# What is the Role of Computer Simulation in the Ecologically Sustainable Development of Australian Fisheries?

**J. Scandol**

*Centre for Research on Ecological Impacts of Coastal Cities, Marine Ecology Laboratories A11, University of Sydney NSW 2006, Australia (jscandol@bio.usyd.edu.au)*

**Abstract:** Fisheries management in Australia has the objective of ecologically sustainable development (ESD). ESD is to be assessed or monitored using a set of indicators that should be informative about the underlying system. After defining appropriate process models, computers can simulate indicators for the principles of ESD, and we can assess particular management strategies. But is this a valuable thing to do? ESD is as much a political process as it is technical goal. Use of inappropriate computer-based methods could be inefficient and even counterproductive as computers have the potential to alienate stakeholders. This paper will consider the principles of ESD and identify which principles are most amenable to worthwhile input from simulation methods. These issues will be explored for high-value, data-rich fisheries and low-value, data-poor fisheries.

***Keywords:*** Management; Fisheries; ESD; Sustainable development; Computer simulation

## 1. INTRODUCTION

This paper explores the role of computer simulation within the ecologically sustainable development of Australian fisheries. Computer simulation is a powerful tool for exploring alternative futures based upon a set of coded rules. Fisheries science in particular has many experts who advocate the application of computer modelling to support decision-making for sustainable fisheries [Hilborn and Walters, 1992; Quinn and Deriso, 1999]. A sustainable fishery is however a multifarious concept, with biological, economic and social objectives intertwined with complex political processes. Determining the appropriate and optimal use of simulation methods is not a trivial task.

Sustainable development is now the dominant global discourse of ecological concern [Dryzek, 1997]. The concept was developed by the World Commission on Environment and Development (WCED) in 1987. Common [1995] described the report, *Our Common Future* [WCED, 1987], as a brilliant political document which had been widely praised and little criticised. The original articulation of sustainable development indicated how the usually isolated issues of development, environmental issues, population, peace/security and social justice both within and across generations can be combined [WCED, 1987]. Australia has adopted the phrase "Ecologically Sustainable Development" (ESD) to emphasise the role of ecological processes within sustainable development.

ESD is now, either explicitly or implicitly, an objective of all state and federal fisheries legislation in Australia [Sainsbury et al., 2000]. Since it has been legislated, policy makers in fisheries management agencies have started to tackle exactly what is an ecologically sustainable fishery. ESD is defined as a set of principles (see below) which act as guidelines for decision-makers developing policy frameworks and making day-to-day managerial decisions. Some of these decisions will make use of expert advice from scientists, economists and social scientists. These experts will have many methodological tools to draw upon including computer simulation. At the International Congress on Modelling and Simulation it seems appropriate to explore which aspects of ESD are likely to benefit from computer simulation.

## 2. ECOLOGICALLY SUSTAINABLE DEVELOPMENT

### 2. 1 Principles of ESD

There are numerous definitions but the one that shall be used here is that within the Environment Protection and Biodiversity Conservation Act 1999 - Sect 3A that The principles of ecologically sustainable development are that:

(a) decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations;

(b) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;

(c) the principle of inter-generational equity - that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;

(d) the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making;

(e) improved valuation, pricing and incentive mechanisms should be promoted.

### 2.2 Decision Process and Outcomes

An often-repeated joke about ESD is that if you want an ecologically sustainable society then don't start from here! This quip is a clever differentiation between process (how do you get somewhere) versus outcomes (what is there when you arrive). This difference is important and is at the core of how societies make decisions that affect the environment. Gough and Ward [1996] defined decision process as how a decision is made and decision outcome as what actually happens. An efficient decision reflects good process and an effective decision would represent good outcomes.

