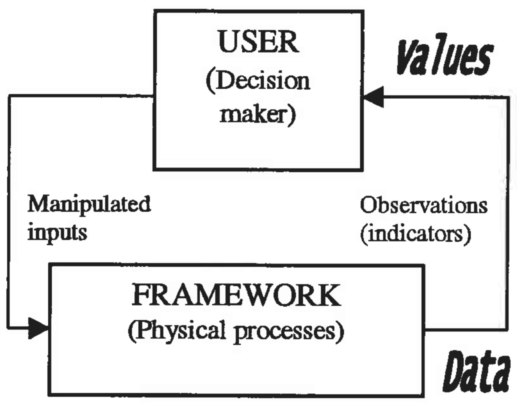

Figure 1. An illustration of the *design approach* to scenario modelling.

In this figure, the user makes the decisions for the settings of input variables, which determine other variables within the framework of physical processes. Additional variables, acting as indicators, inform the user which he/she uses to make necessary adjustments to the inputs. Thus the user completes the information feedback loop and explores the implications of decisions and changes in the environment. In this way the physical data is separated from subjective values. The main aim is to produce different, physically realistic scenarios representing various policy positions. The user learns both from the final scenarios produced and the iterative process of producing these scenarios through resolution of various tensions. This provides the user with learning about the system dynamics, constraining factors and possible options.

An example that illustrates the concept of tensions is a scenario where there is a calculation of the amount of labour available and the amount of labour required to perform all the activities in that scenario. If the amount of labour available was less than the amount of labour required, this would be a physically infeasible situation and the user would be forced to adjust the scenario until this tension was resolved. However, if the labour available was more than the amount of labour required, then this can be viewed as unemployment, and although it may be socially undesirable, it is not physically inconsistent, and the user has the discretion to alter the scenario.

3. THE MODELLING FRAMEWORK

3.1. The Australian Stocks and Flows Framework (ASFF)

The specific analytical structure that is continuing to be developed is known as the *Australian Stocks and Flows Framework* (ASFF). ASFF is a hierarchical and integrative model which describes the important physical components (*stocks*) and their linkages (*flows*) that comprise the Australian economy. ASFF has been applied to such issues as population [Foran et al., 2000] and land and water usage [Dunlop et al., 2001].

The fisheries sector is included as one of the fundamental modules in the framework. A simplified schematic of the ASFF structure illustrating the position of the fisheries module in the hierarchy is shown in Figure 2. An important aspect of the framework not illustrated in this figure is the flow of information between modules. It is important to note that the modules are connected in a manner that only allows a unidirectional flow of materials and energy through the framework. In other words, implicit feedback loops are excluded from the framework. This ensures that the user must explicitly complete any necessary information loops by manipulating input variables as illustrated in Figure 1 without the confounding effects of hidden feedback loops. Further details of ASFF can be found in the paper by Turner and Poldy [2001].

3.2. The Fisheries Calculator

In keeping with the philosophy of the rest of the framework, the fisheries module is constructed to model the stocks and flows of materials and energy, within and through that sector.

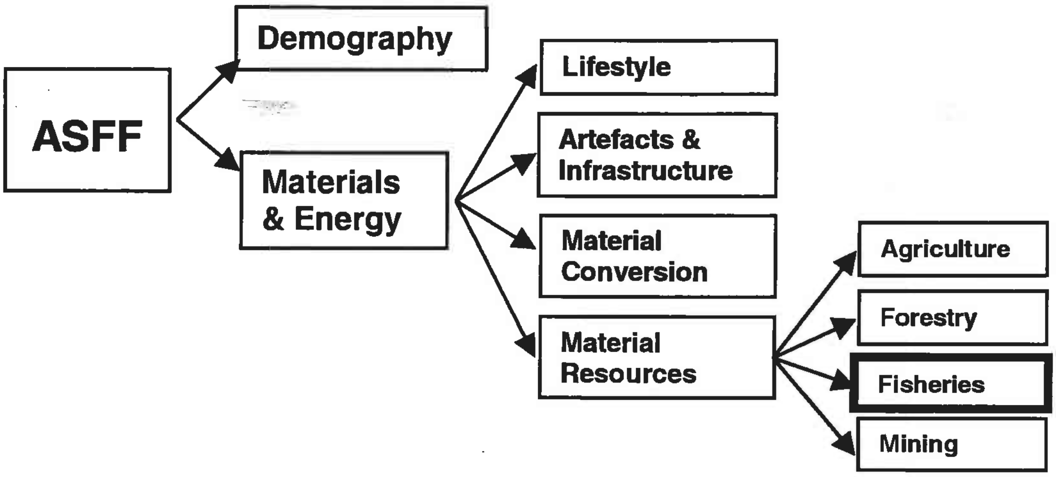

Figure 2. Simplified schematic of the ASFF hierarchy (for reasons of clarity, not all elements of the structure are shown)

