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Integrating research, modelling and decision making: A network and knowledge processing approach for sustainable management of a coral reef

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Abstract: A large scale research program has been developed for Ningaloo Reef Western Australia. Significant contributions are being made by a variety of university and government researchers. There are at least fifty stand alone research projects currently underway. Many of these have been organised under umbrella organisations such as the WA Marine Science Institute (WAMSI), CSIRO's Wealth from Oceans Flagship and its associated cluster (a joint CSIRO and multiple Universities Research Program). Research varies from bathymetry through studies of fish species to the social science of visitor behaviour. One of the significant activities is the development of models of various types that will serve as a major integrating output. While there is an "all encompassing" model (InVitro) there are also activities to incorporate qualitative modelling and "user friendly" modelling of components.

The intent is that these efforts will result in informed decision makers and managers who will have tools that they will regularly use to reach intelligent decisions that enable them to manage the uncertainties associated with what is a complex socio-ecological system. To help ensure that adoption happens, CSIRO's Wealth from Oceans Flagship created a small "client outreach" project, the purpose of which was to monitor the decision support needs of government and to help match these with the outcomes of the modelling. Initially this was considered to be a relatively simple process of maintaining and developing key links with decision makers and with the modellers and in a relatively straightforward way act as knowledge brokers.

We were soon to realise however that our simple expectations contained a number of pitfalls that required examination and that there would be many challenges in demonstrating that the research activities and modelling did in fact have a positive impact for the reef. These challenges related among other things to understanding the role of formal and informal networks in creating understanding and implementing decisions, the nature of knowledge exchange requirements in decision making, the ability of individuals to think in dynamic systems terms, and the conceptual and methodological issues associated with evaluating how any adoption of the models may have improved the decisions made and the management implementation of these decisions.

This paper describes progress in defining and addressing these issues which we believe to be common to all large scale multidisciplinary research programs. Nevertheless they are particularly relevant to modelling exercises that are conducted to integrate research and provide useful decision support tools for policy and management. While discussing each of the above issues separately suggestions are made for an integrated approach for assisting and evaluating the impact of models in the context of ecosystem management.

Keywords: *networks, knowledge, information, decision making roles, evaluation, cognitions, coral reefs.*

1. INTRODUCTION

As the pressures on Australia's coasts mount, there is an increasing need for systems and evidence-based information to inform our policy and management decision making for icons such as coral reefs. This is reflected in the burgeoning research effort in these areas. Nevertheless, marine scientists like all others are under an increasing obligation by funders to ensure that their output has a relevant impact.

A large scale research program has been developed for Ningaloo Reef, Western Australia. Significant contributions are being made by a variety of university and government researchers. There are at least fifty stand alone research projects currently underway. Many of these have been organised under umbrella organisations such as the WA Marine Science Institute (WAMSI), CSIRO's Wealth from Oceans Flagship and its associated cluster (a joint CSIRO and multiple Universities Research Program). Research varies from bathymetry, through studies of turtles and fish, choice modelling visitor valuation studies to the social science of visitor behaviour. One of the significant activities is the development of models of various types that will serve as a major integrating output. While there is an “all encompassing” model (InVitro) there are also activities to incorporate qualitative modelling and “user friendly” modelling of components.

The hope is that these efforts will result in informed decision makers and managers who will have tools they will regularly use to reach intelligent decisions that enable them to manage the uncertainties associated with what is a complex socio-ecological system. To help ensure that adoption happened CSIRO’s Wealth from Oceans Flagship created a small “client outreach” project. This was to monitor the decision support needs of government and industry and voluntary groups and to help match these with the outcomes of the modelling. Initially this was considered to be a relatively simple process of maintaining and developing key links with decision makers and with the modellers and in a relatively straightforward way act as knowledge brokers.

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2. THE ROLE AND INTEGRATION OF RESEARCH NETWORKS INTO DECISION MAKING

Attendance at a Ningaloo research symposium soon revealed at least fifty projects conducted by at least 11 different organisations. There are now over 140 projects of various sizes. Some of these projects pertained to individual doctoral projects; others reflected quite large scale and ongoing research commitments. Some were integrative (particularly the modelling), others were more stand alone. To enhance our own understanding, we created a network of the perceived potential relationships between projects by senior scientists to establish how information could potentially flow if the efforts were integrated. While there are clear connections between some projects, there are also isolates. Interestingly, it does not appear that such a simple use of subjective network analysis was used on this occasion in the development of the wider research cluster including university and government researchers. Simple network analysis may be a useful tool when planning future large research efforts. It enables researchers and modellers to see their potential impact and to plan critical information paths.