Unfortunately such definitions fail to untangle the role of process in defining outcomes. Lindblom [1959] recognised that for complex public policy problems separation of means and ends was impossible and developed a model of incrementalism or "muddling through". Constraints on what actions can be taken end up modifying our beliefs in what we might be trying to achieve. Rather than considering the "big picture", decision-makers restricted themselves to successive limited comparisons of alternative actions restricted by the history of events to that date. The consequence was that the contribution of "theory" to these complex decision processes become very diluted. Lindblom [1959, 1979] did not describe his thesis as a prescriptive model of decision making but rather a descriptive model. The introduction of "public participation" into environmentally orientated legislation is likely to further restrict possible comparisons because most stakeholders will negotiate back towards the status quo rather away from it. Incremental or small changes are the likely outcomes from complex decision-making processes.

### 2.3 Australian Fisheries and Indicators of ESD

Sainsbury et al. [2000] summarise the current use of sustainability indicators for Australian fisheries. They define a *sustainability indicator* as "a quantity that can be measured and used to track changes in the status of a key component of the system that is thought to relate to sustainability". A common example indicator is the estimated biomass of a fish stock. A *reference point* is "the value of a sustainability indicator that corresponds to some agreed management target, limit or trigger for management action". For example, it is usually accepted that if the estimated biomass falls below 20% of the virgin stock size (the reference point) then management action is required. This example is pertinent because almost all biomass estimates are generated from computer simulation models.

Almost all indicators for ESD currently in use or being developed in Australia are for the target stock. There is recognition that indicators are required for the "ecosystem" but these are still under development. Sainsbury et al. [2000] make important comments about indicators for the economic and social dimensions of ESD. All Australian jurisdictions recognise the importance of economic and social factors but few, if any, indicators and reference points have been defined. There is recognition among management agencies that economic and social factors are a critical aspect of ESD but their measurement will have little influence on the decisions that are made. This is mainly because responsibilities for those issues are outside the direct jurisdiction the agency. Priority should be given to indicators of the biological components of ESD.

These observations are interpretable within Lindblom's [1959, 1979] model of incremental decision making. Economic and social dimensions of ESD are associated with equity considerations that are not particularly amenable to "theory based" input. These issues end up becoming resolved with narrative processes such as negotiation and consultation. It makes perfect sense that the definition of indicators is not deemed particularly valuable.

The importance of political process in ESD was illustrated to the author at a recent workshop "ESD and Fisheries: What, Why, How and When. A Stakeholders Workshop." [Smith and Hodge 2001]. This workshop was an important event that aimed to capture the issues facing Australian fisheries with respect to ESD. There was very little scientific representation at the meeting and the issue of whether sustainability indicators were robust (represented what they were supposed to) was introduced but not dwelt upon. One colleague mentioned that he thought that there was a feeling of "superficial goodwill" and that the hard decisions had been deferred to different fora. There was emphasis on getting agreement on process rather than getting distracted by the details of what ESD meant for the various stakeholder groups. Skilled negotiators will often attempt to get an agreement on processes rather than outcomes.

## 3. COMPUTER SIMULATION IN AUSTRALIAN FISHERIES

### 3.1 Application of Computer Models for Decision Support

Readers of this paper do not need a definition of computer simulation nor do they need the methods to be advocated. Research into fisheries is particularly well endowed with authors who support the use of simulation and modelling for illuminating and communicating the consequences of management options [Hilborn and Walters, 1992; Francis and Shotton, 1997].

What has been lacking in the literature is a critical examination of how the results of computer simulation are interfaced with decision processes that result in societal outcomes. A recent publication by Sarewitz et al. [2000] has attempted to fill this gap for the physical sciences. The conclusions from this volume include the comment that "prediction products" (usually the results from modelling studies) should only be relied upon if: predictive skill is known (tested or quantitatively evaluated), decision makers have experience in using the results, the characteristic time of the predicted outcome is short, there are limited alternatives, the uncertain outcomes of alternative actions are understood. In contrast, alternatives to these models should be sought when predictive skill is low or unknown, there is little experience with the system, the characteristic time of the predicted outcome is long, alternatives are available, or the outcomes of alternative actions are uncertain.