The starting point for such an analysis is the production potential of the wild fisheries. The minimum requirement of such a model is that it must describe growth of the biomass and its response to exploitation. One of the earliest models of fish populations is based upon the logistic growth model [Schaefer, 1954],

$$dB/dt = rB(1-B/k) \quad (1)$$

where B is the current biomass, r is the growth parameter and k is the virgin biomass. This function has the benefits of simplicity of use and understanding, minimal data requirements and minimal parameterisation and these characteristics make it quite suitable for this modelling approach. Certainly, there are specific cases for which more detailed and comprehensive fisheries populations models exist, which may include information such as fecundity, age structure and the ecosystem. However such models are not available for all fisheries and it is unlikely that combining a variety of models of variable type and quality will perform significantly better over the long time frames under investigation.

Within ASFF, Australia's living marine resources are divided into seven jurisdictions (Commonwealth, States and Territories), which are further subdivided into fisheries that are the management units as defined by the appropriate management agency[1]. Currently, there are 288 marine species included in the database aggregated into 112 taxonomic families in approximately 80 fisheries across Australia.

[1] In the case of Western Australia and Northern Territory, the data has not been disaggregated in this fashion at this time.

A model such as the Schaefer (logistic growth) model should be applied to an isolated, single-species population. Within ASFF, we have initially chosen to apply the Schaefer model to entities called 'fish units', which are combinations of a fishery by a taxonomic family, selecting the most significant for detailed modelling. This resulted in a list of 159 fish units to which the Schaefer model is applied. This is generally justifiable as most families have only one important species caught in any particular fishery. However, there are clear examples where this doesn't apply such as the mackerel and tuna (Scombridae) family and the penaeid prawn (Penaeidae) family and these are outstanding issues.

Each of the fish units identified require two parameters to be estimated, the growth rate parameter, r, and the virgin biomass, k. Depending on the information available, these parameters are calculated from established literature values or previous modelling efforts, informed by expert or stakeholder opinion on their probable value or if necessary, estimated broadly from the catch and species data on hand. In the last case, two "rules of thumb" are used: (1) there is a relationship between the growth rate parameter and the lifespan of the species and (2) a lower bound for the virgin biomass can be calculated from the previous catch data and the growth rate parameter.

Fisheries have four significant sectors: commercial wild, recreational, traditional and aquaculture. Only scenarios for the commercial wild fishing sector are presented here. Subsequent scenarios will include the other fishing sectors and integration with the rest of the economy, including domestic consumption and trade.

3.3. Test Scenario Development

An important aspect of producing useful scenarios of the future is ensuring that the historical datasets are reliable. In constructing these historical datasets, data gathered from a variety of sources must be made consistent and ultimately fitted into a structured data framework. Since one of the key uncertainties in the historical datasets is the estimation of the virgin biomass, two histories have been developed. One is a conservative estimate of the virgin biomass, that uses the lowest possible virgin biomass that is consistent with the known historical catches (the low-estimate history) and the other is a best-knowledge estimate of the virgin biomass, based on current information (the best-estimate history). On the basis of these histories, scenarios exploring future possibilities are developed.

Three test scenarios have been developed:

1. **Constant-catch scenario:** This is a simple scenario where the average catch of the past decade in each fishery is applied at a constant rate to that fishery.
2. **Fast-recovery scenario:** In this scenario, fisheries that are currently considered overexploited are closed until they have recovered to a point that permits the desired long-term sustainable yield to be taken.
3. **Slow-recovery scenario:** This is a scenario where fisheries that are currently considered overexploited are still fished, but at a rate that allows gradual recovery until the long-term sustainable yield is available.

These scenarios can be considered "policy actions" in the broadest sense of the term. They represent possible futures based around physical outcomes, in this case, the quantities of fish. The exact details of achieving these physical outcomes are not described because that level of detail is not justified in such broad-brushed analyses. Any number of causes, such as management actions, economic forces or some other factor or combination of factors, could have resulted in these outcomes.

The constant-catch scenario assumes that the catches of the last decade will be maintained (or at least attempted). In this case, some individual fish units may be fished to negligible biomass once the annual catch target exceeds the available biomass. While this is not realistic, as practical management of these fish units would have aimed to prevent serious collapse, it is a useful starting point for comparing wide-ranging scenarios, and shows the long-term effects of continuing current practices.