In our informal discussions with the decision making stakeholder community it became quickly evident that there were potentially a large number of stakeholders who could benefit from access to a decision support system or model. The expectations of what could be offered by modelling varied, some hoping for an InVitro comprehensive model others for a more specific tool or outcome (e.g. fish stocks, interactions of tourists with the environment). The informants included Commonwealth government agencies and State government agencies. State government agencies not only included the obvious players such as environmental managers and tourism planners but also infrastructure providers, utilities and even treasury. State government interests were also reflected in qualitatively different roles between the regions and “head office”. Finally other stakeholders included local government, industry groups, indigenous communities, and highly influential individuals who had a long association with the region. All had different roles and expectations of research findings and the models derived from them. Who then should we extend the scientific findings to and if models were to be used how much should they be tailored to the individual roles?

In part this can be addressed by discussing the reported information needs of individuals acting in each role as is discussed below. But the model(s) need to support a resilient management system at the overall system level. It is apparent that there is a need to understand the role network and its functioning to find the critical insights that models can provide and how that information is likely to be transmitted within the network itself. The information required by differing stakeholders is likely to be highly reliant on the context within the individual’s role is performed (Yakhlef, 2007). The influence of an “all things to all people” model is unlikely to be effective and will have high transaction costs of the dynamics of the network are not understood. Even with participative modelling a lack of apparent impact of a model may have more to do with a universal lack of understanding of how the network functions than the characteristics of the model per se.

The obvious place for us to turn in methodological terms was the social network literature. This has had some application to local and regional environmental problem solving in the past (e.g. Bodin and Norberg, 2005, Ernstson et al, 2008). The purpose of this application of social network methodology is to establish whether there are any critical roles which act to facilitate information and judgement to ensure that the network can function and whether the necessary links hypothesised within the models for integrated decision making and implementation were in existence. From there we can examine the support required for each of the critical nodes and where common knowledge among roles was required for the functioning of the decision making and management system.

As a start we interviewed a number of people to establish a list of government and non government organisations and to identify key individuals who were regarded as having distinct ongoing roles in the sustainability of the Ningaloo reef. It must be noted that these individuals were questioned in terms of their role rather than in regard to their organisation, address or structural location. Concentration on roles rather than individuals was adopted because it was thought that in modern society organisations and structures are often hampered by lack of organisational memory because of the increasing mobility of the workforce and the current penchant for structural rather than process solutions to public management problems.. Individuals also can play significant roles which may need to be replicated by others in future if the network is to function in a resilient way. As with many other network studies we used a combination of sociometric and egocentric techniques (Marsden, 1990, Wasserman and Faust, 1994, pp 45-59).

A list of 44 organisations and roles had been identified in the original interviews as having a distinctive role in the ongoing welfare of the Ningaloo reef. Participants were asked to place the names in three piles, those organisations that were helpful in them fulfilling their role in Ningaloo, others who were less helpful in fulfilling their role and those they hadn't interacted with. It was emphasised that the less than helpful designation did not necessarily imply individual lack of responsiveness but may reflect a variety of issues such as lack of resources or information. This provided a provisional map of where critical positive interactions occurred and also where there may be disruptive feedback loops or structural holes (Reagans and Zuckerman, 2001). See Figure 1 for a preliminary network after 10 interviews from people with key regional and state responsibilities. The utility of this approach can be seen by noting that if the role of the Gascoyne Development Commission were withdrawn there would be significant isolation of the research institutions probably to the great detriment of the uptake of research and its associated models. This group was not intuitively thought to be a key "player" at the beginning of the study.