The primary indicator for the biological dimensions of ESD that is used in Australian fisheries is the estimated biomass of a fish stock. Recommendations on future catches are usually based upon risk analyses that attempt to quantify the consequences of alternative harvesting decisions upon this indicator. The criteria outlined by Sarewitz et al. [2000] would suggest that models and projections of stock biomass are not the ideal structures on which to base general policy and management. The lack of alternatives, however, and the international momentum that has accumulated behind this strategy will result in continued use of biomass estimates as a key indicator of target species. Simulation models of target stocks will continue to play an important role in the decision-making for ESD of Australian fisheries.

### 3.2 Models for Data Rich and Data Poor Fisheries

Fisheries can be differentiated into "data rich" and "data poor/deficient". Data rich fisheries are characterised by their high economic/social value and sufficient data to get credible estimates of stock biomass, an Australian example would be the WA western rock lobster fishery. In contrast, a data deficient fishery has little economic value and few data to get credible estimates of stock size. It is not unusual for these fisheries to have high social value, especially in low-income regions. An example would be the NSW Estuary General Fishery. Conventional models that have been developed for data-rich fisheries will not work reliably with the meagre data available for data-deficient fisheries.

Data-rich fisheries are sometimes supported by more sophisticated economic and social models such as the application of game theory [Klieve and Macaulay, 1993]. Rather than being part of the operational machinery of management, these types of studies appear to be opportunistic investigations undertaken by interested researchers. Sainsbury et al. [2000] found no systematic application of economic or social indicators in their recent review. Economic models are most likely to be represented with simple methods such as cost-benefit analysis.

## 4. COMPUTER SIMULATION AND ESD

### 4.1 More Data and Modelling Needed?

It is tempting to claim that "given more data and better models" the sustainability of Australian fisheries will be assured. There is merit to this claim but also a requirement for critique. First, there are many international examples where large fisheries have collapsed even with state-of-the-art stock models [Walters and Maguire, 1996]. Some blame can be attributed to the modelling but most have occurred because of a failure of the decision processes [Finlayson, 1994]. It is almost always because of the economic and social dimensions of a fishery that have impeded the necessary actions to reduce fishing effort.

Second, collection of "more data" begs the question of why the data are being collected. Different questions, and the hypotheses required to explore them, usually require different data. The quantity of data required to test these hypotheses will depend upon the variability of the systems, the magnitude of the effect that is to be detected, and the probability of type I and type II errors that are to be accepted [Peterman, 1990]. These are important issues and have direct consequences for ESD principle (b): or the precautionary principle [Underwood, 1997]. Collection of "more data" without an appropriate interpretative framework is a waste of the limited resources that are available to research and manage these fisheries.

Simulation models of entire ecological systems have had a long history in ecology and will have a long future. Recent developments such as ECOSIM [Walters et al., 1997] have made it easier to develop models for fishery systems but authors such as Hall [1999] have suggested that scientists maintain a healthy degree of scepticism. Continued development and investment into these types of models is inevitable but the modellers should be forced to engage with the empirical scientists about the data limitations that will forever constrain the interpretation and application of these models.

### 4.2 The values and limits of computer modelling

Dawkins [1986, p 74] once commented "For those, like me, who are not mathematicians, the computer can be a powerful friend to the imagination." These machines enable us to explore the deductive consequences of rules in ways that used to be impossible except for gifted mathematicians.

Langendorf [1985] articulated the difficulties of introducing technological methods into environmental planning. His comment that "decision-making often involves judgemental and other "soft" criteria, multiple criteria or objectives, and individual and group preferences that the formal models typically do not accommodate." Lein [1997] commented this issue remains unresolved.

Economic and social dimensions of complex systems such as fisheries have been and will be simulated with computers and there are undoubtedly some valuable theoretical and academic outcomes from such studies. Straightforward economic models such as cost-benefit analysis will continue to be contracted and the results used to support particular arguments. More elaborate economic models may play a role in high value data rich Australian fisheries. Yet the line of argument presented in this short paper is that these applications will always have restricted application within the actual decision-making process. This will be particularly true in data poor fisheries.