The two recovery scenarios assume that adaptive fishing practices are undertaken on an annual basis with the dual goals of aiming for a continuous long-term yield with an adequate standing biomass. In the long term, the goal is for 80% of maximum sustainable yield (MSY) and when using the Schaefer logistic model, this occurs when the biomass is not less than 72% of virgin biomass. The two scenarios only differ in the proportion of the annual biomass growth that is caught if a fish unit is over-exploited (below 50% of virgin biomass). In this situation, 0% of the annual growth is taken in the fast-recovery scenario while 95% of the annual growth is taken in the slow-recovery scenario. When the biomass is above 50% of virgin biomass, the target yield becomes 80% of MSY in both scenarios.

At this point, it is worthwhile to note the operational scale of this modelling approach. It is not meant to be a replacement for good, detailed stock assessments of species at the level of an individual fishery. As a consequence, it shouldn't be used to manage fisheries or a species at a regional level. The ultimate goal of this work is to produce integrated views of the nation's fisheries, at best at the level of the jurisdictions. However, to achieve this, it is necessary to provide a functional and transparent model at the level of fisheries so that fisheries managers, scientists and the industry can openly discuss the validity of the overall analysis.

4. RESULTS AND DISCUSSION

There are six possible combinations for the two histories and three future scenarios under consideration here. An example of the output from scenarios is given in Figure 3, which shows a graph of Australia's total fish production (including crustaceans and molluscs) against time, for the best-estimate history with the constant-catch scenario.

This figure shows graphs of both the *planned catches* and the *actual catches*. Planned catches are the yield targets that the scenario demands from the fisheries while the actual catches are the yields that the fisheries are able to supply. In the past (1950 to 2000), the actual catch is identically equal to the planned catch, by definition[2]. This will be the same for all six combinations. In the future

[2] The historical catch is identical to the *actual catch* because this is what was actually caught. It is also identical to the *planned catch* because this is the amount that was physically required to be supplied to permit the actual catch to occur.

(2001 to 2050), the actual catch quickly becomes lower than the planned catch, as different fisheries become unable to supply the fish demanded of them in this constant-catch scenario. In the case of the recovery scenarios, the actual catch will equal the planned catch, since by design they are both being fished at rates that ensure recovery in all fisheries. However, they will differ in the time evolution of the catches. Figure 4 shows only the rapid-recovery scenario assuming a best-estimate history. Apart from a small oscillation caused by short-lived species, the actual catch equals the planned catch into the future. It shows a rapid and then gradual increase in total catch. It also shows that the total fish catch could increase slightly from current averages in the long term.

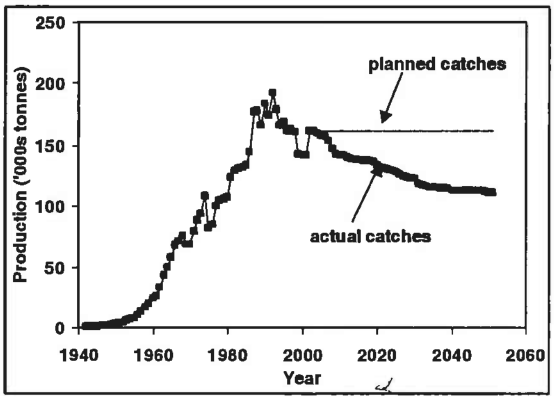

Figure 3. Australia's total fish production for the constant-catch scenario assuming the best-estimate history showing planned and actual catches.

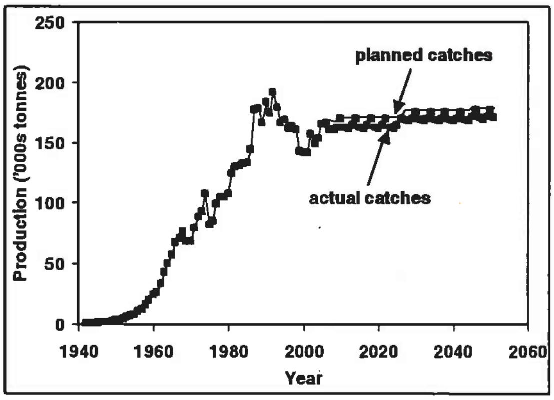

Figure 4. Australia's total fish production for the rapid-recovery scenario assuming the best-estimate history showing planned and actual catches.

One of the interesting outputs from this approach is the comparison of cumulative production over time. This represents a measure of the opportunity cost of different policy actions in terms of fish production. Figure 5 and Figure 6 show the cumulative production starting from the year 2000 for the three scenarios assuming the low-estimate history and best-estimate history, respectively. These scenarios suggest a range for the long-term cumulative production of Australia's fisheries from a minimum of about 3 million tonnes to a maximum of about 8.5 million tonnes by 2050. It also shows that differences between scenarios in the total aggregate catch take up to a decade to become significant, no matter the history. This reflects the capability of any scenario to sustain similar catches in the short-term.

