Modeling and Decision Support Workgroup

Bleaching

Connectivity

Disease

Modeling

Remote Sensing

Restoration

The purpose of the MDS group is to create an integrated scientific understanding of the way in which people interact with coral reefs. We want to be able to help decision makers and reef users better understand and use reefs in a sustainable way. We want to do this by allowing them to see the dynamics of whole system that is, both the biophysical and socio-economic parts.

The task is multidisciplinary, multi-scaled and highly spatial. It deals with the complex phenomenology of coral reef ecosystems together with the equally complex phenomenology of the associated human socio-economic systems. There are a large number of entities interacting to create the observed dynamics, and the entities are usually described by large numbers of attributes.

The research problem falls squarely within the new discipline of complex systems science. This discipline started to become coherent in the 1980s and is now an area of active research both on problem domains like ours, and on analytical and modelling technique. There are now stand-alone institutes (like the Santa Fe Institute[1]), major government research initiatives (such as at Argonne National Laboratory[2], CSIRO Centre for Complex Systems Science[3] or France's CIRAD[4]), and university centres (such as CoMPLEX at University College London[5]) and consortia (such as New England Complex Systems Institute[6] or the EU's Exystence[7]).

This effort, while not all directed at sustainability issues, has produced a body of research work and a community of practice that has made great progress in taming large unruly problems like ours.

Much of the work has been on modelling biophysical or socio-economic systems, and some has been directly on sustainability issues (that is, linking biophysical and socio-economic systems). There are some important international projects in this area, such as the EU's FIRMA (Freshwater Integrated Resource Management with Agents)[8] project, and some specialised research groups such as the Resilience Alliance[9] with its cutting-edge journal *Ecology and Society: A Journal of Integrative Science for Resilience and Sustainability*[10].

The hard-won experience of these research groups tells us that "the coral reef problem" is tractable with current knowledge and techniques, but that we should not expect a traditional scientific solution—some sort of grand unified analysis and canonical prediction. Complex systems are not, in principle, predictable. Instead we should expect progress to come in the form of clusters of models that help us understand the present dynamics and explore possible futures. In the best outcomes, this exploration can become an integral part of the policy development process in an ongoing iteration between scientists and decision makers[11].

The MDS group will build its program within the complex systems science domain. Because complex systems science is a new discipline, the MDS group intends to ensure that its clients and stakeholders develop an understanding of the strengths and limitations of the complex systems approach. Experience in other large complex sustainability projects has shown the best way to do this is through a process of top-down and stepwise-refinement model building to create

1 http://www.santafe.edu/
2 http://www.dis.anl.gov/DIAS/index.html
3 http://www.csiro.au/css/
4 http://cormas.cirad.fr/indexeng.htm
5 http://www.ucl.ac.uk/CoMPLEX/
6 http://necsi.org/
7 http://www.complexityscience.org/index.php
8 http://firma.cfpm.org/
9 http://www.resalliance.org/ev_en.php
10 http://www.ecologyandsociety.org
11 M. A. Janssen (ed.) (2002) Complexity and ecosystem management: The theory and practice of multi-agent systems. Cheltenham, Edward Elgar
12 http://cormas.cirad.fr/indexeng.htm
13 Foran, B., and F. Poldy. 2002. Future dilemmas: Options to 2050 for Australia's population, technology, resources and environment, Pages 336. Canberra, CSIRO Sustainable Ecosystems.
14 A recent review has found that the best framework is Argonne's DIAS/FACET (http://www.dis.anl.gov/DIAS/index.html)
15 E. R. Tufte (1997) Visual explanations: Images and quantities, evidence and narrative. Graphics Press, Cheshire CT.
16 http://www.sgi.com/