Any reader of this paper would however be quick to criticise and find flaws within a simulation model that made them redundant because their career was environmentally destructive or economically inefficient. Ecological sustainability is a concept that includes principles that ensure that those sorts of actions do not occur. Decision-making mechanisms for ESD will continue to be human-centred and will always have a restricted role for computer simulation.

Yet there are simple under-utilised methods based upon computer simulation that can be used to understand and improve decision processes in fisheries. Two examples include:

**Simulation of experiments or sampling programmes to understand the collection and analysis of data.** It is wasteful to spend time and money collecting information about a fishery when there is no credible and evaluated method to interpret that information. Computer simulation should be used to determine if data collection strategies that are proposed or are in place will answer the questions that are being asked. Such calculations might appear a little pedestrian for sophisticated modellers but these approaches are not routine in fisheries management agencies. Furthermore, there needs to be work done applying these methods for multivariate analyses. As mentioned above, there is also a need for some of the data issues associated with "ecosystem" models to be thoroughly explored.

These types of strategies are particularly pertinent for rare or threatened species. Sampling strategies to detect changes in uncommon species are difficult to design and interpret. This is particularly true if the sampling is dependent upon industry vessels or data. Population viability analysis has proved a valuable tool in terrestrial systems [Possingham and Davies, 1995] and the issues associated with employing these methods for marine systems, which generally have much more variable data, need to be evaluated.

**Gaming simulation (not computer based) of decision processes using computer simulated data as a resource.** Simulations do not have to be realised with computers. Large institutions routinely hold emergency simulation exercises and military forces use simulated training exercises to understand how personnel will react to realistic, but simulated, situations. Such methods could be used to evaluate and improve decision processes within fisheries management. Decision-makers could be exposed to the likely results that scientists would observe if a fishery started to fail. Studies could then be conducted about the sort of decisions that are been made or recommended. Consequences and effectiveness of these results could be evaluated, thus providing a partial test of the decision process. Results from such studies might be simple but might produce valuable outcomes like understanding the most effective way to present quantitative information. Such exercises might be particularly valuable for members of fishery Management Advisory Committees or new fishery managers.

## 5. CONCLUSIONS

Understanding the role of technical methods such as simulation modelling in environmental decision making is a subject worthy of investigation and discussion. When environmental problems become vexed there will be a temptation by the decision-makers to look for technical approaches that will reduce the uncertainty of possible decisions, or at least, move the decision into future so that it is not longer "their problem". Environmental issues are usually difficult to manage because of the differing value judgements of the stakeholders involved rather than lack of technical precision.

Many committed stakeholders within environmental issues believe they already know the answers to technical questions [Dobbs 2000]. Sometimes a computer model, (or empirical study for that matter), will generate results that are at odds with deeply held stakeholder beliefs but it will take more than impressive computer graphics to convince these people that they were wrong (and maybe they are not!). Principles of ESD such as "decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations" remind us that getting the political dimensions of decision-making right is crucial, otherwise ESD will fail as a process and as an outcome.

Lindblom [1959, 1979] presented an incremental model of decision-making which remains pertinent to this day. There is little doubt that popular methods such as Strategic Planning have helped focus incremental management, but it does not take a cynic to see that large numbers of important decisions which effect the environment are a result of "muddling through". It is important to appreciate that rational methods are only a subset of decision models that sociologists have identified [Dryzek 1997]. Furthermore, if it was easy to design systems that got people to change their minds and their behaviour the advertising industry would have discovered the answer years ago.

The following are two non-exhaustive suggestions for simulation modellers, and other technically orientated professionals, to help focus their contribution to ESD. First, understand the decision-making structures that are responsible for the management of the phenomena that you study. This will enable you to pinpoint where, when and how simulation tools might be efficiently applied in a decision support role. Second, be realistic about the contribution your area of speciality can make to ESD. People like to do what they have been trained to do and will justify that activity without critical reason. If you only have access to a hammer everything can tend to look like a nail. Simply assuming that developing a simulation model of a phenomenon will help management is overly simplistic. A corollary to this second suggestion is to be willing to admit when a particular approach will not be fruitful. This can be a more difficult judgement to make if the primary purpose of a project is training (e.g. a PhD) but people should consider the opportunity costs of research projects.