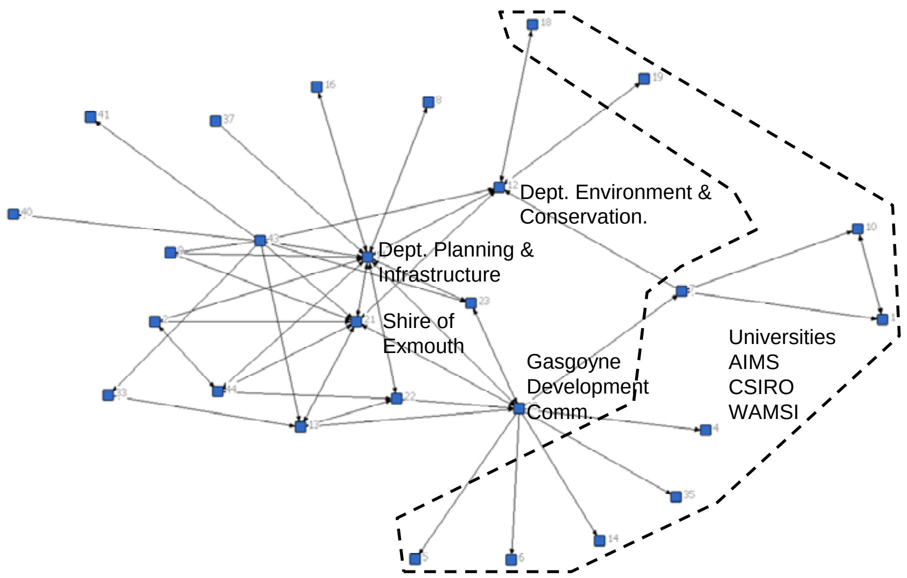

Figure 1. Directed graph of social network for individuals representing organizations working toward sustainability of Ningaloo Coast WA. Arrow direction denotes support given by one node to another in sustainability role for Ningaloo Coast.

The second task required of the respondents was to draw a directed egocentric graph of all those who they had to interact with in order to fulfil their role and the perceived relationship between them. By overlaying these graphs critical roles for the transmission and interpretation of particular forms information could be identified. Some of the results of the data available at this time are showing promise. If persisted with they will be able to demonstrate role equivalence, areas where perhaps institutional changes may be needed. As with the sociometric analyses, gaps in transmission lines between roles could also be identified From the participative planning viewpoint key community government roles and their interactions can be highlighted. Model building and its adoption can then be built around these role nodes

As briefly discussed above structural analysis of the science system itself may also be of assistance in planning for integrated programs and the interaction between the integrative activities and the governance structure. By concentrating science outcomes to the key roles transaction costs may be minimised. This would certainly be welcome to many scientists who face questions about impact when even quite basic and long term research is being funded.

As with many studies of this nature we have begun with attempting to illustrate structure but there are many issues that need to be addressed when we wish to add meaning to the structural description (Stacey et al, 2000). This lack is common to other studies of environmental management to this point. Perhaps the key area for progress is in the understanding of the nature of the information we are trying to offer and the relationship between the flow of this information, its characteristics and network structure.

3. KNOWLEDGE AND ITS TRANSFER IN NETWORKS

3.1 Types of Knowledge

At the beginning of this investigation we had assumed that the information that we were concerned about packaging for decision makers via modelling was codified. That is it can be represented in numbers and can be interpreted by cognitive or logical interpretation of patterns of at least ordinal data. Since most decision makers and managers share a common ability to express codified data at least at an arithmetic level the original purpose of our project was to count the impacts on the most important variables and assume that we had achieved a defensible numeric outcome. So models which enabled the decision maker to alter the number of fish and then examine its ramifications in terms of numbers of other species would be the type of outcomes we were looking for. (Or to put it simplistically in the context of the treasury, the dollar return for the dollar invested in either Ningaloo or in our research program).

There are a number of problems to this approach which became very evident quite early on in proceedings. Firstly as those involved with knowledge s transfer with information systems have discovered that there are several types of knowledge. These include encoded, tacit, embodied, embrained, procedural and embedded (Joshi et al, 2007). To quote Joshi et al (2007): "Tacit knowledge refers to the type of knowledge that is difficult to explicate or articulate. Embodied knowledge can be partially articulated and results from physical presence (i.e. from interpersonal communication). Encoded knowledge is the knowledge that refers to the knowledge residing in text books and in data banks. Embrained knowledge refers to the cognitive ability of understanding underlying patterns of a given phenomenon (e.g. double loop learning). Procedural knowledge refers to knowledge about the processes. *(in our case human processes).* Finally, embedded knowledge refers to knowledge that is contained within a variety of contextual factor and is not pre given." It is clear that all these knowledge forms are pertinent to the requirements of models if they are to be readily extended or constructed in a participative way. From the network and role perspective it is clear that the different forms of knowledge may require alternative structures in which to disseminate effectively.

Unfortunately there has been little research on this issue in the environmental management literature, although there have been a number of hypotheses that have been tested in the study of innovation in commercial organisations (e.g. Reagans and McEvily, 2003). These hypotheses include the contention that codified knowledge travels naturally over a greater range of a network than other forms of information. It is also surmised that as tie strength between node members increases the possibility of transfer of tacit knowledge increases and so on. While such hypotheses are simple they remain to be tested in integrated and participative settings. They are very relevant to the uptake of models and need to be systematically investigated especially in regard to role delivery.