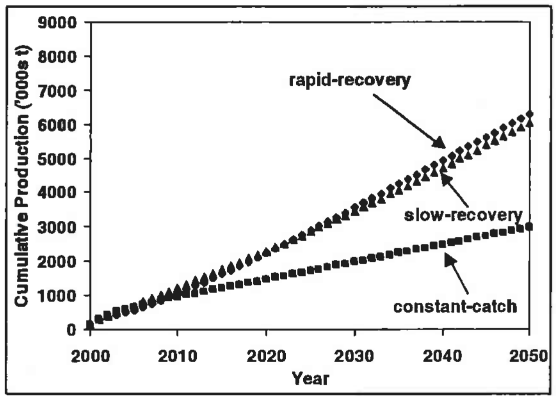

Figure 5. Cumulative fish production starting from the year 2000 for the three scenarios assuming the low-estimate history.

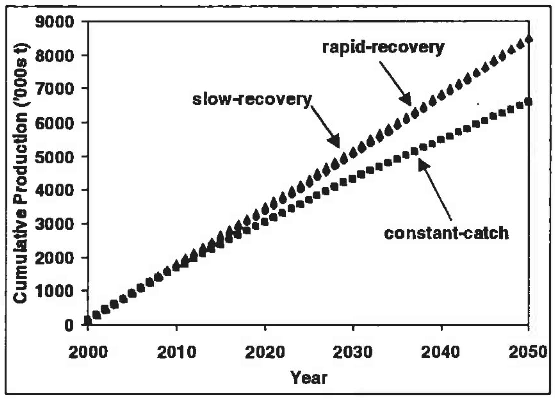

Figure 6. Cumulative fish production starting from the year 2000 for the three scenarios assuming the best-estimate history.

The two recovery scenarios turn out to be very similar in the long run (to 2050) for each history. This might suggest that there is marginal benefit in the long term, from drastic reduction in fish production in the short term. However, this would need to be examined in more detail at the level of the jurisdictions, fisheries and species. It also does not measure the risk involved in keeping fisheries biomass at a low level for long periods of time.

Assuming the best-estimate history as shown in Figure 6, there is an increase of 2 million tonnes (30%) in cumulative production by 2050 when comparing the recovery scenarios to the constant-catch scenario. There is an increase of 3 million tonnes (100%) for a similar comparison in the case of the low-estimate history shown in Figure 5. This shows how different fisheries practices might impact on future fisheries production.

For the recovery scenarios, the cumulative production by 2050 increases by over 2 million tonnes (about 40%) under the best-estimate history as compared to the low-estimate history. In the case of the constant-catch scenarios, there is an increase of 3.5 million tonnes (120%) for the same comparison of histories. This represents the sensitivity of the results to the uncertainty in the value of the virgin biomass.

These short results provide a sample of the style and type of outputs that this modelling approach can provide. Further analysis requires a more detailed examination of disaggregated quantities. Furthermore, these simple production scenarios are just the basis for more complicated scenarios as more information is integrated into the model. These will be presented in later publications.

5. CONCLUSIONS

A methodology and framework for examining national, long-term issues of fisheries production has been presented. Variations in both production scenarios and assumed virgin biomass can cause significant changes in cumulative production to 2050. However, differences in the total aggregate catch between scenarios are not apparent for up to a decade. Preliminary results show that there is a potential maximum cumulative production over the next 50 years of about 8.5 million tonnes. This is 2 million tonnes more than that achieved if the average catch of the past decade is maintained.

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7. REFERENCES

Dunlop, M., B.D. Foran, and F. Poldy, Exploring Solutions to Australia's Long-term Land and Water Problems Using Scenario Modelling, paper presented at the MODSIM 2001 International Congress on Modelling and Simulation, Canberra, Australia, December 10-13 2001.

Foran, B and F. Poldy, Between a rock and a hard place: Options to 2050 for Australia's population, Resource Futures Program Draft Working Paper 00/06, CSIRO Sustainable Ecosystems, Canberra, 2000.

Gault, F.D., K.E. Hamilton, R.B. Hoffman and B.C. McInnis, The design approach to socio-economic modelling, *Futures*, 3-25, February 1987.

Schaefer, M.B., Some aspects of the dynamics of populations important to the management of commercial marine fisheries, *Inter-American Tropical Tuna Commission Bulletin*, *1*(2), 26-56, 1954.

Turner, G. and F. Poldy, Let's get Physical: Creating a Stocks and Flows View of the Australian Economy, paper presented at the MODSIM 2001 International Congress on Modelling and Simulation, Canberra, Australia, December 10-13 2001.