## 6. ACKNOWLEDGEMENTS

The author would like to acknowledge the financial support of the Centre for Research on Ecological Impacts of Coastal Cities.

## 7. REFERENCES


Smith, D. C. and R. Hodge, (Eds), ESD and Fisheries: What, Why, How and When. A Stakeholders Workshop, Geelong, Marine and Freshwater Resources Institute & Seafood Industry Victoria, 2001.

Common, M. S., *Sustainability and Policy: Limits to Economics*, Cambridge, Cambridge University Press, 348 pp, 1995.

Dawkins, R., *The Blind Watchmaker*, London, Penguin Books, 332 pp, 1986.

Dobbs, D., *The Great Gulf*, Washington D.C., The Island Press, 206 pp, 2000.

Dryzek, J. S., *The Politics of the Earth: Environmental Discourses*, Oxford, Oxford University Press, 220 pp, 1997.

Finlayson, A. C., *Fishing for Truth: A Sociological Analysis of the Northern Cod Stock Assessments from 1977 to 1990*, St John's, Institute of Social and Economic Research, Memorial University, 176 pp, 1994.

Francis, R. I. C. C. and R. Shotton, "Risk" in fisheries management: a review, *Canadian Journal of Fisheries and Aquatic Sciences*, 54: 1699-1715, 1997.

Gough, J. D. and J. C. Ward, Environmental decision-making and lake management, *Journal of Environmental Management*, 48: 1-15, 1996.

Hall, S. J., *The Effects of Fishing on Marine Ecosystems and Communities*, Oxford, Blackwell Science, 274 pp, 1999.

Hilborn, R. and C. J. Walters, *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*, London, Chapman and Hall, 570 pp, 1992.

Klieve, H. and T. G. Macaulay, A Game Theory analysis of management strategies for the Southern Bluefin Tuna industry, *Australian Journal of Agricultural Economics*, 37: 17-32, 1993.

Lagendorf, R., Computer and decision making, *Journal of the American Planning Association*, 27: 422-433, 1985.

Lein, J. K., *Environmental Decision Making: An Information Technology Approach*, London, Blackwell Science, 213 pp, 1997.

Lindblom, C., The science of muddling through, *Public Administration Review*, 19: 79-88, 1959.

Lindblom, C., Still muddling, not yet through, *Public Administration Review*, 39: 517-526, 1979.

Peterman, R. M., Statistical power analysis can improve fisheries research and management, *Canadian Journal of Fisheries & Aquatic Sciences*, 47(1): 2-15, 1990.

Possingham, H. P. and I. Davies, ALEX: A population viability analysis model for spatially structured populations, *Biological Conservation*, 73: 143-150, 1995.

Quinn, T. J. and R. B. Deriso, *Quantitative Fish Dynamics*, New York, Oxford University Press, 542 pp, 1999.

Sainsbury, K. J., A. D. M. Smith and H. Webb, Current use and recommendations for future development of sustainability indicators to measure performance of Australian fisheries against ESD objectives, FRDC Final Report 98/168, Hobart, CSIRO Marine Research: 105, 2000.

Sarewitz, D., R. A. Pielke and R. R. Byerly, (Eds), *Prediction: Science, Decision Making, and the Future of Nature*, Washington D.C., Island Press, 405pp, 2000.

Underwood, A. J., Environmental decision-making and the precautionary principle: what does this principle mean in environmental sampling practice?, *Landscape and Urban Planning*, 37: 137-146, 1997.

Walters, C. and J.-J. Maguire, Lesson for stock assessment from the northern cod collapse, *Reviews in Fish Biology and Fisheries*, 6(2): 125-137, 1996.

Walters, C. J., V. Christensen and D. Pauly, Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments, *Reviews in Fish Biology and Fisheries*, 7: 139-172, 1997.

WCED, *Our Common Future*. Oxford, Oxford University Press, 400 pp, 1987.