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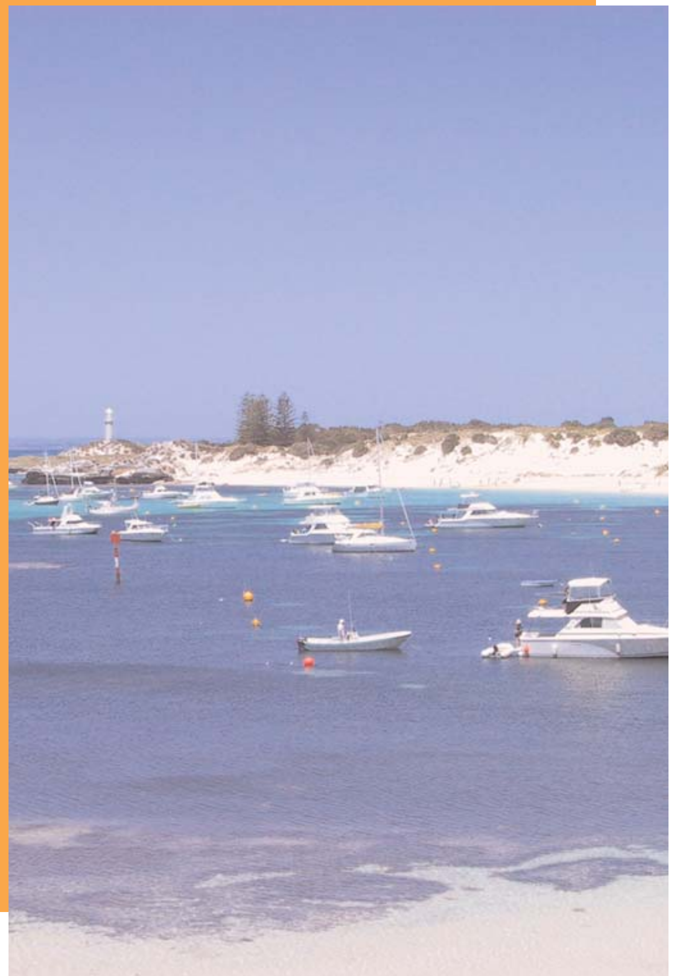
This project is part of a major initiative of the World Bank, with support of the Global Environmental Facility, to provide the best available scientific information on coral reef response to environmental disturbances and climate change. The "Coral Reef Targeted Research and Capacity Building for Management" project aims to conduct specific, targeted research to fill critically important information gaps in the fundamental understanding of coral reef ecosystems so that management and policy interventions can be strengthened globally.



clusters of models. We have also learned that strong visualisation metaphors of the system are highly effective in engaging widely different classes of users.

Any modelling strategy for a long-lived project also needs to consider how to future-proof itself. The rapid growth of computing power and improvements in modelling complex systems meaNs that special attention must be focussed on ensuring that the project is not locked in to old technologies or outdated methods.

Top-down modelling starts with the whole problem and gradually breaks it down in to its components. In contrast, bottom-up modelling starts with the fundamental components of the system and joins them together to model the whole system. Top-down modelling allows the model builders to interact with the users and build models that are relevant and meaningful to them in a transparent way.

A very successful approach to top-down modelling has been elaborated by France's overseas development research agency (CIRAD). They call their approach "companion modelling"[12] and it provides a very effective and general way to rapidly prototype complex sustainability models in direct collaboration with stakeholders. Similar approaches have been developed by, for example, the CSIRO Resource Futures group[13].

Stepwise-refinement means that the model building proceeds through iterative steps each of which progressively refines the understanding of the problem and elaborates the complexity of the model. The depth to which the modelling eventually develops is not set by any hard and fast rule, but rather by the sufficiency of understanding created for both modellers and users. In this way, the users and stakeholders have an important and continuing say in how the modelling develops.

Top-down and stepwise-refinement, when used correctly, are important principles for empowering the users. They encourage the creation of a shared understanding of the problem, and help prevent the capture of the process by any particular discipline. A bottom-up approach is susceptible, for example, to takeover by, say, ecology or economics, both powerful, quantitative disciplines, with the result that the models—and hence the problems—start to look like ecology (or economics) problems with other bits tacked on. The top-down and stepwise-refinement approach, by contrast, encourages the primacy of the problem over any particular disciplines.