3.2 Dimensions of Knowledge Exchange

While there are different types of knowledge, according to Cross et al (2001) there are also a number of dimensions of knowledge exchange which all have to be present to some extent to promote the easy flow of information between those representing different roles. There are four primary dimensions and all are relevant if knowledge is to flow. The four dimensions identified by Cross et al (2001) include: knowing what another person knows and thus when to turn to them; being able to gain timely access to that person; the willingness of the person sought out to engage in problem solving rather than dump information; and the degree of safety in the relationship that promoted learning and creativity. All of these dimensions have been raised in the informal interviews conducted for this study.

Cross et al go on to map their networks in all four dimensions to find where the weaknesses if any in the information occur. For example in our case study it is evident that in many circumstances there is appears to be a lack of understanding of others roles (procedural information). Work can than be done to alleviate this by modifying the network structure and the production of a procedural representation of roles.

It is evident that because of the relatively high level of tacit knowledge required for interpreting model output it is important that all four dimensions are analysed systematically from the model uptake point of view.. This is emphasised because in many cases the modeller may be the only one to have the range of knowledge (whether codified or tacit) of the system as a whole both physically and institutionally. A lack of awareness of this by the modeller can lead to communication difficulties because as information is processed it can become implicit (or tacit) in one's thinking and is difficult to describe. The access to information can put the modeller in a potentially powerful but also vulnerable position within both scientific and role networks. If it promotes relative information deprivation among key stakeholders it can threaten all four dimensions suggested by Cross et al for effective communication between the differing decision making roles. In addition modellers can receive criticism if the model seems intuitively "wrong" to some in the decision making system because there is not a good understanding of the basis for each other's knowledge. These factors need to be carefully considered by those involved with model "outreach".

3.3 Do People Understand Systems?

There have been several attempts in this cluster and elsewhere to simplify models of ecological systems to make them accessible to decision makers. Particularly, visual representations of food webs or pictorial presentations of the effects of tourism and human interaction with the reef with opportunities for hands on interaction have intuitively been seen as the best way to achieve understanding. The question remains however as to whether what is seen as the meaning of such models is the same as that comprehended by the modeller. There may be discrepancies in interpretation among people with differing backgrounds and occupying different roles. The understanding of dynamic and complex systems may not be evident, for example, to a treasury official steeped in economics or an infrastructure engineer who may have important roles in the sustainable management of the ecosystem. In short, this issue is one of the challenges associated with "embrained" knowledge. While this may be seen as a problem of individual psychology it also will determine much of the functioning of the decision network in dealing with dynamic systems and needs to be understood.

Unfortunately this is not purely speculation. There is a significant literature on how people understand systems from the psychological and systems dynamics literatures. Empirical research has shown that people find it very difficult to understand dynamic systems and most intuitively think in a linear and non recursive fashion. Studies by psychologists (White, 1997, 2008, Green, 1997) indicate that that there is generally a poor understanding of dynamic systems and feedback loops in ecological systems. Rather people tend to think naturally in dissipative physical terms in which any perturbation to a node in a system such as a change in resources dissipates the further the organism is away from that perturbation. This has also been demonstrated in the system dynamics literature where Sweeney and Sterman (2000) have shown a very poor understanding by students at an elite business school; of stock and flow relationships and time delays. Some authors have been so pessimistic as to suggest that humans are incapable of cognitively or socially functioning at dynamic or complex systems level (see Dorner, 1996 for a review).

There are however many courses which are available to imbue systems thinking within individuals and some computer models which seem to help (e.g. Dresner, 2008, Hogan and Thomas, 2001, Kurtz dos Santos and Ogborn, 1994). The results seem to indicate that improvements in systems thinking can occur but as to how much of this that is carried to specific roles within a decision making or science network is moot at this stage. Issues such as hierarchies of power between disciplines and a downgrading of the role of communication in research systems functioning have been observed in at least one large scale integrated project (Jakobsen and McLaughlin, 2004).

In short this issue has the potential to be a major barrier if not addressed in the roles inherent in both the scientific and decision making networks. For this reason field investigations of systems thinking will be conducted as part of gaining an understanding of the current role of systems thinking in facilitating model adoption within the Ningaloo cluster.

3.4 Can the Model be Evaluated Specifically in Impact Terms?

Having established the key issues and investigations that need to be considered in ensuring that the modelling activities met the role network, informational and cognitive prerequisites for influence the next issue was how an adaptive evaluation methodology could be designed and implemented to assess the impact of the modelling activity. No doubt many sources of influence affect the judgements of both scientists and decision makers in fulfilling their roles. How to sort out over time what the relative influence of model use versus negotiation, compromise, political and economic influences of the day is somewhat problematic. In the end do we rely on the subjective response of key role players that the model was deemed useful or that the process of using it and discussions with the modeller during its development and training were useful? Alternatively because conflict between differing stakeholders values were not resolved during planning did this reflect on a view that the model was unhelpful?

These issues are inevitable and sometimes all that can be offered in relation to impact is the fact that the modelling effort has been planned systematically and along the lines suggested above. The problem is that there are hopefully many different stakeholders potentially benefitting from the modelling and its related research and from differing perspectives. Precise criteria, apart perhaps from sustainability criteria which may be reflected in the goals of general strategies or specific plans for ultimate success of sustainable management are difficult to define.

In this case we are beginning with the often ignored Integrated Figure of Merit developed by Geisler, (1996) for public good research with potentially multiple beneficiaries. Geisler suggests four temporal and conceptual stages when thinking about research (or modelling) outputs. These are *immediate* (e.g. publications), *Intermediate* (e.g. the number of regular users that use the model for specific problem solving), *Pre-Ultimate* (e.g. specific management activities that can be demonstrated to have occurred from the model), *Ultimate* (the role of these activities in achieving overall societal benefit). This framework, over time, can be monitored using an influence diagram tracing model use through the differing levels (this is similar to the network methodology identified above) or an analytical hierarchy process suggested by Syme et al, 2006 to measure wellbeing outcomes of water research. More importantly it can establish the potential links to benefit before the modelling begins and assist with the effective placing of the model in the roles network.

There may well be other potential and existing methodologies for the evaluation of modelling impact. The above is an example only, But it is disappointing that authors such as Geisler,(1996) have been largely ignored in other than conceptual terms..

Pragmatically, any evaluation process needs to be longitudinal and may struggle over time for funding and the waning motivation of those of who have moved on to new problems and new differing modelling challenges. As Matthews et al (2009) in this symposium point out successful policy supporting modelling requires long term relationships between modellers and institutions which may carry value implications such as supporting the status quo or inadvertently creating inequities. But such ethical issues are not the preserve of modellers as planners have found over the years (see Wachs et al, (1985) for a range of discussions in this regard) and need to be faced for the long term welfare of modelling in this area.

4. CONCLUSIONS

This research project started with the intent that it would be a relatively simple task of finding user needs. It started as a relatively simple task with two organisationally oriented researchers budgeting a comparatively short time to ensuring that the needs of the key stakeholders in research for Ningaloo were met. Despite strongly resisting the urge to "complicate" things it soon became evident that there were major challenges for the modelling community as a whole.

Some of those relating to networks, the nature of information, and the mechanics of getting it accepted and even the cognitive capacity of humans became of relevance. More recently it became very evident that deciding whether modelling has been effective and the degree of effectiveness needs to be met will need to be informed by a consistent model of evaluation. One has been briefly introduced here but alternatives will need to be devised. But unless evaluation is an integral component of model application there is little hope for adaptive earning to occur. Currently the perceived effectiveness of models seems to rely heavily on subjective opinions of non users as much as users in the Ningaloo community.

All of these challenges can be met with standard methodologies but these need to be applied systematically and in an integrated fashion if we are to improve the impact of modelling projects. It is possible to classify the roles and their interactions to establish overlap and isolation. It is possible to at least roughly categorise the types of knowledge required to meet each role. Cross and his colleagues also routinely use the four dimensions of knowledge exchange in their work with multi-national and multi site companies in network analyses. There are simple methods to show whether key players requiring systems understanding do in fact have it. If these insights are included in the design of both the decision making and science networks and continually posed as specific hypotheses (rather than tacit assumptions) some general principles of modelling practice for ecosystems will emerge. Finally, Geisler type evaluation models of evaluation don't require new thinking just the motivation to carry them out. So while this project has tended to widen the debate about model impact we have the tools to move beyond conjecture.

There are a number of issues that have not been addressed here such as scale of network, the need for flat or hierarchical networks of roles and so on. Nevertheless if the issues identified above are confronted substantial improvement in the understanding of how to efficiently gain progress through modelling will be attained.

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