This approach also encourages generalisation of the problem. This is very important in the present project. We need to understand the particularities of local reef problems as well the global aspects of reef problems as a whole. The top-down approach allows us to examine and understand a particular reef within the context of reefs of the world. It also allows us to think about the problems of the sustainability of coral reefs within the context of natural resource management problems as a whole. And finally it allows us to transfer our understanding from one reef system to another in a structured way—because our models are simultaneously models of all reefs and, at deeper levels, of particular reefs.

Clusters of models have been shown to be particularly effective when a range of disciplines is involved, or when the types of questions posed are themselves evolving. And even in some traditional "unified" modelling domains, such as oceanography or meteorology, where the range of disciplines is restricted and the questions clear, clustering is beginning to become a strategy of choice.

As a strategy, clustering provides valuable openness to a project, since it does not lock it in to one model for its duration. Instead, over the life a project, models of different parts of the problem may be replaced by better models, or different models of the same part of the problem may co-exist in the project and be used for different questions. The strategy also encourages the use of one set of models to build prototypes of the problem, another to handle routine production, and perhaps another for future development. Complex systems problems have no single "answer", and so no single tool can be the "solution".

But clustering creates a technical problem of how to stitch together the different models—how to get them to talk to one another. Clusters typically consist of models that "speak" in their own disciplinary dialects—whether physics, biology or sociology—and this is a powerful "comfort factor" in managing a multidisciplinary project, in that it builds confidence within the disciplines in the integrity of the multidisciplinary whole. But the models also need to speak to each other. Much work has been done on this matter, and "modelling frameworks" now exist that, while not trivial—in fact they are intellectual *tours de force*, make clustering a viable strategy for large complex problems such as ours.

Visualisation is another vital component of a research strategy for complex systems. Much of our subject matter has a strong spatial component, and so presenting model results as maps is an obvious way to engage users. Maps have been found to be particularly powerful ways of reaching across disciplinary divides, and for reaching out to non-technical users. Indeed, experience shows that the presentation capabilities of GIS may account for more of that technology's success in recent years than its actual abilities to manipulate spatial data. But visualisation is more than the representation of spatial relationships and much more than GIS[15]. And it is the visualisation rather than the spatiality that allows disciplines to be transcended and scientists to engage with lay persons.

While maps may be a valuable starting point, there are many other ways to visually represent the complexities of our problems in ways that assist understanding. Multi-dimensional objects can now be displayed and manipulated coherently, and movies can show dynamics. Models can be organized so that the results of scenarios or "what if" questions can be computed and visualised immediately. The universe of possibilities of a model can be explored in dynamic visual ways that uncover unexpected pathways to a particular user's goals. Visualisation can be extended to insert the user inside the space of the model using virtual reality techniques and allow the user to walk through different dimensions of the model.

Visualisation technology thus extends from the use of simple mapping metaphors of GIS through to cutting-edge virtual reality and immersion tools produced by specialist computing firms like Silicon Graphics . The history of visualisation shows that leading edge technologies like virtual reality become broadly available within about 5 years. Thus, in a long-lived project like ours, we should plan to stay close to the leading edge of visualisation technology.

Future-proofing strategies revolve around staying flexible, and ensuring that the tools chosen have the potential to grow and change as technology develops, and that new opportunities are seen and embraced. Using open source tools and adopting open standards are of great assistance in this, but this does not mean that proprietary tools should not be used, but rather that they should be used with an eye to their future utility.

Two technologies that show great promise in the immediate future—grid computing and sensor webs—are likely to impact strongly on the work of the group.

The MDSWG will adopt a clear top-down and stepwise-refinement modelling approach as the best way to handle the complexity of the problem and the need to closely interact with its users and stakeholders. In particular, the "companion modelling" approach will be investigated as a powerful practical way to involve stakeholders from the earliest prototyping stage. The MDSWG group will develop clusters of models rather than a single unified model of "the coral reef problem". In particular, the MDS group should investigate the use of different sorts of models for prototyping, production and future development. The MDS group should also use a modelling framework system to coherently organise model clusters, taking note of the technical overheads of managing such systems, and will use the full range of visualisation techniques, including leading edge ones, to stimulate a deep engagement with the program's stakeholders.